Analysis of Policy Measures to Reduce Ship Emissions in the Context of the Revision of the National Emissions Ceilings Directive

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Final Report

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Submitted to the
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Abstract

Maritime activities constitute a significant fraction of anthropogenic emissions of air pollutants in Europe. In 2000, SO_2 and NO_x emissions from international maritime shipping in Europe amounted to approximately 30 percent of the land-based emissions in the EU-25. While legislation is in force to control emission from international shipping, the expected increase in the volume of ship movements will compensate the positive environmental impacts of these measures and will lead to a further growth in ship emissions. Under business-as-usual assumptions, by 2020 emissions from maritime activities would come close to the projected baseline emission levels from land-based sources, and surpass the target levels established by the European Commission in its Thematic Strategy on Air Pollution for land-based sources.

This anticipated increase in ship emissions will counteract the envisaged benefits of the costly efforts to control the remaining emissions from land-based sources in Europe. While at present emissions from ships are responsible for 10 to 20 percent of sulphur deposition in coastal areas, their contribution is expected for 2020 to increase to more than 30 percent in large areas in Europe, and up to 50 percent in coastal areas.

Technologies exist to reduce emissions from shipping beyond what is currently legally required. The study has identified a set of emission control measures that are technically available and that could – if fully applied – reduce by 2020 80 percent of the SO_2 emissions from international shipping, and almost 90 percent of the NO_x emissions. Total costs of these measures are estimated at 5.5 billion €/yr. For comparison, the costs of the measures proposed by the Thematic Strategy amount to 7.1 billion €/yr.

The study has explored several packages of measures that could reduce emissions at lower costs. These include combinations of seawater sulphur scrubbing, lower sulphur content in residual oil, humid air engines for new built ships, slide valves retrofitting in existing ship engines, as well as the use of selective catalytic reduction (SCR). Marginal costs of these measures are well below the costs of the measures for land-based sources that have been proposed by the Thematic Strategy.

To judge the cost-effectiveness of such measures against those for land-based sources, the analysis considered the impacts that emission reductions from shipping have on human health and natural environment. That analysis included the distance between the location of emissions from shipping and the receptor areas.

The study examined potential contribution of four emission scenarios from shipping to achieving air quality targets from the EU Thematic Strategy on Air Pollution. Cost-optimal emission reductions and control costs by national emission sources were determined and compared with costs of reducing emissions from maritime shipping. Analysis clearly demonstrates that limiting air pollution from shipping reduces the necessity to further control emissions from land-based sources and provides important cost savings in achieving air quality targets in Europe.

Glossary of terms used in this report

CAFE	Clean Air For Europe Programme
CLE	Current legislation
CO_2	Carbon dioxide
EMEP	European Monitoring and Evaluation Programme
Entec	Entec UK Limited
EU	European Union
GAINS	Greenhouse gas - Air pollution Interactions and Synergies model
GW	Gigawatt
IIASA	International Institute for Applied Systems Analysis
IMO	International Maritime Organization
IPPC	Integrated Pollution Prevention and Control
kt	kilotons = 10^3 tons
MET.NO	Norwegian Meteorological Institute
Mt	megatons = 10^6 tons
N_2O	Nitrous oxides
NEC	National Emission Ceilings
NH_3	Ammonia
NO_x	Nitrogen oxides
O_3	Ozone
PJ	Petajoule = 10^{15} joule
PM10	Fine particles with an aerodynamic diameter of less than 10 µm
PM2.5	Fine particles with an aerodynamic diameter of less than 2.5 µm
RAINS	Regional Air Pollution Information and Simulation model
SECA	Sulphur Emissions Control Area
SO_2	Sulphur dioxide
SOMO35	Sum of excess of daily maximum 8-h means over the cut-off of 35 ppb calculated for all days in a year
TREMOVE	Transport Model
UNECE	United Nations Economic Commission for Europe
VOC	Volatile organic compounds

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1 Introduction

Ships release a significant fraction of the total anthropogenic emissions of air pollutants. In the year 2000, emissions from international shipping in the seas surrounding the territory of the European Union (i.e., Baltic, North Sea, Northeast Atlantic, and Mediterranean Sea) amounted to 20 to 30 percent of the sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emissions from land-based sources in the EU. While EU air quality legislation will lead to a decline of land-based emissions in the future, ship emissions, without additional emission control measures, are poised to grow further as a consequence of steadily increasing transport volumes.

Health and environmental impacts of air pollutants are critically determined by the proximity of the emission sources to sensitive receptor sites. This means that, compared to land-based sources, at least some of the maritime emissions have less health and environmental impacts since they are released sometimes far from populated areas or sensitive ecosystems. However, in harbour cities ship emissions are in many cases a dominant source of urban pollution and need to be addressed when compliance with EU air quality limit values for fine particulate matter is an issue. Furthermore, as for all other sources, also emissions from ships are transported in the atmosphere over several hundreds of kilometres, and thus can contribute to air quality problems on land, even if they are emitted on the sea. This pathway is especially relevant for deposition of sulphur and nitrogen compounds, which cause acidification of natural ecosystems and freshwater bodies and threaten biodiversity through excessive nitrogen input.

The anticipated increase in ship emissions will counteract the envisaged benefits of the costly efforts to control the remaining emissions from land-based sources in Europe. Technologies exist to reduce emissions from shipping more than what is currently legally required. Costs for some of these options are low compared with the costs of measures to further reduce emissions from land-based sources.

Sensitivity analyses performed within the Clean Air for Europe (CAFE) Programme have suggested that for the environmental targets of the Thematic Strategy on Air Pollution it might be more cost-efficient to reduce emissions from shipping beyond current legislation instead of implementing costly measures on stationary land-based sources. Following on from the Thematic Strategy, the European Commission develops a legislative proposal to revise the national emissions ceilings directive 2001/81/EC (NECD). While the NEC directive does not include emissions from international shipping, their contribution to the environmental problems and their potential role in cost-effective approaches for improving European air quality requires attention.

Recently the European Union developed a strategy for reducing the atmospheric emissions from maritime transport. It sets out a series of actions to reduce the impact of maritime transport on acidification, ground level ozone, eutrophication, health, climate change and ozone depletion. One result of the strategy was an amendment to the Sulphur Content of Certain Liquid Fuels Directive (1999/32/EC) – Directive 2005/33/EC (OJ L 191/59, 2005), which is linked to Annex VI of the Marine Pollution Convention, MARPOL 73/78, of the International Maritime Organisation (IMO). Annex VI (Air Pollution) of the Marine Pollution Convention (MARPOL) came into force in May 2005 when the requisite number of flag states and shipping tonnage ratified its provisions. Following the entry into force of Annex VI, several Member States have submitted a request to the International Maritime Organization (IMO) for changes to ship emissions standards. These proposals will be discussed in due course and will need to be fully justified if they are to be adopted by the IMO. Moreover, the Council of Ministers has concluded that the Community should adopt its own measures to reduce NO_x emissions from EU-flagged ships if progress is not forthcoming at the IMO.

This situation calls for a more systematic assessment of the possible measures to reduce atmospheric emissions from maritime sources. This report examines the possible development of future ship emissions for a range of emission control scenarios, examines their costs and discusses their environmental impacts. Although the analysis concentrates on international shipping, emissions from national navigation (and national fishing) are included in national emissions estimates. The analysis uses the integrated assessment framework of the RAINS/GAINS model (compare Amann *et al.*, 2004 and Klaassen *et al.*, 2005).

The remainder of the report is organized as follows: Section 2 presents the objectives and the scope of the study in more detail. Section 3 describes the methodology and assumptions used for preparation of emission inventory for the base year (2000) and reviews the resulting emission estimates. Section 4 presents emission projections from shipping up to 2020. Assumptions on the development of sea transport activities and on the emission control measures analyzed in each scenario are summarized, and the resulting emissions and emission control costs are discussed. Section 5 outlines the use of the EMEP model to derive information on the dispersion characteristics of air pollutants from shipping. Section 6 presents environmental impact indicators for each of the scenarios. Section 7 discusses potential contribution of ship measures to cost-efficient achievement of air quality objectives of the EU Thematic Strategy on Air Pollution (CEC, 2005). Major findings from the study and conclusions can be found in Section 7.

2 Objectives and scope of the study

This study explores the potential for measures to control NO_x, SO_2, and primary PM2.5 emissions from international shipping in the European sea areas. It estimates current emissions from different vessel categories in the various sea regions, projects emissions into the future for a range of alternative assumptions about the implementation of emission control measures, and assesses the environmental impacts of the different emission control scenarios.

The study entails the following three core elements:

- Compilation and update of ship emission inventories;
- Development of source-receptor (SR) relationships of atmospheric transport of pollution;
- Analysis of policy scenarios to control ship emissions.

The study covers five sea regions:

- the Baltic Sea,
- the North Sea (with the English Channel),
- the Mediterranean Sea,
- the Black sea and
- the North East Atlantic Ocean.

In each of these sea regions, potential measures are studied in terms of their cost-efficiency for

- EU-flagged ships vs. non-EU flagged ships,
- vessel types [cargo, passenger ships (ferries)],
- shipping movements within the 12-mile limit zone from shore vs. shipping movements beyond the 12-mile limit zone.

This report results from a joint effort of three institutions: Entec UK Limited, the Norwegian Meteorological Institute (MET.NO), and the International Institute for Applied Systems Analysis (IIASA). The individual teams had shared the responsibilities as follows:

- Entec UK Limited (Entec) prepared gridded emission inventories of air pollutants for each sea region and vessel type and developed emission and cost characteristics of the available control technologies.
- MET.NO applied its EMEP Eulerian dispersion model to perform calculations of atmospheric transport of air pollutants, so that pollution transfer coefficients could be derived.
- IIASA extended its RAINS/GAINS integrated assessment model to include detailed information on shipping into its calculation framework, developed pollution control scenarios and assessed their environmental impacts and costs.

In order to maintain consistency in modelling assumptions and approaches and to ensure comparability with the analysis performed in connection with the revision of the NEC directive, the same methodology for integrated assessment modelling as applied for the NEC analysis has been used by the project team. IIASA has extended its calculation framework to accommodate a more detailed representation of the sources of maritime emissions. MET.NO used its EMEP unified model to provide source-receptor relationships for the new source categories. Both the modelling tools and the project teams are the same as in the analysis for the revision of the NECD. The work under this project draws heavily on the results of previous studies performed by Entec (Whall *et al.*, 2002) and its follow-up (Entec, 2005a-d). In addition, for this project Entec's databases were updated to include the most up-to date information on the distribution of emission sources and on emission control costs. With these refinements the analysis of this report is expected to improve the quality of modelling emissions from shipping and thereby strengthen the NECD analysis, and provide background material for the analysis undertaken for the IMO process.

3 Emission inventory

As an important input to the other work elements, an updated inventory of the emissions of marine activities has been developed by Entec. This inventory is based on earlier estimates of emissions from ship movements between ports of the European Community that were compiled by Entec in 2002 and 2005 (Entec 2002, 2005a,b). The current inventory refined the earlier work through more detailed spatial resolution of emissions in the various sea areas distinguishing national and international emissions, emissions by flag state and emissions within the 12-mile territorial waters.

3.1 Methodology

The inventory estimates emissions in a 'bottom-up' way on the basis of kilometres travelled by individual vessels and uses weighted emission factors for each vessel type as opposed to fuel based emission factors. The underlying vessel movement data for the year 2000 were provided by Lloyds Marine Intelligence Unit (LMIU) and data on vessel characteristics by Lloyds Register Fairplay.

With this approach, the inventory was not originally designed to estimate fuel consumption data, which is a type of data required by the RAINS model. To enable separate fuel consumption estimates of residual oil and marine distillates to be made from total emissions, an assumption has been made that approximately 90 percent of fuel consumption is residual oil and that approximately 10 percent is marine distillate. Available databases and other statistics do not enable the actual split in fuel consumption for ships in European waters to be estimated to a high degree of accuracy. With these assumptions, fuel consumption estimates were derived from the calculated NO_x emissions and aggregated NO_x emission factors, for residual oil and marine distillates (Table 3.1).

Table 3.1: Fuel consumption for international shipping in 2000 by sea region, zone and vessel type [PJ]

Ship category		Baltic Sea		Black Sea		Remaining NE Atlantic	
Flag	Fuel[1)]	<12-mile	>12-mile	<12-mile	>12-mile	<12-mile	>12-mile
Cargo - EU	RO	16.7	61.9	2.7	18.2	7.9	112.9
Cargo - EU	MD	1.9	6.9	0.3	2.0	0.9	12.6
Ferry - EU	RO	0.4	1.1	0.0	0.2	0.2	2.3
Ferry - EU	MD	0.0	0.1	0.0	0.0	0.0	0.3
Cargo - Non EU	RO	13.3	44.4	2.5	17.0	13.4	225.6
Cargo - Non EU	MD	1.5	4.9	0.3	1.9	1.5	25.1
Ferry - Non EU	RO	0.1	0.5	0.0	0.1	0.1	0.6
Ferry - Non EU	MD	0.0	0.1	0.0	0.0	0.0	0.1
Total		33.9	119.7	5.8	39.6	24.0	379.3

Ship category		Mediterranean Sea		North Sea		Total European seas	
Flag	Fuel[1]	<12-mile	>12-mile	<12-mile	>12-mile	<12-mile	>12-mile
Cargo - EU	RO	22.6	294.8	19.5	119.7	69.5	607.5
Cargo - EU	MD	2.5	32.8	2.2	13.3	7.7	67.5
Ferry - EU	RO	6.5	34.5	0.9	5.7	7.9	43.8
Ferry - EU	MD	0.7	3.8	0.1	0.6	0.9	4.9
Cargo - Non EU	RO	24.9	394.1	27.0	150.9	81.1	831.9
Cargo - Non EU	MD	2.8	43.8	3.0	16.8	9.0	92.4
Ferry - Non EU	RO	0.7	6.9	0.2	1.6	1.2	9.7
Ferry - Non EU	MD	0.1	0.8	0.0	0.2	0.1	1.1
Total		60.9	811.4	52.8	308.8	177.4	1658.9

[1] Fuel types: RO – residual oil; MD – marine diesel.

3.2 Coverage

The gridded emissions inventory distinguishes for each grid cell in the EMEP domain emissions from

- passenger and
- cargo ships,

distinguishing

- national and
- international ships (by flag)

and emissions (by flag)

- within the 12-mile territorial waters
- and outside this zone.

The inventory covers the following pollutants:

- sulphur dioxide (SO_2),
- nitrogen oxides (NO_x),
- total hydrocarbons (HC)[1],
- primary particulate matter (PM), and
- carbon dioxide (CO_2).

Emissions were estimated on the basis of vessel movement data and the underlying vessel emission factors as specified in Entec (2005b-d). For estimating sulphur emissions, sulphur contents in residual oil (RO) of 2.7 percent and for marine distillates (MD) of 0.2 percent have been assumed.

For pollutants that are necessary for the computations of the chemical transport model calculations with the EMEP Unified model, gridded inventories have been compiled for

- coarse primary particulate matter (PM10-PM2.5) PMcoarse,
- fine primary particulate matter (PM2.5),
- non-methane volatile organic compounds (NMVOC), and
- carbon monoxide (CO).

The inventories of these pollutants were derived in the following way:

- For CO emissions, a constant ratio of 0.24 percent of CO_2 has been assumed (consistent with the CORINAIR emission factors).
- NMVOC was assumed to be amount to 99 percent of HC.
- $PM_{2.5}$ was assumed to be equivalent to 90 percent of total PM, consistent with the CORINAIR emission factors.
- PMcoarse (all particles with a diameter between 2.5 and 10µm) was assumed to be equivalent to 5 percent of total PM. This is consistent with the CORINAIR emission factors.

The inventory distinguishes the following five sea areas**:**

- North Sea,
- Black Sea,
- Mediterranean Sea,
- Baltic Sea,
- Atlantic Ocean (North-East part, within the EMEP domain).

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[1] These are exhaust emissions only, i.e., they do not include VOC emitted during loading, unloading and gas-freeing of petro-chemical vessels. Loading and unloading emissions were quantified in a separate study for the EC available at http://www.europa.eu.int/comm/environment/air/pdf/vocloading.pdf

The earlier Entec and EMEP inventories of ship emissions studies applied slightly different definitions of sea areas. Entec's study for the EC included a requirement to separately identify emissions for the English Channel and Irish Sea, whereas the EMEP inventory includes the English Channel within either the North Sea or the North-East Atlantic, while the Irish Sea is included with the North-East Atlantic. Definitions also differed for the North-East Atlantic, which Entec had previously subdivided into two categories (North-East Atlantic and Rest of EMEP Area).

Table 3.2 lists the countries that are explicitly distinguished in this inventory. These include the 27 EU countries and the tow candidate countries (Croatia and Turkey). All other countries form the Non-EU group.

Furthermore, the inventory estimates emissions for two vessel types:

- cargo vessels and
- passenger vessels (ferries).

Further consideration has been given to emissions from smaller vessels as described below.

National movements are defined as movements between ports of the same country (e.g., UK to UK). Where national emissions are presented by vessel flag, this represents all combinations of national emissions under that particular flag state (e.g., Belgium flagged vessels on any domestic routes, which may include UK to UK, Belgium to Belgium, France to France, etc). Emissions from inland waterways are not included in the disaggregated dataset.

International movements are defined as movements between ports of different countries (e.g., UK to France). Where international emissions are presented by vessel flag, this represents all combinations of international emissions under that particular flag state (i.e., Belgium flagged vessels on any international routes which may include UK to France, Belgium to Spain, Italy to North America, etc).

The LMIU ship movement database includes all vessels above 500 gross registered tonnes (GRT). Smaller vessels, which are not routinely included in the movement database, were assumed to be operating closer to land and using lower sulphur marine fuels as opposed to heavy fuel oil. The fuel consumption for the range 100-500 GRT is estimated to be less than eight percent of the total estimated consumption for >100 GRT (Endresen *et al.*, 2003). On the basis of uncertainties over the movements of smaller vessels and in line with the scope of this study, a top-down approach has been adopted by assuming that an additional 10 percent of emissions in the 12-mile zones are attributable to vessels <500 GRT. Therefore, gridded emissions estimated for larger vessels in each of the 50 km x 50 km grid cells that include the 12-mile zone have been multiplied by a factor of 1.1.

When interpreting the results of the emissions assessment, the issues concerning uncertainty presented in Appendix E of Entec's 2005 Task 1 report should be considered.

Table 3.2: EU27 and candidate countries.

Reference	Country code	Country name
1	AUT	Austria (EU)
2	BEL	Belgium (EU)
3	DNK	Denmark (EU)
4	FIN	Finland (EU)
5	FRA	France (EU)
6	GER	Germany (EU)
7	GRC	Greece (EU)
8	IRL	Ireland (EU)
9	ITA	Italy (EU)
10	LUX	Luxembourg (EU)
11	NLD	Netherlands (EU)
12	PRT	Portugal (EU)
13	ESP	Spain (EU)
14	SWE	Sweden (EU)
15	GBR	United Kingdom (EU)
16	CYP	Cyprus (EU)
17	CZE	Czech Republic (EU)
18	EST	Estonia (EU)
19	HUN	Hungary (EU)
20	LVA	Latvia (EU)
21	LTU	Lithuania (EU)
22	MLT	Malta (EU)
23	POL	Poland (EU)
24	SVK	Slovakia (EU)
25	SVN	Slovenia (EU)
26	BGR	Bulgaria (EU)
27	ROM	Romania (EU)
28	TUR	Turkey (Candidate)
29	CRO	Croatia (Candidate)

3.3 Estimates of total ship emissions

The emission inventory provides estimates of air pollutant emissions for the various sea regions, distinguishing international and national movements. The inventory is disaggregated on the basis of vessel flags.

The spatial distribution of emissions within each sea region has been estimated based on ship movement data along the various routes and on information about the main engine power of the ships, assuming that the main engine power represents a good proxy for total kW power and the associated emissions. Data on main engine power were further categorised by sea area, vessel type (cargo or passenger) and movement type (national or international) to enable emissions to be calculated for the various categories.

The inventory is summarized in Table 3.3 (for larger vessels only) and Table 3.4 for all vessels. Smaller vessels add between two and six percent to total emissions in each sea region, depending on the share of the 12-mile zone in the sea area. This estimate assumes that smaller vessels are predominantly part of national fleets and are not involved in international trade. More detailed data are presented in the appendices. Appendix A presents national and international emissions disaggregated by the 12-mile zones of each EU country. Emissions by sea area, vessel flag (EU or Non-EU), movement type (at sea, manoeuvring, at berth) and vessel type (cargo or passenger) are presented in Appendix B. Spatial distribution of emissions from international shipping in the year 2000 is shown in Figure 3.1 and Figure 3.2.

Table 3.3: Emissions from larger vessels (>500 GRT) by sea region for the year 2000, in kilotons/year.

Sea area	CO_2	SO_2	NO_x	HC	PMtotal
North Sea	29664	496	693	25	59
Black Sea	3721	62	86	3	7
Mediterranean	75484	1251	1781	61	151
Baltic Sea	12727	212	299	10	24
NE Atlantic	31109	522	764	26	67
Total	152705	2543	3623	125	308

Table 3.4: Emissions from all vessels by sea region for the year 2000, in kilotons/year.

Sea area	CO_2	SO_2	NO_x	HC	PMtotal
North Sea	30878	516	720	26	61
Black Sea	3852	65	89	3	8
Mediterranean	77140	1278	1818	62	154
Baltic Sea	13447	224	315	11	26
NE Atlantic	31673	532	777	26	68
Total	156989	2615	3719	129	316

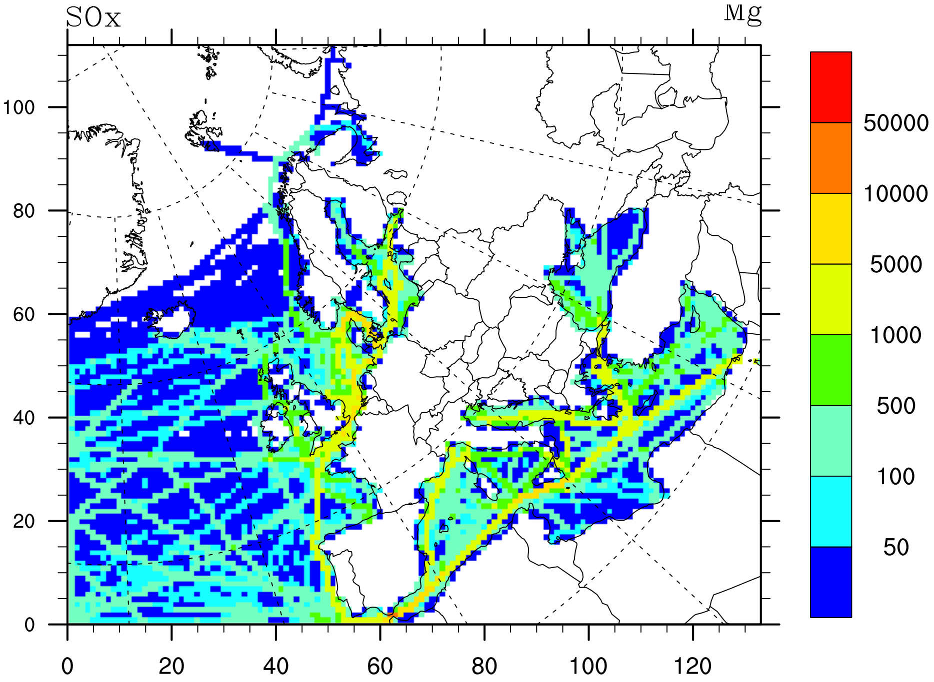

Figure 3.1: Spatial distribution of SO_2 emissions from international shipping in the year 2000

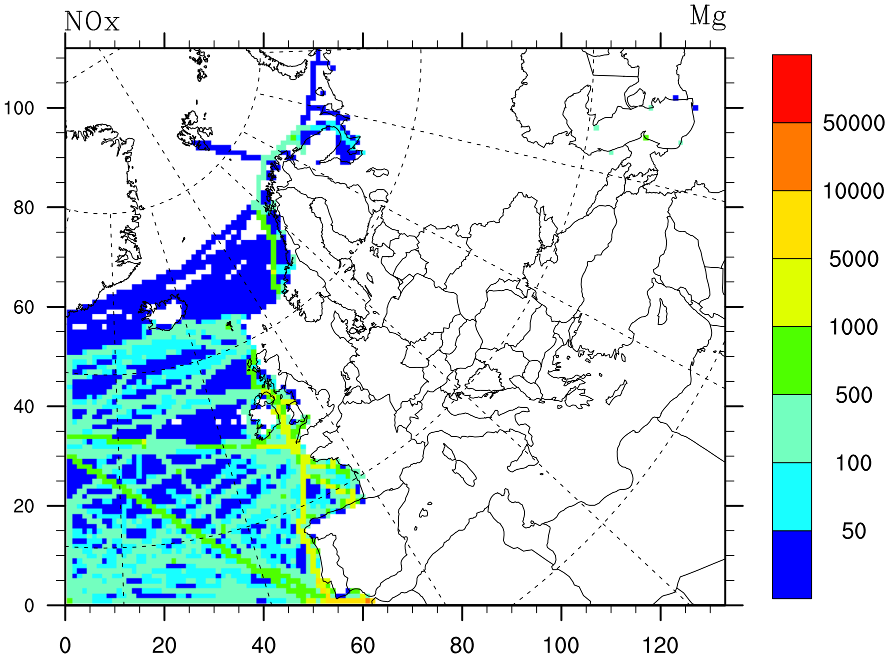

Figure 3.2: Spatial distribution of NO_x emissions from international shipping in the year 2000

3.4 Emissions in the 12-mile zone territorial seas

Ship emissions have also been estimated for the 12-mile coastal zones by apportioning a share of the emissions of the coastal 50*50 km EMEP grid cells. It is assumed that the share of emissions in the 12-mile zones is proportional to the area that the 12-mile zone constitutes in a coastal 50*50 km grid cell. This assumption may tend to underestimate actual emissions in these zones, because national coastal shipping might use routes closer to the coast lines. Results are presented in Table 3.5. Spatial distribution of the emissions is shown in Figure 3.3 and Figure 3.4.

Table 3.5: Emissions of vessels >500 GRT in the 12-mile zones in the year 2000 (kilotons)

	CO_2	SO_2	NO_x	*HC*	*PMtotal*
Austria	0	0	0	0	0
Belgium	753.1	12.6	15.4	0.6	1.3
Bulgaria	112.4	1.9	2.4	0.1	0.2
Croatia	317.4	5.1	6.7	0.2	0.5
Cyprus	182	3	3.6	0.1	0.3
Czech Republic	0	0	0	0	0
Denmark	3247.3	54.3	77.1	2.7	6.4
Estonia	400.6	6.7	9	0.3	0.7
Finland	573	9.6	12.2	0.5	1
France	2692.9	44.2	58.2	2.3	4.9
Germany	2187.2	36.6	49.4	1.8	4.1
Greece	3942.5	64.3	86.8	3.1	7
Hungary	0	0	0	0	0
Ireland	329.6	5.6	7.1	0.2	0.6
Italy	3516	56.8	71.2	3	5.8
Latvia	241.8	4	5.1	0.2	0.4
Lithuania	74	1.2	1.5	0.1	0.1
Luxembourg	0	0	0	0	0
Malta	159	2.7	3.3	0.1	0.3
Netherlands	2197.5	36.8	47.8	1.9	4.2
Poland	225.8	3.8	4.7	0.2	0.4
Portugal	490.9	8.2	10.5	0.4	0.9
Romania	166.9	2.8	3.5	0.1	0.4
Slovakia	0	0	0	0	0
Slovenia	55.7	0.9	1.1	0	0.1
Spain	3393.6	56.8	75.1	2.9	6.5
Sweden	1344.8	22.5	29.5	1.2	2.5
Turkey	2155.8	36	47.6	1.8	4.2
UK	5999.4	100.4	133.0	5.1	11.7
Total	34759	577	761	29	65

Appendix A presents the estimated emissions within the 12-mile zones of each EU country, further disaggregated into national and international movements. Table A.1 presents the results excluding the estimated emissions from smaller vessels. On average, national emissions account for approximately 24 percent of total emissions in the 12-mile zones.

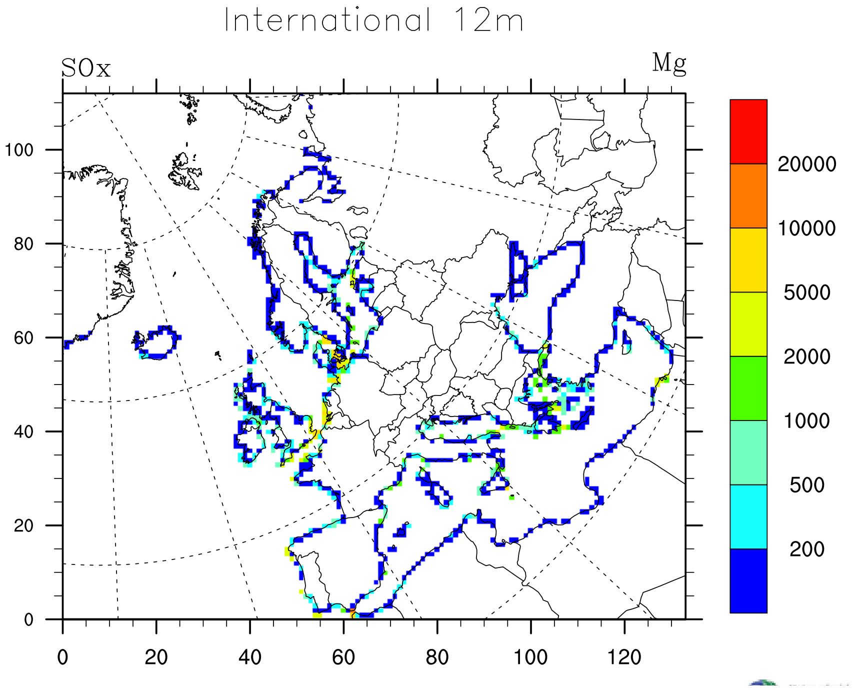

Figure 3.3: SO_2 emissions from international ship traffic within the 12-mile zone for all flags, in kilotons

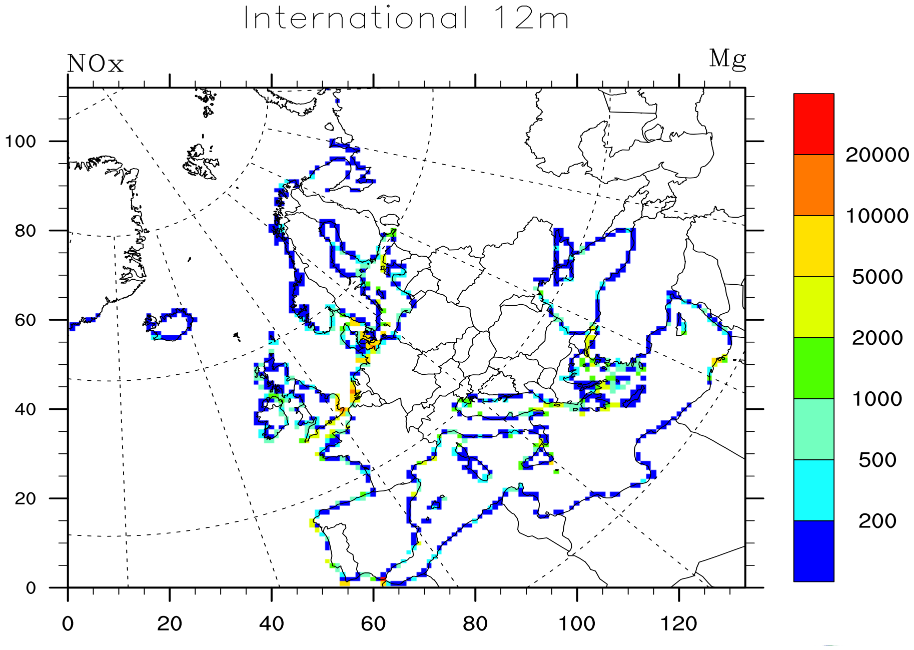

Figure 3.4: NO_x emissions from international ship traffic within the 12-mile zone for all flags, in kilotons

3.5 Emissions from national sea traffic

The inventory also estimates emissions from national sea traffic, which comprises ship movements between two ports of the same country. The estimates are based on activity data developed by Entec in its 2005 study. Table 3.6 compares the Entec estimates with inventory data reported by Member States to EMEP[2]. It has not been within the scope of this study to investigate the methods used by Member States to estimate their national emissions. Therefore, discrepancies between these two datasets cannot be explained with the current information.

Compared to the estimate of total ship emissions, assessments of the emissions from national shipping are burdened with additional uncertainties owing to differences in sectoral aggregations used by individual countries. In some cases even different institutions within the same country use different definitions and aggregations. Particularly large uncertainties emerge for estimates for the candidate countries and the non-EU countries. However, emissions from national shipping constitute a relatively small portion of total maritime emissions (7-10 percent for SO_2 and PM, 12-14 percent for NO_x).

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[2] According to CORINAIR (2004) national sea traffic is defined as all national ship transport including ferries and fishing, for all ships of more than 100 gross tonnes, irrespective of flag, between ports in the same country, within the EMEP area. This means that, e.g., Danish traffic to east Greenland is included as national shipping in UNECE reports, but not the traffic to west Greenland. Military vessels should be included if data are available.

Table 3.6: Emissions from national sea traffic in the EU and Candidate countries for the year 2000, in kilotons. The Entec estimates exclude emissions from smaller vessels.

Country	Entec estimates				Estimates reported in the national emission inventories			
	SO_2	NO_X	$PM_{2.5}$	PM_{10}	SO_2	NO_X	$PM_{2.5}$	PM_{10}
Austria	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Belgium	0.6	0.7	0.1	0.1	2.1	6.4	0.9	1.0
Bulgaria	0.1	0.1	0.0	0.0	2.6	12.9	0.2	0.3
Croatia	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Cyprus	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Czech Republic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Denmark	3.8	4.7	0.4	0.4	2.6	17.6	0.5	0.5
Estonia	0.1	0.1	0.0	0.0	0.1	0.3	0.0	0.0
Finland	7.4	10.1	0.8	0.8	0.8	7.7	0.3	0.3
France	15.3	20.2	1.4	1.4	9.9	27.8	1.9	2.0
Germany	6.2	7.8	0.6	0.6	0.0	0.0	0.0	0.0
Greece	13.5	16.9	1.3	1.4	22.3	40.4	1.6	1.7
Hungary	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	1.3	1.6	0.1	0.1	1.4	1.0	0.1	0.1
Italy	102.0	135.8	9.2	9.7	60.9	89.1	4.4	4.6
Latvia	0.3	0.3	0.0	0.0	0.1	0.6	0.0	0.0
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malta	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	2.8	3.3	0.3	0.3	0.9	16.1	0.3	0.3
Poland	0.6	0.8	0.1	0.1	1.0	2.7	0.2	0.2
Portugal	2.9	4.3	0.3	0.3	3.0	5.0	0.3	0.3
Romania	0.5	0.7	0.1	0.1	7.4	31.2	0.8	0.8
Slovakia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spain	40.2	54.0	4.2	4.4	26.5	50.5	2.0	2.1
Sweden	6.8	9.0	0.7	0.7	3.0	49.6	1.2	1.3
Turkey	17.7	22.8	1.8	1.9	4.3	5.0	0.4	0.4
UK	39.3	49.9	4.1	4.3	20.1	54.6	1.2	1.3
TOTAL	262	344	25	27	169	419	16	17

4 Emission scenarios

On the basis of disaggregated emissions and activity data provided by Entec, IIASA has implemented new source categories into the RAINS/GAINS framework that describe more detailed sea regions, vessel types and their flags. Work concentrated on international shipping, since national shipping is already included in the national inventories and in the national emission projections prepared for the revision of the NEC directive (Amann *et al.*, 2007). A detailed description of the RAINS and GAINS models is provided in Amann *et al.*, 2004 and Klaassen *et al.*, 2005.

4.1 Activity data

Projections of future shipping activities distinguish the following dimensions:

- The EMEP sea areas,
- within / outside the 12-mile zones,
- EU / non-EU flagged vessels,
- passenger / cargo vessels,
- marine distillates / residual fuel oil,
- international / national shipping.

For the emission projections in this study, the development of future shipping activities follow the assumptions of the TREMOVE European transport model (de Ceuster, 2006), which suggest for the baseline case annual growth rates of 2.5 percent for cargo vessels and 3.9 percent for passenger vessels. TREMOVE assumes constant fuel economy for international shipping in the projection period. In addition, the emission projections assume constant shares between the activities in- and outside the 12-mile zones, between the flag types of vessels, and apply the same growth rates to international shipping activities across all sea regions.

Growth rates for shipping activities assumed in this report are rather at the low end of a range of projections considered by other studies. For instance, the IMO GHG study (Skjolskvik *et al.*, 2000) assumes 3 percent per year average growth rate between 2000 and 2030. Study by Corbett et al, 2007 comes up with 4.1 percent per year growth in the same period for the Base case scenario. Historic and projected development of major indices for shipping activities according to various sources is shown in Figure 4.1.

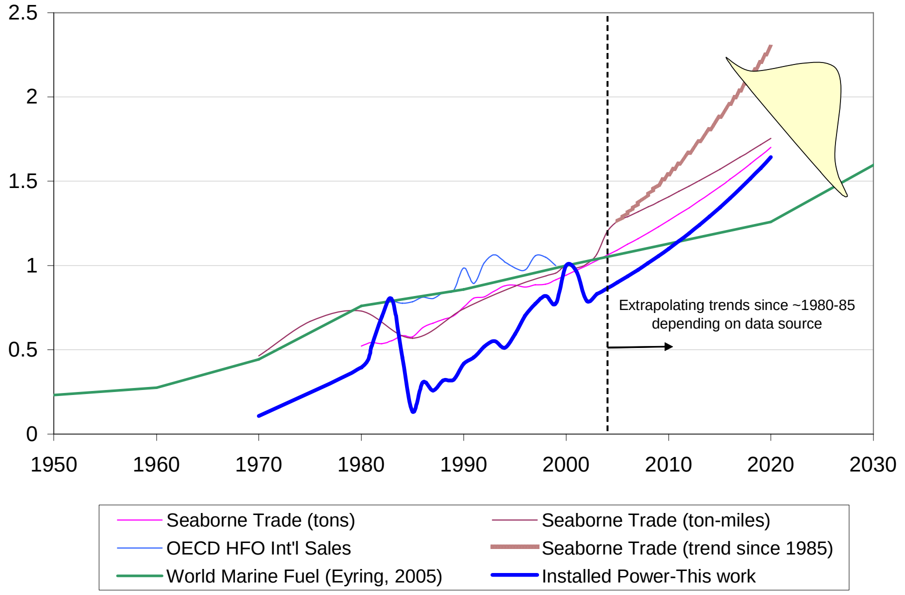

Figure 4.1: Global indices for seaborne trade, ship energy/fuel demand, and installed power. Source: Corbett *et al.*, 2007.

4.2 *Emission control technologies and their costs*

Future emissions are critically influenced by the application of emission control measures. For this purpose, the RAINS model distinguishes a set of emission control measures (Table 4.1) and their reduction efficiencies in relation to the reference emission factors that represent pre-MARPOL conditions. Input data have been prepared by Entec (Entec, 2005b).

Table 4.2 lists the estimated technical potentials for application of the emission control measures beyond what is anticipated to occur under the "current legislation" baseline scenario. These application potentials relate to the technical feasibility as opposed to potentials derived from cost-effectiveness, political or economic considerations. Furthermore, the applicability estimates do not take into account potential limitations related to other pollutants that are co-released by a control technique or limitations related to supply capacities. More detailed information on NO_x abatement techniques and sea water scrubbing is given in Entec (2005c,d). Details of abatement cost data for specific control techniques are summarised in Table 4.3 and Table 4.4.

Table 4.1: Emission control technologies and their reduction efficiencies compared to the pre-MARPOL 2000 conditions

Measure	% emissions reduction (-) / increase (+) per vessel			
	SO_2	NO_X	PM	VOC
Basic internal engine modifications (IEM) for 2-stroke slow speed only	0%	-20%	0%	0%
Advanced internal engine modifications	0%	-30%	0%	0%
Direct water injection	0%	-50%	0%	0%
Humid air motors	0%	-70%	0%	0%
Exhaust gas recirculation [1]	-93%	-35%	>-63% [2]	± [3]
Selective catalytic reduction (2.7% residual oil)	0%	-90%	0%	0%
Sea water scrubbing	-75%	0%	-25% [4]	±
Fuel switching 2.7->1.5% S residual oil fuel	-44%	±	-18%	±
Fuel switching 2.7->0.5% S residual oil fuel	-81%	±	-20% [5]	±
Low S marine diesel 0.5->0.1 % S	-80%	±	±	±

[1] Assumed switch from 2.7 percent sulphur RO to MD for technical reasons.

[2] US EPA 2003 outlines that a switch from 2.7 percent sulphur RO to 0.3 percent MD reduces PM by 63 percent. The PM reduction to 0.1 percent MD will therefore be slightly higher than 63 percent.

[3] ± no or not conclusive information available.

[4] MES measured sludge production from the Pride of Kent as 0.2 g/kWh and particles suspended in overboard water as 0.05g/kWh. Based on a PM emission factor of 0.8 g/kWh in the exhaust for the type of auxiliary engine used in MES's trials, the PM removal rate by the EcoSilencer® can be approximated as around 31 percent. However, since this calculation assumed that all sludge consists of particulates, and that the suspended solids in the scrubber inflow is negligible, the actual removal rate is likely to be lower than 31 percent. A conservative estimate of 25 percent PM reductions was therefore chosen.

[5] Conservative figure. It is estimated that PM removal will be more than 18 percent but is likely to be significantly less than the 63 percent (US EPA 2003) reported for a switch to 0.3 percent MD. Switching to a 0.5 percent S distillate fuel (MD) may give PM reductions towards the high end of this emission reduction range.

Table 4.2: Technically viable implementation rates beyond business-as-usual.

Measure	Existing vessels			New vessels		
	2010	2015	2020	2010	2015	2020
Basic IEM (slide valves, 2-stroke slow speed only)	33%	33%	33%	0%	0%	0%
Advanced IEM	Up to 100%[1]	Up to 100%	Up to 100%	100%	100%	100%
Direct water injection	>99%	>99%	>99%	>99%	>99%	>99%
Humid air motors	100%	100%	100%	100%	100%	100%
Exhaust gas recirculation	100%	100%	100%	100%	100%	100%
Selective catalytic reduction	99%	99%	99%	99%	99%	99%
Sea water scrubbing	100%	100%	100%	100%	100%	100%

[1] Scope for retrofitting advanced IEM must be further investigated. Retrofitting of the advanced IEM studied in this report may not be applicable to all engine types, and needs to be analysed on a case by case basis.

Table 4.3: Technological emission control measures and costs

Technology	Annualised capital investment [€/MWh] (for an average ship)[1]	Average operating and maintenance costs [€/MWh][1]	Average cost effectiveness [€/t NO_x (or SO_2 for SWS)[2]]
Basic IEM (slide valves, 2-stroke slow speed only)	0.03	0.0	9
Advanced IEM	0.2	0.0	40
Direct water injection	0.6	2.1	363
Humid air motors - New build	2.2	0.2	225
Humid air motors – Retrofit	2.8	0.2	279
Selective catalytic reduction – Residual oil outside ECA - New build	1.0	6.9	580
Selective catalytic reduction – Residual oil outside ECA – Retrofit	1.7	6.9	631
Selective catalytic reduction – Residual oil inside ECA - New build	1.0	4.9	435
Selective catalytic reduction – Residual oil inside ECA – Retrofit	1.7	4.9	487
Selective catalytic reduction - Marine distillates – New build	1.0	3.6	506
Selective catalytic reduction - Marine distillates – Retrofit	1.7	3.6	584
Sea water scrubbing - New build (SO_2)	2.4	0.5	347
Sea water scrubbing - Retrofit (SO_2)	3.9	0.5	531

[1] Capital costs (Euro/vessel) and operating costs (€/MWh) for small, medium and large vessels are taken from Entec 2005c,d. A weighted value was derived for an average vessel based on the proportion of total installed engine capacity.

[2] Cost effectiveness for engines using marine distillates assumes that the raw gas (unabated) emission factors are 33 percent lower than for engines fuelled with residual oil.

Notes:

– The estimates of cost-effectiveness for these measures are subject to 30–40 percent uncertainty range compared to the best estimate figures that are quoted, as reported in Entec, 2005c

– Calculated with a discount rate of four percent.

Table 4.4: Costs for low sulphur fuels (switching from 2.7 percent sulphur content)

Sulphur content	Scenario	Price premium [€/ton][2]	€/t SO_2 abated[1]	Removal efficiency per vessel
1.5%	MARPOL (for SECAs)	9	360	44%
1.5%	EU Directive (for SECAs & all ferries operating from and to an EU port)	14	581	44%
1.5%	%S all residual marine fuel	19	783	44%
0.5%	%S all residual marine fuel	39	879	81%
0.2%	%S MD (Switching from RO to MD)	110	2200	93%
0.1%	%S MD (Switching from RO to MD)	130	2500	96%

[1] The estimates of cost-effectiveness for this measure are considered to be subject to an approximate 50 percent uncertainty range.

[2] Data for switching to 1.5 percent and 0.5 percent have been derived from CONCAWE, 2006. Data are for the "Complying with S limits while meeting the demand" case. Values adjusted for four percent discount rate and 20 year economic life. CONCAWE warns that heavy investments necessary to desulphurize residual oil down to 0.5 percent S might cause problems with availability of that fuel because European refineries might decide to change their profile and produce higher market value middle distillates instead of residual oil. Availability constraints have not been considered in this report.

4.3 Emission control scenarios

Based on information described in Sections 4.1 and 4.2 and after discussions with representatives of the European Commission, DG Environment, alternative emission control scenarios for shipping have been prepared by IIASA. Sections 4.4. and 4.5 of this report present results for the year 2020. Emissions and control costs for interim years (2005 to 2015) are presented in appendices. The scenarios feature combinations of emission and fuel standards for different ship categories and sea regions/zones. The analyzed scenarios are characterized in Table 4.5.

The analysis starts with the "Baseline" scenario, which outlines the effects of "Current legislation" on emissions from shipping. At the other end the "Maximum technically feasible reductions" (MTFR) scenario quantifies emissions, environmental effects and costs of implementing the best available control technology on international shipping. To explore the range between these two extreme benchmark cases, several scenarios with different ambition levels have been analyzed. In addition, the study analyzes cost-efficiency of some of these scenarios in achieving air quality targets defined by the Thematic Strategy (CEC, 2005) – compare Section 7.

Table 4.5: Legislation considered in the emission scenarios for international shipping

Pollutant	Measures
	Baseline
SO_2	Sulphur content as in the EU Marine Fuel Directive (OJ L 191/59, 2005): 1.5 percent S in residual oil for all ships in SECA (North Sea and Baltic Sea); 1.5 percent S fuel all passenger ships in other sea regions surrounding the European Union; 0.1 percent S fuel at berth in ports
NO_x	MARPOL NO_x standards for ships built since 2000
	Ambition level 1 – EU ships
SO_2	As in the baseline
NO_x	Slide valve retrofit on all slow-speed engines pre-2000 [1] Internal engine modifications for all new engines post-2010
	Ambition level 2 – EU ships
SO_2	0.5 percent S in residual oil or scrubbing equivalent (2g SO_2/kWh) in SECA, and for passenger vessels everywhere [2]
NO_x	Slide valve retrofit on all slow-speed engines pre-2000 Humid air motors for all new engines post-2010
	Ambition level 1 – all ships
SO_2	As in the baseline
NO_x	Slide valve retrofit on all slow-speed engines pre-2000 Internal engine modifications for all new engines post-2010
	Ambition level 2 – all ships
SO_2	0.5 percent S in residual oil or scrubbing equivalent (2g SO_2/kWh) in SECA, and for passenger vessels everywhere. Cargo vessels as in the baseline
NO_x	Slide valve retrofit on all slow-speed engines pre-2000 Humid air motors for all new engines post-2010
	Ambition level 2 – all ships plus sulphur measures in 12-mile zones
SO_2	0.5 percent S in residual oil or scrubbing equivalent in SECA, and for passenger vessels everywhere. 1.5 percent S fuel for cargo vessels within the 12-mile zone in other sea regions
NO_x	Slide valve retrofit on all slow-speed engines pre-2000 Humid Air Motors for all new engines post-2010
	Ambition level 3 – all ships
SO_2	Passenger and cargo ships: SECA – 1.0 percent S in residual oil from 2010, 0.5 percent or scrubbing equivalent from 2015. Other sea regions - as in the baseline but 0.5 percent or scrubbing equivalent from 2020
NO_x	Pre-2010 vessels: 15 percent reduction above baseline level through available retrofit measures. Post-2010 vessels: 50 percent reduction above baseline level.
	Ambition level 4 – all ships
SO_2	As ambition level 3
NO_x	Pre-2010 vessels: 15 percent reduction above baseline level through available retrofit measures. Post-2010 vessels: Selective catalytic reduction (SCR) technology
	Maximum technically feasible reduction
SO_2	0.5 percent S fuel for all ships in all EU seas, 0.1 percent at berth.
NO_x	SCR on all ships (retrofit & new build).

[1] Later engines already have these installed.

[2] Penetration rate of seawater scrubbing was limited in all scenarios to 25 percent. This is due to uncertainties regarding the pace of implementation of that technology. Thus in all scenarios with stringent sulphur controls remaining ships (75 percent of total) use 0.5 percent residual fuel oil.

4.4 Resulting emissions

Table 4.6 presents emissions of air pollutants from international shipping in 2000 and in 2020 for the scenarios specified in Section 4.3. Details by sea regions as are presented in Appendix C. Emissions for interim years and a more detailed split of emission sources can be found in Appendix D. Aggregated emissions in the 12-mile zone are provided in Table 4.7. Details are available in Appendices C and D.

Compared to 2000, emissions of SO_2 from international shipping are expected to increase till 2020 in the "Baseline" scenario by 42 percent, and NO_x and $PM_{2.5}$ emissions by 47 and 55 percent, respectively. This growth is mainly related to the assumed increase in traffic volume, while the additional emission control measures that are considered in the baseline (i.e., sulphur controls according to the EU Marine Fuel Directive, MARPOL standards on new vessels) show only limited impact. The "Ambition level 1" scenario for all ships reduces NO_x emissions in 2020 by nine percent compared with the baseline projection, while representing a 33 percent increase compared to the year 2000.

The "Ambition level 2" scenario for all ships reduces the baseline 2020 emissions of SO_2 and NO_x by 29 and 27 percent, respectively. Unilateral measures (controls on EU-flagged ships only) would trigger about half of the total reduction. Reduction of S content of residual oil down to 1.5 percent in 12 12-miles zone on seas outside sulphur emission control areas (SECAs) would bring additional SO_2 reduction of about 73 ktons (2.3 percent of the baseline level). As will be demonstrated in Section 6, such a reduction brings little environmental improvement. "Ambition level 3" and "Ambition level 4" scenarios reduce SO_2 emissions down to about 760 kilotons (minus 76 percent). NO_x emissions decrease by 1.6 and 2.1 million tons respectively.

Maximum technically feasible emission reductions would decline SO_2 and NO_x emissions by 78 and 89 percent, respectively. As a side effect of using low sulphur fuel, emissions of PM decrease by 15 percent compared with the baseline.

In all scenarios and years, emissions in the 12-mile zone account for eight to ten percent of total emissions from international shipping. A reduction of the sulphur content for cargo ships within that zone in Atlantic Ocean, Black Sea and Mediterranean Sea (i.e., the "Ambition level 2" scenario for all ships plus sulphur measures in 12-mile zone) would decrease SO_2 emissions by about 73 kilotons (i.e., 36 percent of the emissions in the 12-mile zone) compared with the "Ambition level 2" scenario without sulphur measures. In this scenario the share of SO_2 emissions from the 12-mile zone decreases to only five percent.

Table 4.6: Total emissions of air pollutants from international shipping in 2000 and in 2020 in all sea regions [kilotons]

Pollutant	Vessel type	2000	2020 - ambition level								
			Baseline	Level 1 EU ships	Level 2 EU ships	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships	Max. techn. feasible reduction
SO2	Ferry	85.3	101.7	101.7	48.5	101.7	37.3	37.3	37.3	37.3	34.3
	Cargo	2164.8	3084.1	3084.1	2913.8	3084.1	2729.4	2656.6	721.0	721.0	663.9
	Total	2250.1	3185.8	3185.8	2962.2	3185.8	2766.6	2693.9	758.2	758.2	698.2
NOx	Ferry	123.8	246.4	227.9	192.6	224.0	181.2	181.2	167.9	137.8	27.0
	Cargo	3170.9	4582.0	4401.8	4048.8	4158.9	3330.1	3330.1	3043.9	2594.0	523.2
	Total	3294.7	4828.4	4629.7	4241.4	4382.9	3511.3	3511.3	3211.8	2731.8	550.2
PM2.5	Ferry	9.6	17.0	17.0	16.7	17.0	16.6	16.6	16.6	16.6	16.6
	Cargo	244.5	379.4	379.4	378.4	379.4	377.2	373.9	320.9	320.9	320.9
	Total	254.2	396.4	396.4	395.0	396.4	393.8	390.5	337.5	337.5	337.5

Table 4.7: Emissions of air pollutants from international shipping in the 12-mile zones, all sea regions [kilotons]

Pollutant	Vessel type	2000	2020 - ambition level								
			Baseline	Level 1 EU ships	Level 2 EU ships	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships	Max. techn. feasible reduction
SO2	Ferry	12.4	14.7	14.7	6.6	14.7	5.4	5.4	5.4	5.4	5.0
	Cargo	203.8	257.9	257.9	230.0	257.9	198.9	126.1	68.0	68.0	62.6
	Total	216.1	272.6	272.6	236.6	272.6	204.3	131.5	73.4	73.4	67.6
NOx	Ferry	18.0	35.8	33.0	27.6	32.6	26.4	26.4	24.4	20.1	3.9
	Cargo	302.3	437.3	418.6	382.1	396.8	317.8	317.8	290.6	254.3	49.9
	Total	320.3	473.1	451.6	409.6	429.4	344.2	344.2	315.0	274.4	53.8
PM2.5	Ferry	1.4	2.5	2.5	2.4	2.5	2.4	2.4	2.4	2.4	2.4
	Cargo	23.1	34.3	34.3	34.1	34.3	33.9	30.6	30.3	30.3	30.3
	Total	24.5	36.8	36.8	36.6	36.8	36.4	33.1	32.7	32.7	32.7

Projections of emissions from national shipping as estimated for the NEC baseline are presented in Table 4.8. Between 2000 and 2020 emissions of SO_2 from these sources are expected to decrease by about 40 percent, which is due to higher proportion of diesel fuel in total fuel use by national maritime activities and lower sulphur content of marine fuels. Baseline NO_x emissions remain at the 2000 level. As already pointed out earlier, estimates of emissions from national shipping are quite uncertain because of different classifications used by individual countries for reporting their emissions.

Table 4.8: Emissions of air pollutants in 2000 and in 2020 from national shipping, kilotons

	SO_2		*NO_x*		*PM2.5*	
	2000	*2020*	*2000*	*2020*	*2000*	*2020*
Belgium	2.1	2.1	6.4	6.7	0.9	1.0
Bulgaria	2.6	0.6	12.9	14.9	0.2	0.3
Denmark	2.6	2.2	17.6	17.2	0.5	0.5
Estonia	0.1	0.0	0.3	0.4	0.0	0.0
Finland	0.8	0.8	7.7	9.5	0.3	0.4
France	9.9	2.6	27.8	27.7	1.9	1.9
Greece	22.3	1.8	40.4	50.3	1.6	1.0
Ireland	1.4	1.3	1.0	1.0	0.1	0.1
Italy	60.9	56.4	89.1	92.6	4.4	4.6
Latvia	0.1	0.0	0.6	0.3	0.0	0.0
Netherlands	0.9	0.3	16.1	10.1	0.3	0.2
Norway	2.6	2.4	86.3	90.0	1.0	1.1
Poland	1.0	1.0	2.7	2.7	0.2	0.2
Portugal	3.0	2.8	5.0	5.2	0.3	0.3
Romania	7.4	6.4	31.2	38.4	0.8	1.4
Spain	26.5	10.5	50.5	38.4	2.0	1.3
Sweden	3.0	2.9	49.6	56.3	1.2	1.4
Turkey	4.3	6.1	5.0	7.6	0.4	0.6
UK	20.1	3.0	54.6	32.6	1.2	0.8
Total	171.5	103.2	505.0	501.8	17.4	17.0

Source: NEC baseline, Amann *et al.*, 2007

Figure 4.2 presents the development of baseline emissions from shipping over time and compares it with the NEC baseline emissions from land-based sources in the EU-25. In 2000 emissions from shipping accounted for about 28 and 32 percent of land–based SO_2 and NO_x emissions, respectively. Till 2020 emissions from land-based sources will significantly decrease (SO_2 by 56 percent, NO_x by 45 percent[3]) due to legislation in place, while (national and international) ship emissions are expected to increase up to 88 percent of land-based emissions of SO_2 and 82 percent of NO_x. The graph also displays the technical potential for reducing emissions from ships (MTFR – blue diamond) and the indicative emission reduction target for land-based sources of the Thematic Strategy on Air (red triangle).

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[3] Values are for the national baseline "Current legislation" scenario, compare Amann *et al.*, 2006.

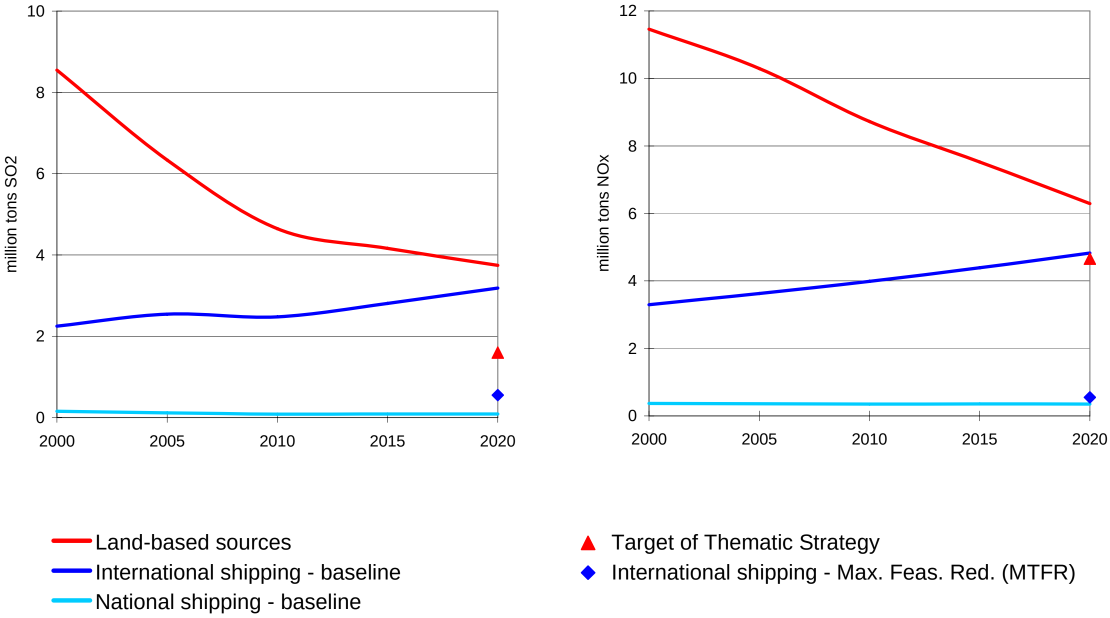

Figure 4.2: Emissions of sulphur dioxide (left panel) and nitrogen oxides (right panel) from shipping (baseline scenario) compared with the emissions from land-based sources in the EU25, million tons.

4.5 Emission control costs

Table 4.9 presents the costs of the various emission scenarios for all sea regions. Details can be found in the appendices. Compared with the "Baseline" case, the "Ambition level 1" scenarios cause an increase in costs of less than 30 million €/year. Costs (on top of the baseline costs) of the "Ambition level 2" scenarios range from about 380 million €/year (for the EU-vessels only case) to 830 million €/yr (for the "all ships with sulphur measures in the 12 miles zone" case). Since "Ambition level 3" and "Ambition level 4" scenarios assume adoption of more stringent options to reduce sulphur and nitrogen oxides, their incremental costs (compared with the Baseline) are higher – 2.5 and 3.2 billion €/a respectively. In the "Maximum technically feasible reduction" (MTFR) scenario costs increase to 5.5 billion €/yr (5.1 billion €/a above the baseline). It needs to be stressed that the MTFR scenario assumes sulphur reduction through the use of low sulphur residual oil. If seawater scrubbing were applied on all ships instead of using fuel with 0.5 percent S content, costs of sulphur control could be halved, although SO_2 emissions were reduced by 72 percent instead of 79 percent compared to the baseline case.

Figure 4.3 and Figure 4.4 compare marginal costs of reducing emissions from shipping with the marginal costs of the sectoral measures at the land-based sources in the EU-25 that have been proposed in the Thematic Strategy on Air Pollution. The analysis is based on the results of the CAFE project (Amann *et al.*, 2005). To achieve the environmental targets of the Thematic Strategy, SO_2 and NO_x emissions need to be reduced by 1.1 and 0.85 million tons below the CAFE baseline projection, respectively. In a cost-optimal solution, these reductions involve sectoral measures with marginal costs ranging from a couple of hundreds Euro per ton (of SO_2 or NO_x) to more than five thousand Euro per ton, depending on the country. Unit costs of SO_2 control for shipping range between 450 and 550 €/t for seawater scrubbing and 800 to 900 €/t for low sulphur residual oil. However, the marginal cost of a step from seawater scrubbing for newer vessels and 1.5 percent S for old (pre-2000) vessels to 0.5 percent residual oil is higher than 3000 €/t. For NO_x, marginal costs range from less than 40 €/t for internal engine modifications, over approximately 500 €/t for humid air motors up to 1200 to 1800 €/t /ton for SCR on new ships, depending on sulphur control policies in a given sea region. Costs of retrofitting existing ships with SCR are typically less than 10 percent higher than the costs for new built vessels.

The cost-efficiency of a specific measure depends heavily on the spatial proximity of the emission source to the environmental receptor. Thus, the marginal abatement costs need to be compared in relation to the environmental impact of the source, taking into account atmospheric transport and dispersion processes. Effects of reducing emissions from shipping on cost-efficient achievement of environmental targets from the Thematic Strategy are discussed in Section 7.

Table 4.9: Emission control costs in 2020, all sea regions, million €/year

Pollutant	Vessel type	2020 - ambition level								
		Baseline	Level 1 EU ships	Level 2 EU ships	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships	Max. techn. feasible reduction
SO2	Ferry	63	63	106	63	116	116	116	116	133
	Cargo	306	306	481	306	671	728	2238	2238	2567
	Total	369	369	587	369	787	844	2354	2354	2699
NOx	Ferry	1	3	16	3	19	19	24	62	142
	Cargo	25	36	169	50	362	362	485	1156	2676
	Total	27	38	185	53	381	381	509	1218	2819
Total	Ferry	64	65	122	66	135	135	139	177	275
	Cargo	331	342	650	356	1034	1091	2724	3395	5243
	Total	395	407	772	421	1168	1225	2863	3572	5518

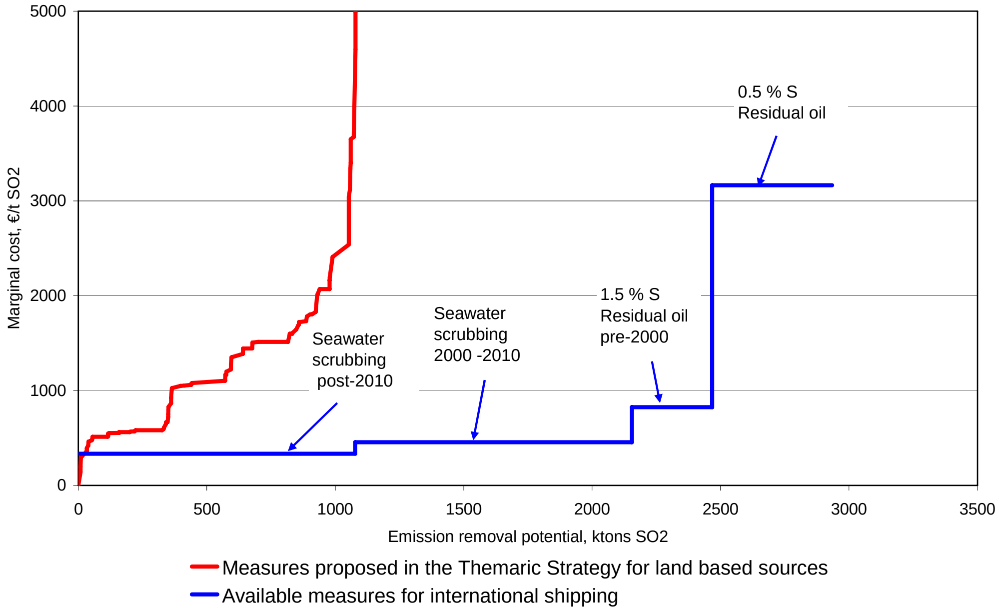

Figure 4.3: SO_2 reductions and marginal costs of the measures proposed in the Thematic Strategy for land-based sources and for the measures identified in this report for international shipping in the year 2020. While this graph illustrates the potentials and costs, the cost-effectiveness of emission controls can only be judged from a full integrated analysis including atmospheric dispersion characteristics of the emissions and their environmental impacts.

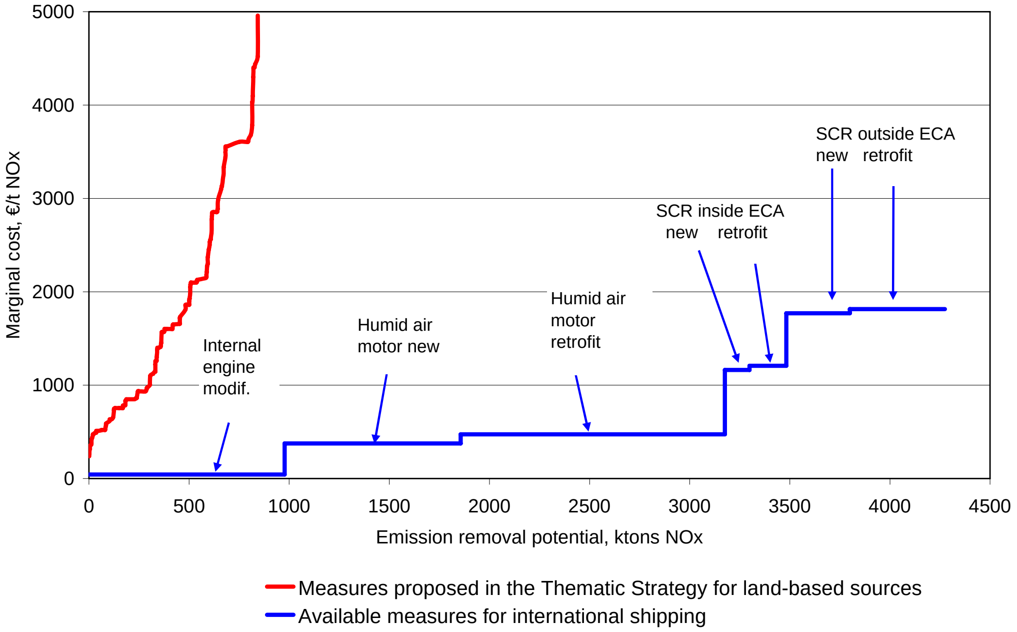

Figure 4.4: NO_x reductions and marginal costs of the measures proposed in the Thematic Strategy for land-based sources and for the measures identified in this report for international shipping in the year 2020. While this graph illustrates the potentials and costs, the cost-effectiveness of emission controls can only be judged from a full integrated analysis including atmospheric dispersion characteristics of the emissions and their environmental impacts.

5 Atmospheric dispersion of ship emissions

5.1 Model description

The EMEP unified model has been used for this study to compute the atmospheric dispersion of ship emissions. The EMEP model is a multi-layer atmospheric dispersion model for simulating the long-range transport of air pollution over several years. The EMEP model has 20 vertical layers in σ-coordinates. The present version has been run on the 50*50 km^2 horizontal resolution in the EMEP polar stereographic grid. The model is described in Simpson *et al.* (2003) with updates in Fagerli *et al.* (2004). A more condensed model description is also available in Jonson *et al.* (2006). This version of the model uses meteorological data from a dedicated version of the operational HIRLAM model (High Resolution Limited Area Model) maintained and verified at MET.NO.

The present version of the EMEP unified model includes 70 species and approximately 140 chemical reactions. The model parameterisation of dry deposition enables the calculation of ozone fluxes to vegetation. The model use flexible boundary conditions provided either by observations or modelled results from global air pollution models. In these model runs lateral boundary concentrations are based on measurements as described in Simpson *et al.* (2003) and Fagerli *et al.* (2004). For ozone an additional 4.5 ppb of ozone is added to the lateral boundary concentrations as tropospheric ozone levels are expected to increase in the northern hemisphere. The EMEP Unified model has been extensively reviewed (UNECE, 2004) and evaluated against measurements (EMEP, 2005, 2006; Jonson *et al,* 2006).

The emission inventory developed by this study is fully harmonized with the official EMEP grid system, i.e., the model domain used in the calculations in this project matches exactly the official EMEP domain. Emissions from national shipping are not accounted under international activities, since they are included in the emission inventories reported by the individual parties to the Convention on Long Range Transport to UNECE.

5.2 Source receptor calculations for ship traffic

To enable an integrated assessment of the cost-effectiveness of emission control measures for ships, the EMEP Eulerian atmospheric dispersion model has been used to derive source-receptor relationships that describe the atmospheric dispersion of ship emissions. For this purpose, a number of model calculations have been conducted in which ship emissions from the various categories have been sequentially permutated. The resulting changes in air quality indicators (concentration and deposition over the entire model domain), together with the causative changes in emissions, allowed the construction of reduced-form source-receptor relationships. Next, these relationships were used for the cost-effectiveness analysis in the RAINS/GAINS model.

The model calculations have been carried out for the chemical regime of year 2020 with emissions from international ship traffic are analysed separately for the following categories:

- International shipping emissions within the 12-mile zone
- International shipping from EU flags
- International shipping from Non EU flags
- Emissions from international ferries in the Mediterranean Sea.

Computations have been carried out for each class by reducing the contributions from the individual sources by 15 percent for each of the five sea areas (Baltic Sea, Black Sea, Mediterranean Sea, North Sea, and Remaining North-East Atlantic Ocean). Three groups of emissions have been considered (SO_2, NO_x + PM, and VOC + CO), and conditions of five meteorological years have been analysed (1996, 1997, 1998, 2000 and 2003). In total, 240 source-receptor model runs have been made. Based on these calculations IIASA has fully integrated the source-receptor relationships for shipping with those for land-based sources. These relations were used in the analysis described in Sections 6 and 7 of this report.

The current analysis does not include emissions from smaller vessels (below 500 GRT). While this is not expected to cause major distortions of the overall dispersion pattern of ship emissions, this simplification might cause certain inaccuracies for the emissions with the 12-mile zones, where most of the smaller ships are likely to operate. However, to judge the overall robustness of the current approach, it is important to remember that, for reasons of consistency with the Europe-wide assessment of land-based and marine emissions, the atmospheric dispersions calculations employ the 50x50 km^2 regional scale version of the EMEP model. Obviously, since the 12-mile zone is actually much smaller, such a resolution is too coarse to determine the actual impact of these sources in coastal areas in great spatial detail, so that this approach can in any case only deliver an initial estimate. However, the numerical diffusion effects from such a simplified approach are to a certain extend compensated by the underestimation of emissions in the 12-mile zones that has been discussed in the preceding chapter. In summary, the overall results could therefore be considered as a valid indication of the order of magnitude of the actual impact of the contribution from the 12-mile zone shipping emissions.

5.3 Model results

The EMEP model has been run for the base year 2000 and for 240 emission control cases perturbating the expected baseline emission for the year 2020. Calculations included meteorological conditions of five years (1996, 1997, 1998, 2000 and 2003). As examples for the model output, Sections 5.3.1 and 5.3.2 present the spatial distribution of selected indicators for ground-level ozone and sulphur deposition calculated with 5-years average meteorological conditions.

5.3.1 Ground-level ozone

Figure 5.1 demonstrates the spatial distribution of the SOMO35 indicator across Europe for the baseline situation in 2020. Figure 5.2 to Figure 5.6 display the contributions made by ships with EU flags in the various sea regions to the SOMO35 levels that are anticipated for the 2020 baseline scenario. It should be mentioned that emissions from EU ships constitute about half of total ship emissions. Similar calculations have been carried out for ferries, and for ships in the 12-mile zones.

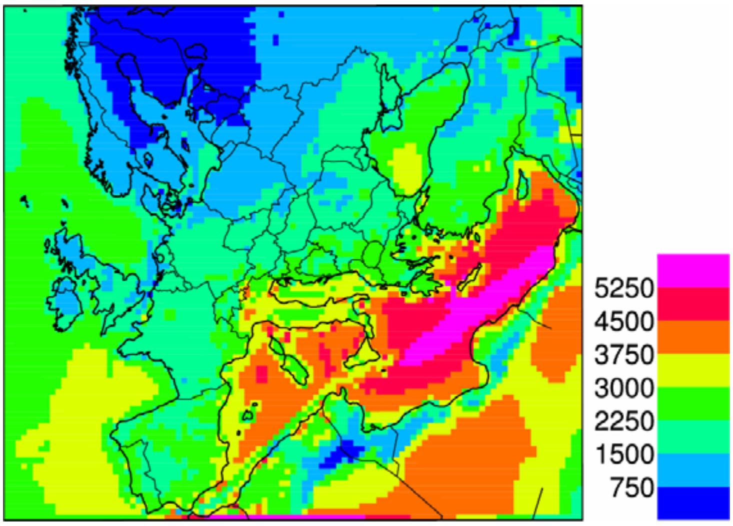

Figure 5.1: The SOMO35 indicator for health impacts of ozone for the year 2020 in ppb.days

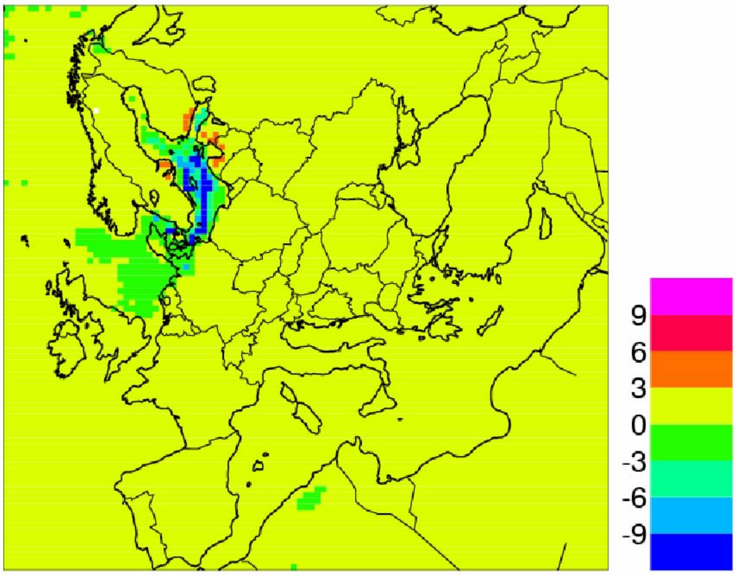

Figure 5.2: Percentage contribution to the SOMO35 ozone health indicator from NO_x emissions from EU flagged international shipping in the Baltic Sea for the baseline emissions of the year 2020

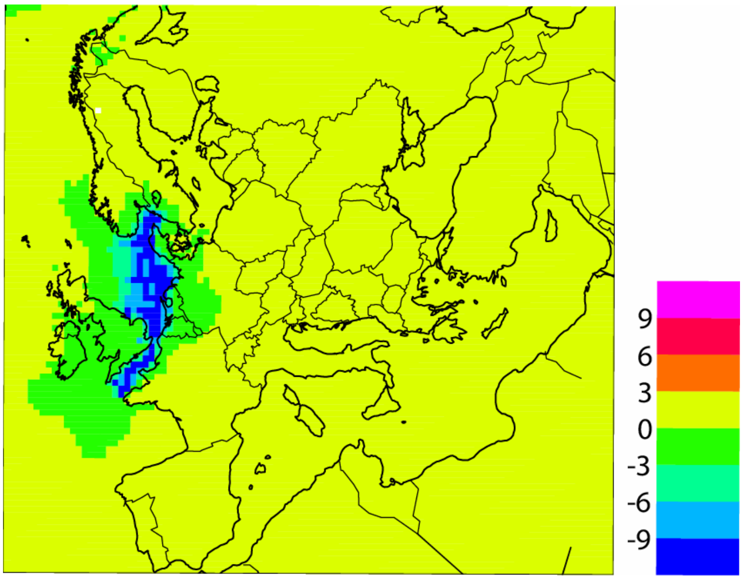

Figure 5.3: Percentage contribution to the SOMO35 ozone health indicator from NO_x emissions from EU flagged international shipping in the North Sea for the baseline emissions of the year 2020

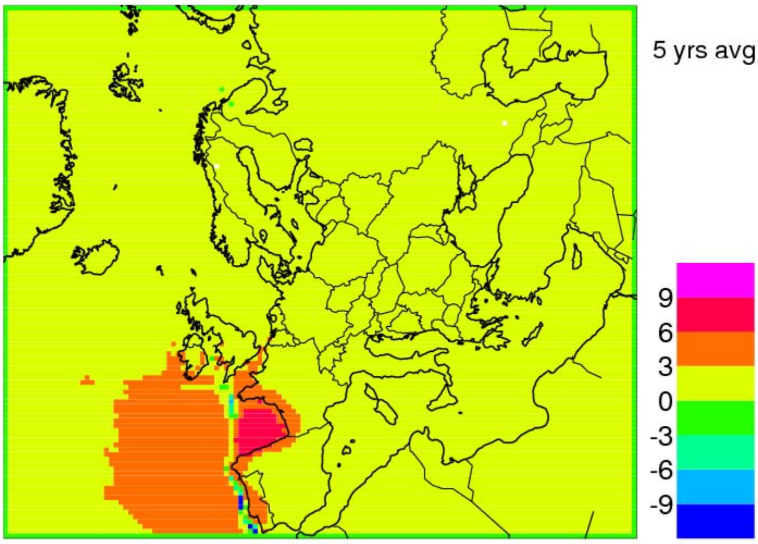

Figure 5.4: Percentage contribution to the SOMO35 ozone health indicator from NO_x emissions from EU flagged international shipping in the Atlantic Ocean for the baseline emissions of the year 2020

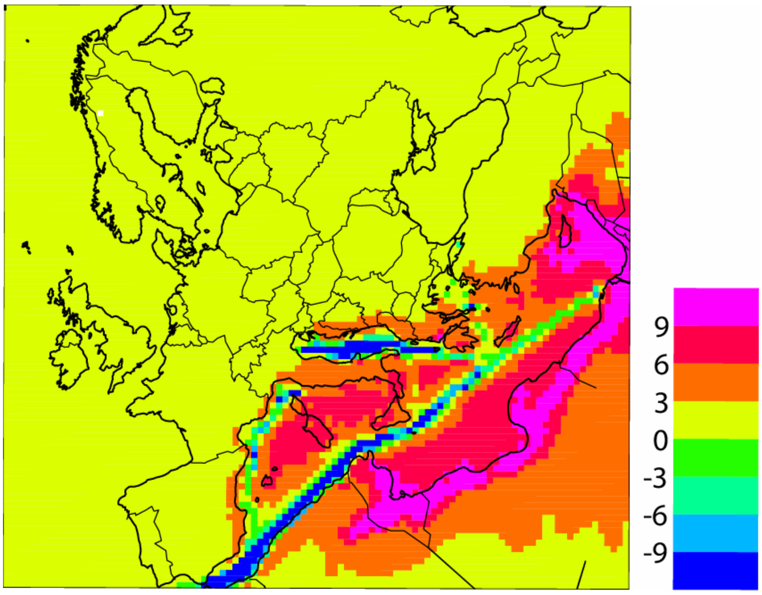

Figure 5.5: Percentage contribution to the SOMO35 ozone health indicator from NO_x emissions from EU flagged international shipping the Mediterranean Sea for the baseline emissions of the year 2020

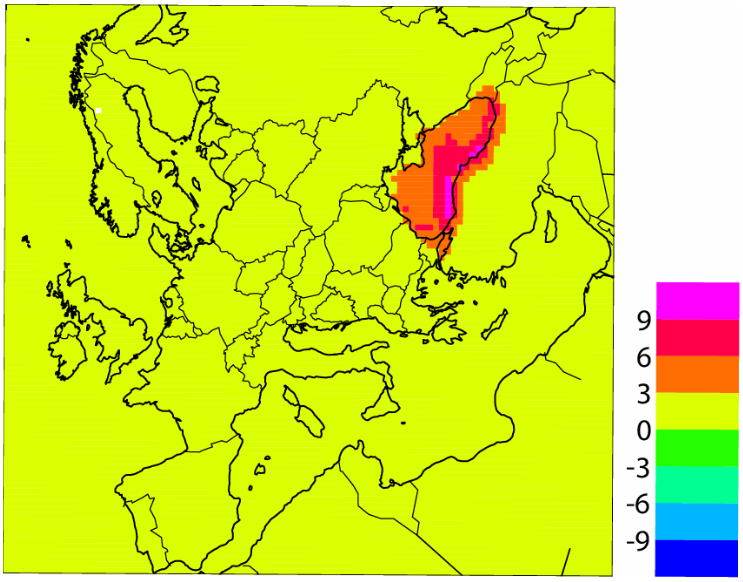

Figure 5.6: Percentage contribution to the SOMO35 ozone health indicator from NO_x emissions from EU flagged international shipping the Black Sea for the baseline emissions of the year 2020

5.3.2 Acid deposition

Figure 5.7 to Figure 5.13 display the contributions made by ships with EU flags in the various sea regions to the dry sulphur deposition that are anticipated for the 2020 baseline scenario. Emissions from EU ships constitute about half of total ship emissions. Similar calculations have been carried out for ferries, for ships in the 12-mile zones, for wet deposition of sulphur and for nitrogen deposition. These model results provide the basis for the development of source-receptor relationships for the cost-effectiveness analysis with the RAINS/GAINS model.

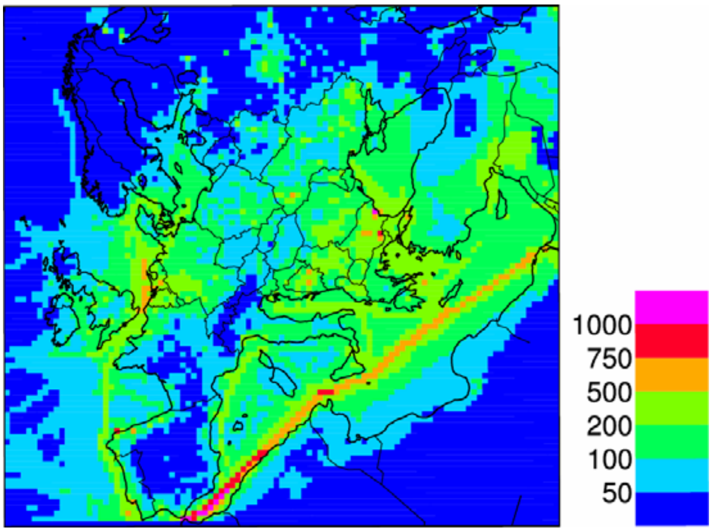

Figure 5.7: Dry deposition of sulphur from EU flagged international shipping (in mg Sm^{-2}) for the baseline emissions in 2020

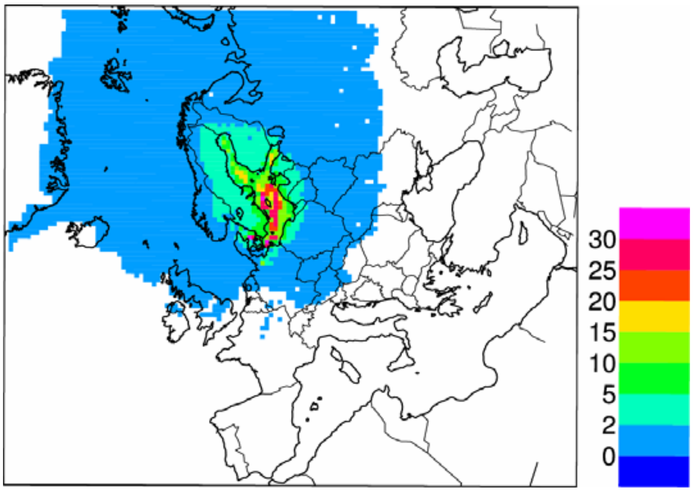

Figure 5.8: Percentage contribution made by EU flagged international shipping in the Baltic Sea to the dry deposition of sulphur (in mg Sm^{-2}) for the baseline emissions in 2020

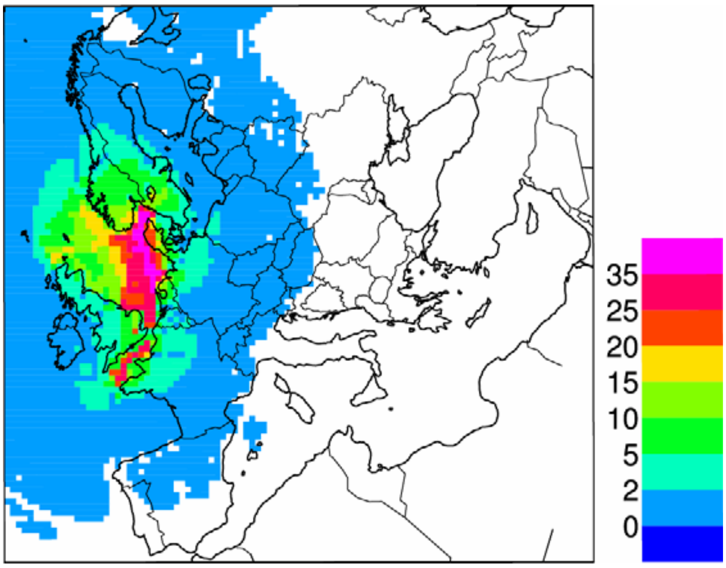

Figure 5.9: Percentage contribution made EU flagged international shipping in the North Sea to the dry deposition of sulphur (in mg Sm^{-2}) for the baseline emissions in 2020

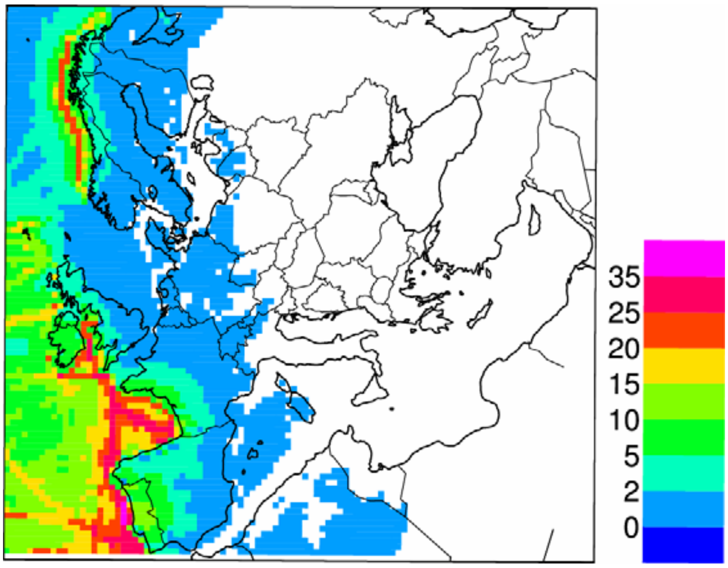

Figure 5.10: Percentage contribution made by EU flagged international shipping in the North Atlantic to the dry deposition of sulphur (in mg Sm^{-2}) for the baseline emissions in 2020

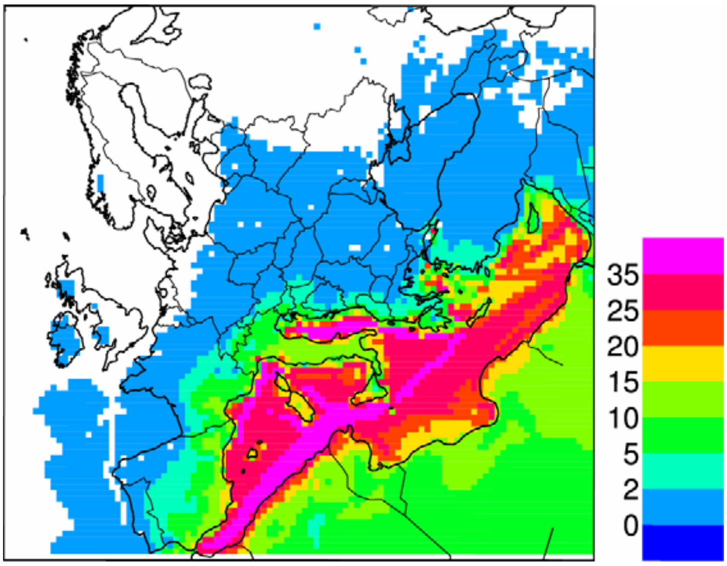

Figure 5.11: Percentage contribution made by EU flagged international shipping in the Mediterranean Sea to the dry deposition of sulphur (in mg Sm^{-2}) for the baseline emissions in 2020

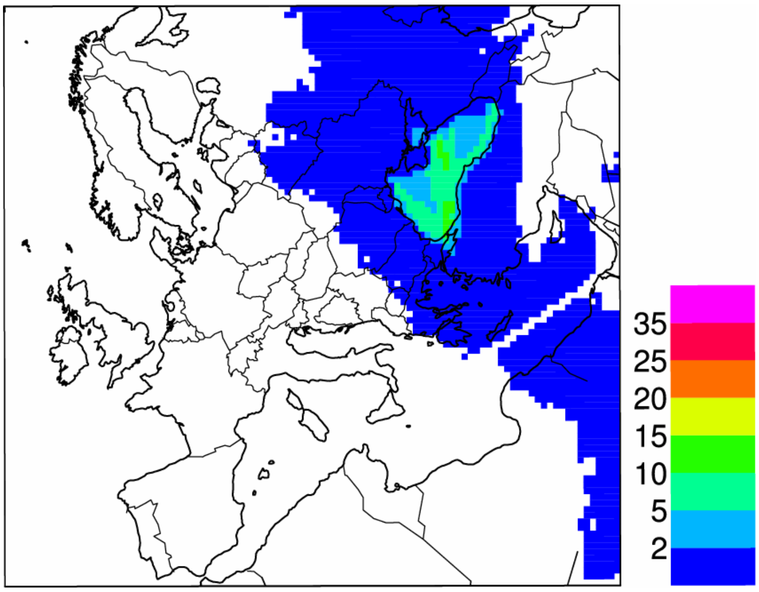

Figure 5.12: Percentage contribution made by EU flagged international shipping in the Black Sea to the dry deposition of sulphur (in mg Sm^{-2}) for the baseline emissions in 2020

Analysis suggests that, at present, emissions from ships are responsible for 10 to 20 percent of sulphur deposition in coastal areas. Until 2020 their contribution is expected to increase to more than 30 percent in large areas along the coast in Europe. In many coastal areas, ships will be responsible for more than 50 percent of sulphur deposition (Figure 5.13). Emission controls on shipping will bring down the depositions to much lower levels.

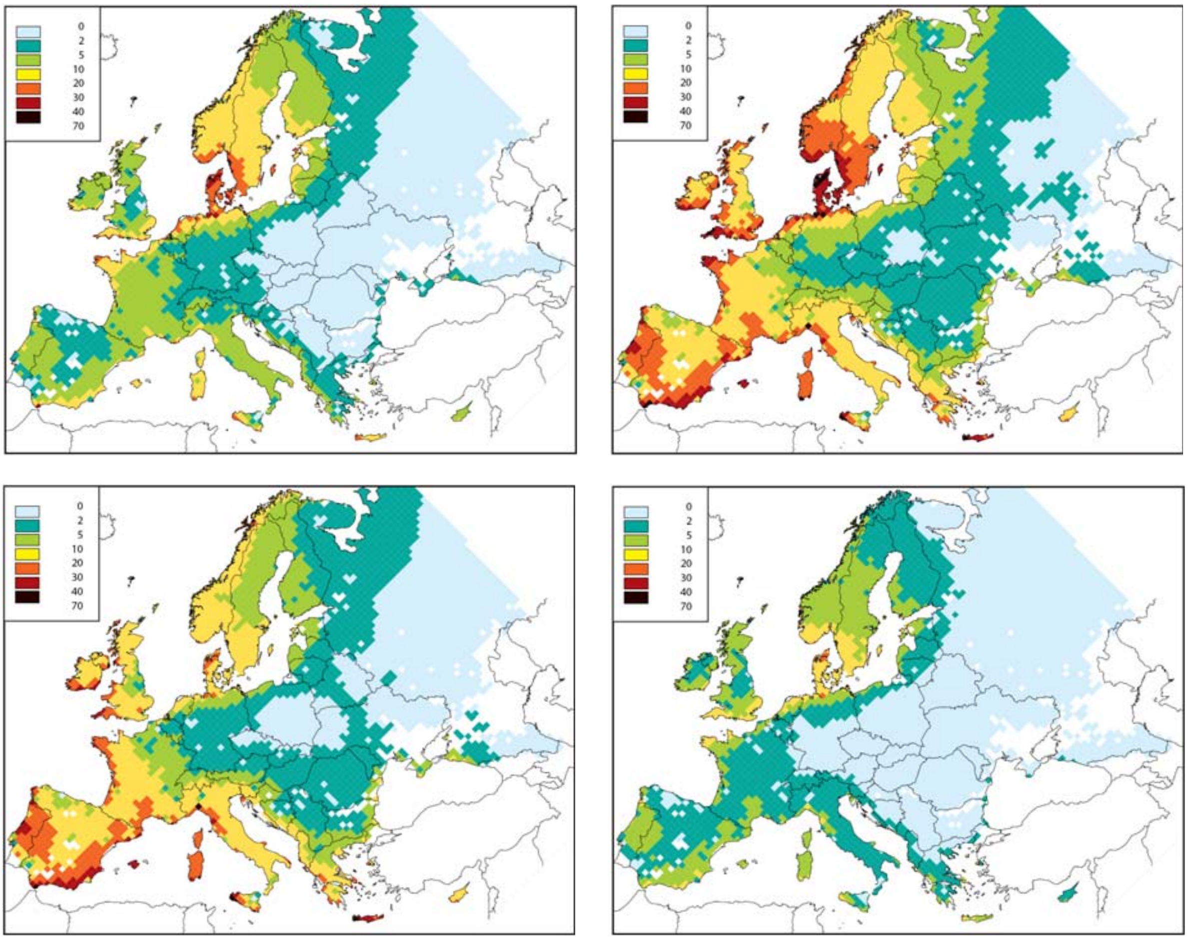

Figure 5.13: Percent of sulphur deposition originating from international shipping in 2000 (upper left panel) and for the “Baseline” scenario in 2020 (upper right panel). Lower panels show the situation in 2020 for the “Ambition level 2” and the “Maximum technically feasible reduction” scenarios. Values calculated with average transfer coefficients for five meteorological years (1996, 1997, 1998, 2000 and 2003)

6 Health and environmental impacts

This section provides an assessment of the health and environmental impacts of the shipping scenarios for the year 2020. The assessment is based on average transfer coefficients calculated for five meteorological years (1996, 1997, 1998, 2000 and 2003). The assessment of ecosystems protection against acidification and eutrophication employs the database on critical loads as approved by the UNECE Working Group on Effects in August 2006 and is consistent with the data set used for the NEC analysis. Impact indicators presented in this section use the "National Baseline Current Legislation" scenario for land-based sources (compare Amann *et al.*, 2007). This scenario includes – for stationary sources – current international and national (if stricter) emission and fuel standards. For transport it includes the effects of the implementation of Euro 5 and 6 emission standards on cars and light-duty trucks but does not take into account Euro VI standards for heavy-duty trucks and buses. All indicators are for the situation when the measures are applied to all vessels, independent of which flag.

6.1 Health impacts of fine particulate matter

In this section a loss in statistical life expectancy attributable to anthropogenic emissions of PM2.5 is used as a health impact indicator. The value of that indicator is highly country- and scenario-specific (compare Table 6.1 and Table 6.2). An improvement is expected for the baseline situation between 2000–2020 (decrease of the EU-27 average loss of life expectancy from 8.0 to 5.2 months). Improvements for the "Ambition level 1" scenario are low (0.5 percent of the baseline value for EU27). For the "Ambition level 2" scenario it increases to 3.1 percent. Implementation of low sulphur residual oil (1.5 percent S) in the 12 miles zone in Atlantic Ocean, Mediterranean Sea and in the Black Sea brings little improvement (additional 0.2 percentage points). In the "Ambition level 3" and "Ambition level 4"scenarios the average loss of life expectancy is lower by 6.5 to 6.9 percent with 10 percent or more improvement for Cyprus, Denmark, Greece, Ireland, Italy, Malta, Portugal, Spain, Sweden, and the UK. The "Maximum technically feasible reduction" (MTFR) measures applied to international shipping achieve an overall EU-27 reduction of nine percent compared to the NEC baseline.

Figure 6.1 shows the spatial distribution of the loss life expectancy indicator for the baseline situation in 2020 and the improvements for selected scenarios. For scenarios with stringent controls large improvements (more than 20 percent, with values up to 50 percent for selected grids) are expected along the coastal zones.

Table 6.1: Loss in statistical life expectancy attributable to the human exposure to fine particulate matter (PM2.5) originating from anthropogenic emission sources in 2000, 2020 Baseline and maximum technically feasible reduction scenario from shipping (months)

		2020		
	2000	National and shipping baselines	Nat. baseline, max. technically feasible reduction from shipping	
Austria	7.77	4.87	4.68	-3.8%
Belgium	12.17	8.54	7.76	-9.2%
Bulgaria	8.23	4.97	4.74	-4.7%
Cyprus	4.39	2.91	2.41	-17.3%
Czech Rep.	9.63	6.05	5.84	-3.6%
Denmark	6.61	4.63	3.77	-18.6%
Estonia	4.82	3.78	3.53	-6.7%
Finland	2.94	2.17	2.01	-7.2%
France	7.60	4.51	4.06	-10.1%
Germany	9.34	6.16	5.68	-7.8%
Greece	7.69	4.32	3.84	-11.0%
Hungary	11.05	7.17	6.94	-3.2%
Ireland	3.81	2.28	1.86	-18.3%
Italy	8.11	5.06	4.47	-11.5%
Latvia	5.88	4.41	4.17	-5.4%
Lithuania	5.68	4.27	3.99	-6.5%
Luxembourg	9.15	5.84	5.42	-7.1%
Malta	6.15	4.93	3.30	-33.1%
Netherlands	11.51	8.31	7.41	-10.8%
Poland	10.00	6.81	6.55	-3.9%
Portugal	5.79	3.44	2.93	-15.0%
Romania	8.86	6.21	5.99	-3.6%
Slovakia	9.43	6.23	6.04	-3.0%
Slovenia	8.37	5.45	5.12	-5.9%
Spain	4.80	2.79	2.28	-18.3%
Sweden	3.40	2.48	2.15	-13.2%
UK	6.71	4.19	3.63	-13.4%
EU-27	8.02	5.18	4.71	-9.0%
Croatia	8.49	5.50	5.15	-6.4%
Turkey				
Norway	2.53	1.70	1.54	-9.8%
Switzerland	6.17	3.63	3.43	-5.6%

Table 6.2: Change in loss in statistical life expectancy attributable to the human exposure to fine particulate matter (PM2.5) originating from anthropogenic emission sources, percentage of 2020 Baseline

	2020 - ambition level				
	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships
Austria	-0.2%	-1.4%	-1.5%	-2.7%	-2.8%
Belgium	-0.7%	-4.4%	-4.5%	-5.6%	-6.1%
Bulgaria	-0.4%	-1.4%	-1.6%	-3.8%	-4.0%
Cyprus	-0.2%	-1.4%	-2.4%	-15.6%	-15.9%
Czech Rep.	-0.3%	-1.6%	-1.7%	-2.3%	-2.5%
Denmark	-1.5%	-9.7%	-9.8%	-11.2%	-12.1%
Estonia	-0.3%	-4.7%	-4.7%	-5.2%	-5.3%
Finland	-0.4%	-5.1%	-5.1%	-5.8%	-6.0%
France	-0.6%	-3.4%	-3.6%	-7.3%	-7.7%
Germany	-0.6%	-3.7%	-3.7%	-4.8%	-5.2%
Greece	-0.2%	-1.1%	-2.1%	-10.5%	-10.6%
Hungary	-0.3%	-1.2%	-1.2%	-2.3%	-2.4%
Ireland	-1.2%	-5.2%	-5.9%	-12.3%	-13.3%
Italy	-0.3%	-1.7%	-2.1%	-9.9%	-10.1%
Latvia	-0.3%	-3.3%	-3.3%	-3.8%	-4.0%
Lithuania	-0.5%	-3.6%	-3.6%	-4.2%	-4.5%
Luxembourg	-0.6%	-3.3%	-3.3%	-4.5%	-4.9%
Malta	0.0%	-1.6%	-3.4%	-32.4%	-32.4%
Netherlands	-0.8%	-5.7%	-5.8%	-6.9%	-7.5%
Poland	-0.3%	-1.9%	-2.0%	-2.5%	-2.7%
Portugal	-0.2%	-1.0%	-1.9%	-13.9%	-14.1%
Romania	-0.5%	-1.4%	-1.5%	-2.7%	-2.8%
Slovakia	-0.2%	-1.3%	-1.3%	-2.1%	-2.2%
Slovenia	-0.3%	-1.5%	-1.8%	-4.4%	-4.7%
Spain	-0.3%	-1.7%	-2.4%	-16.9%	-17.1%
Sweden	-0.9%	-8.3%	-8.4%	-9.5%	-9.9%
UK	-0.9%	-5.7%	-5.9%	-9.0%	-9.6%
EU-27	-0.5%	-3.1%	-3.3%	-6.5%	-6.9%
Croatia	-0.2%	-1.3%	-1.5%	-5.3%	-5.4%
Turkey					
Norway	-0.6%	-6.1%	-6.2%	-7.7%	-7.9%
Switzerland	-0.4%	-2.0%	-2.1%	-4.0%	-4.3%

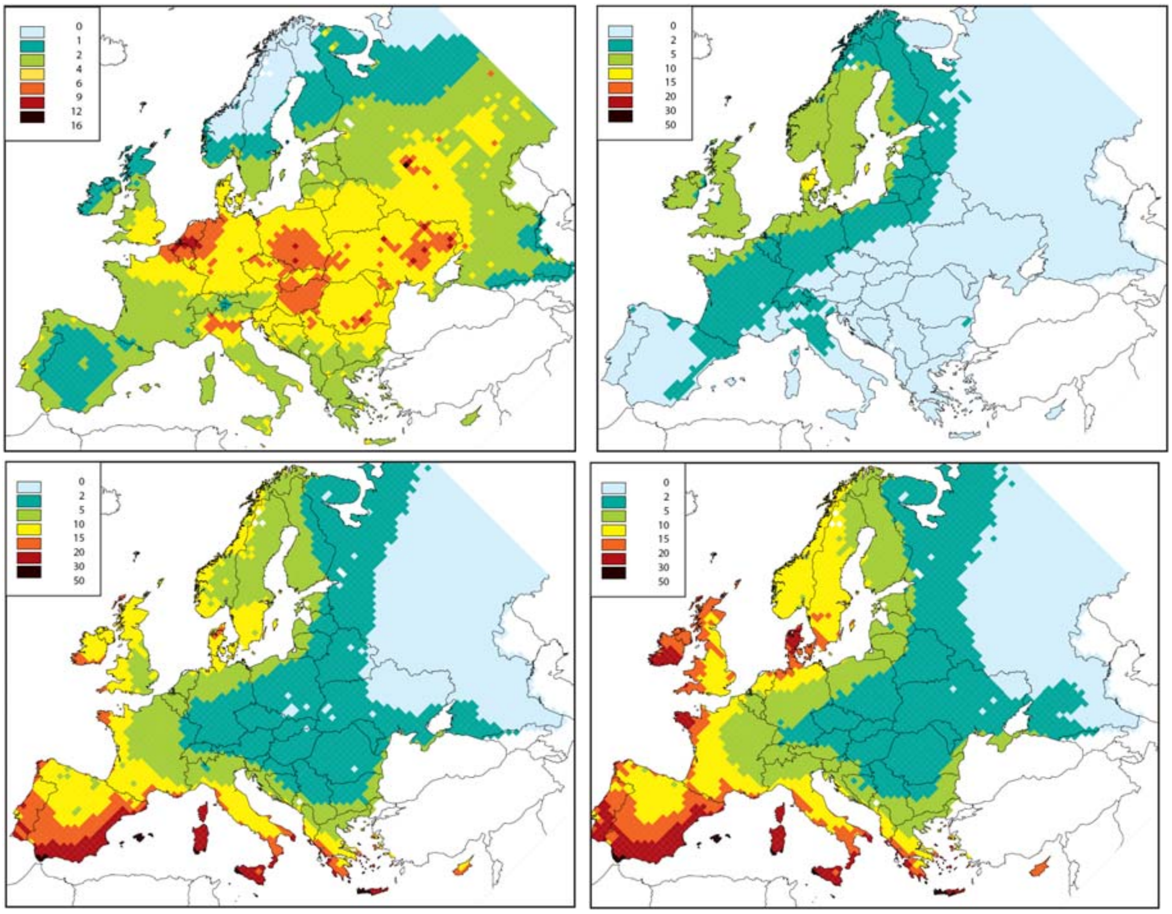

Figure 6.1: Loss of life expectancy (months) due to anthropogenic sources of PM2.5 for the "Baseline" scenario in 2020 (upper left panel) and percentage improvement from the baseline for the "Ambition level 2" (upper right panel), "Ambition level 4" (lower left panel) and MTFR scenario of emissions from international shipping (lower right panel)

6.2 Premature mortality attributable to ground-level ozone

Table 6.3 and Table 6.4 provide estimates of the number of cases of premature deaths attributable to the human exposure to ground-level ozone. This analysis of health impacts suggests that the “Ambition level 2” shipping scenarios achieve a reduction in the number of cases of premature deaths of about 1.9 percent of the estimated value for the NEC baseline scenario for 2020 for the EU-27 as a whole. For “Ambition level 3” and “Ambition level 4” cases the reductions are higher (2.3 and 2.8 percent). Reduction achievable with the MTFR measures is five percent.

Table 6.3: Number of cases of premature deaths attributable to the human exposure to ground-level ozone in 2000, 2020 baseline and maximum technically feasible reduction scenario from shipping.

		2020		
	2000	National and shipping baselines	Nat. baseline, max. technically feasible reduction from shipping	
Austria	397	320	308	-3.7%
Belgium	320	371	353	-4.9%
Bulgaria	482	439	412	-6.1%
Cyprus	29	27	25	-6.5%
Czech Rep.	514	432	414	-4.2%
Denmark	159	163	155	-5.1%
Estonia	18	20	18	-8.7%
Finland	41	49	44	-9.6%
France	2397	2110	1997	-5.3%
Germany	3743	3268	3179	-2.7%
Greece	567	529	491	-7.2%
Hungary	735	598	575	-3.9%
Ireland	57	83	77	-7.0%
Italy	4179	3620	3394	-6.2%
Latvia	46	46	42	-9.3%
Lithuania	74	68	62	-8.3%
Luxembourg	27	26	25	-5.5%
Malta	23	21	20	-6.3%
Netherlands	342	364	347	-4.6%
Poland	1347	1121	1065	-5.0%
Portugal	396	479	447	-6.8%
Romania	1061	968	918	-5.1%
Slovakia	234	196	187	-4.5%
Slovenia	105	85	81	-5.5%
Spain	1755	1681	1590	-5.4%
Sweden	164	172	161	-6.5%
UK	1083	1768	1685	-4.7%
EU-27	20295	19025	18071	-5.0%
Croatia	303	253	238	-5.8%
Turkey	1544	1707	1528	-10.5%
Norway	64	84	81	-4.4%
Switzerland	355	274	264	-3.5%

Table 6.4: Number of cases of premature deaths attributable to the human exposure to ground-level ozone, percentage change from the baseline scenario.

	2020 - ambition level				
	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships
Austria	-0.5%	-1.4%	-1.4%	-1.7%	-2.1%
Belgium	-0.7%	-1.8%	-1.8%	-2.2%	-2.7%
Bulgaria	-1.1%	-2.9%	-2.9%	-3.3%	-3.8%
Cyprus	-0.8%	-2.2%	-2.2%	-2.6%	-3.4%
Czech Rep.	-0.6%	-1.6%	-1.6%	-1.9%	-2.3%
Denmark	-0.9%	-2.4%	-2.4%	-2.6%	-3.1%
Estonia	-1.3%	-3.4%	-3.4%	-4.0%	-4.7%
Finland	-1.3%	-3.7%	-3.7%	-4.3%	-5.1%
France	-0.7%	-2.0%	-2.0%	-2.3%	-2.9%
Germany	-0.4%	-1.1%	-1.1%	-1.3%	-1.6%
Greece	-1.2%	-3.1%	-3.1%	-3.5%	-4.3%
Hungary	-0.6%	-1.6%	-1.6%	-1.8%	-2.2%
Ireland	-0.9%	-2.4%	-2.4%	-2.9%	-3.7%
Italy	-0.7%	-2.3%	-2.3%	-2.7%	-3.4%
Latvia	-1.3%	-3.5%	-3.5%	-4.1%	-4.8%
Lithuania	-1.1%	-3.1%	-3.1%	-3.6%	-4.3%
Luxembourg	-0.8%	-2.2%	-2.2%	-2.5%	-3.1%
Malta	-0.8%	-2.3%	-2.3%	-2.7%	-3.5%
Netherlands	-0.6%	-1.8%	-1.8%	-2.1%	-2.6%
Poland	-0.7%	-1.9%	-1.9%	-2.3%	-2.7%
Portugal	-0.8%	-2.4%	-2.4%	-2.8%	-3.6%
Romania	-1.0%	-2.6%	-2.6%	-2.8%	-3.3%
Slovakia	-0.6%	-1.8%	-1.8%	-2.1%	-2.5%
Slovenia	-0.7%	-2.1%	-2.1%	-2.4%	-3.0%
Spain	-0.7%	-2.0%	-2.0%	-2.4%	-3.0%
Sweden	-1.1%	-2.9%	-2.9%	-3.3%	-3.8%
UK	-0.6%	-1.7%	-1.7%	-2.0%	-2.5%
EU-27	-0.7%	-1.9%	-1.9%	-2.3%	-2.8%
Croatia	-0.7%	-2.1%	-2.1%	-2.5%	-3.1%
Turkey	-1.3%	-3.8%	-3.8%	-4.4%	-5.6%
Norway	-0.8%	-2.0%	-2.0%	-2.2%	-2.6%
Switzerland	-0.5%	-1.4%	-1.4%	-1.6%	-2.0%

6.3 Protection of ecosystems against acidification

Table 6.5 to Table 6.10 provide estimates of the protection of ecosystems against acidification for forests, semi-natural vegetation, freshwater catchments and all ecosystems, respectively.

Whereas in the “Ambition level 1” scenario the improvements are moderate (3.4 percent for forests, 0.9 percent for semi-natural vegetation and 0.3 percent for freshwaters) the “Ambition level 2” scenarios bring an improvement of 14 percent (forests), 6 to 7 percent (semi-natural ecosystems), and 13 to 14 percent (freshwaters). Corresponding values for the MTFR scenario are: 28 percent (forests), 24 percent (semi-natural vegetation) and 24 percent (water). Generally, the relative benefit is seen to be higher in central and northern Europe (compare Figure 6.2).

6.3.1 Forests

Table 6.5: Forest area with acid deposition above critical loads for acidification in 2000, 2020 baseline and maximum technically feasible reduction scenario from shipping, km^2.

		2020		
	2000	National and shipping baselines	Nat. baseline, max. technically feasible reduction from shipping	
Austria	373	0	0	
Belgium	4591	1651	1181	-28.5%
Bulgaria	0	0	0	
Cyprus	0	0	0	
Czech Rep.	9158	4766	4503	-5.5%
Denmark	1200	72	10	-86.1%
Estonia	0	0	0	
Finland	6115	2682	1732	-35.4%
France	19649	11047	6521	-41.0%
Germany	62491	32055	28140	-12.2%
Greece	943	252	170	-32.5%
Hungary	50	0	0	
Ireland	1695	640	420	-34.4%
Italy	0	0	0	
Latvia	538	0	0	
Lithuania	13219	9456	8588	-9.2%
Luxembourg	272	170	170	0.0%
Malta				
Netherlands	5106	4997	4880	-2.3%
Poland	53034	22901	18498	-19.2%
Portugal	3345	1044	850	-18.6%
Romania	3516	176	160	-9.1%
Slovakia	4707	1943	1840	-5.3%
Slovenia	647	2	2	0.0%
Spain	900	100	75	-25.0%
Sweden	58438	20282	5062	-75.0%
UK	9424	3588	2375	-33.8%
EU-27	259412	117824	85178	-27.7%
Croatia	351	0	0	
Turkey				

Norway	2789	424	123	-71.0%
Switzerland	1899	656	595	-9.3%

Table 6.6: Forest area with acid deposition above critical loads for acidification, percentage change from 2020 baseline. Calculated using ecosystem-specific deposition with the critical loads database of 2006

	2020 - ambition level				
	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships
Austria					
Belgium	-5.6%	-17.4%	-17.4%	-19.7%	-20.9%
Bulgaria					
Cyprus					
Czech Rep.	-0.9%	-2.9%	-2.9%	-3.7%	-3.7%
Denmark	-19.4%	-65.3%	-65.3%	-68.1%	-73.6%
Estonia					
Finland	-5.8%	-21.9%	-21.9%	-22.7%	-22.7%
France	-5.8%	-11.9%	-11.9%	-32.4%	-32.5%
Germany	-1.0%	-5.7%	-5.8%	-7.3%	-7.9%
Greece	0.0%	-18.3%	-18.3%	-32.5%	-32.5%
Hungary					
Ireland	-1.9%	-7.7%	-10.0%	-25.2%	-26.9%
Italy					
Latvia					
Lithuania	-0.1%	-3.9%	-3.9%	-4.4%	-4.9%
Luxembourg	0.0%	0.0%	0.0%	0.0%	0.0%
Malta					
Netherlands	-0.2%	-1.4%	-1.4%	-1.5%	-1.6%
Poland	-2.8%	-9.8%	-9.8%	-12.2%	-13.1%
Portugal	0.0%	-0.7%	-0.7%	-2.5%	-6.9%
Romania	-5.1%	-5.1%	-5.1%	-8.0%	-8.0%
Slovakia	-0.4%	-1.6%	-1.7%	-3.2%	-3.6%
Slovenia	0.0%	0.0%	0.0%	0.0%	0.0%
Spain	0.0%	0.0%	0.0%	-25.0%	-25.0%
Sweden	-9.5%	-44.6%	-44.7%	-50.9%	-55.2%
UK	-3.7%	-14.6%	-15.1%	-20.0%	-21.9%
EU-27	-3.4%	-14.1%	-14.2%	-18.5%	-19.8%
Croatia					
Turkey					
Norway	-12.0%	-41.5%	-41.5%	-41.5%	-71.0%
Switzerland	0.0%	0.0%	0.0%	0.0%	-2.4%

6.3.2 Semi-natural vegetation

Table 6.7: Semi-natural ecosystems with acid deposition above critical loads for acidification in 2000, 2020 baseline and maximum technically feasible reduction scenario from shipping. Calculated using ecosystem-specific deposition with the critical loads database of 2006

		2020		
	2000	National and shipping baselines	Nat. baseline, max. technically feasible reduction from shipping	
Belgium	402	186	155	-16.7%
France	4037	2507	1987	-20.7%
Germany	760	264	188	-28.8%
Ireland	297	6	0	-100.0%
Netherlands	1098	981	914	-6.8%
UK	15251	3873	2701	-30.3%
EU-27	21845	7817	5946	-23.9%

Table 6.8: Semi-natural ecosystems with acid deposition above critical loads for acidification, percentage change from 2020 baseline.

	2020 - ambition level				
	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships
Belgium	0.0%	-12.9%	-12.9%	-13.4%	-13.4%
France	0.0%	0.0%	0.0%	-13.7%	-13.7%
Germany	-1.1%	-8.0%	-8.0%	-16.3%	-20.1%
Ireland	-33.3%	-66.7%	-66.7%	-100.0%	-100.0%
Netherlands	0.0%	-5.0%	-5.1%	-5.8%	-6.0%
UK	-1.7%	-10.4%	-12.0%	-17.2%	-19.3%
EU-27	-0.9%	-6.4%	-7.2%	-14.6%	-15.8%

6.3.3 Freshwater ecosystems

Table 6.9: Freshwater ecosystems with acid deposition above critical loads for acidification in 2020 baseline and maximum technically feasible reduction scenario from shipping. Calculated using grid-average deposition with the critical loads database of 2006. Values in km^2.

		2020		
	2000	National and shipping baselines	Nat. baseline, max. technically feasible reduction from shipping	
Finland	91	21	17	-19.0%
Sweden	36812	20735	15820	-23.7%
UK	650	252	199	-21.0%
EU-27	37553	21009	16036	-23.7%
Norway	67597	41319	29705	-28.1%
Switzerland	131	92	81	-12.0%

Table 6.10: Freshwater ecosystems with acid deposition above critical loads in 2020, percentage change from 2020 baseline

	2020 - ambition level				
	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships
Finland	0.0%	0.0%	0.0%	-9.5%	-9.5%
Sweden	-0.3%	-13.5%	-14.4%	-14.5%	-16.1%
UK	-0.4%	-6.7%	-7.1%	-17.9%	-19.0%
EU-27	-0.3%	-13.4%	-14.4%	-14.6%	-16.2%
Norway	-2.1%	-14.4%	-14.4%	-17.8%	-19.5%
Switzerland	0.0%	0.0%	0.0%	-5.4%	-5.4%

6.3.4 All ecosystems

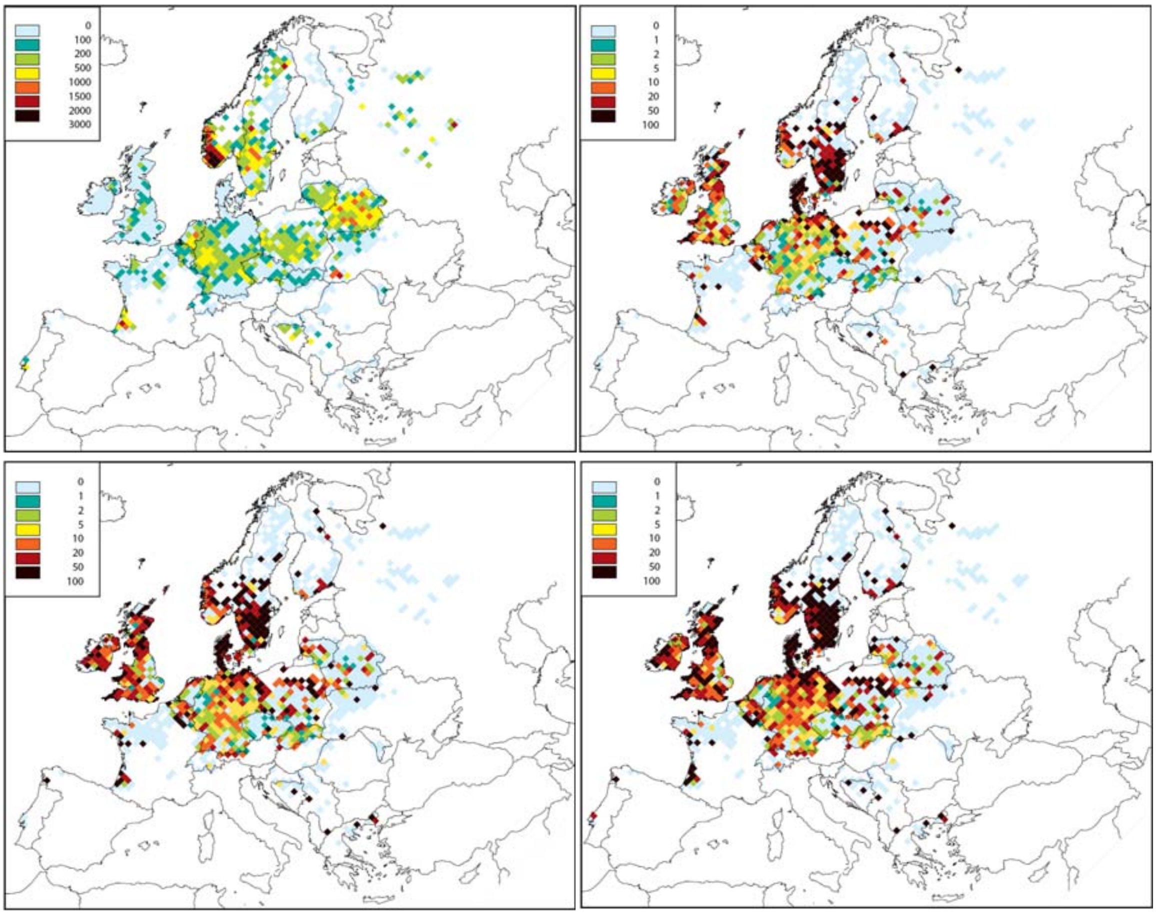

Figure 6.2: Total ecosystems area with acid deposition above critical loads for acidification in 2020 – “Baseline” case (in km2 per grid – upper left panel) and percentage improvement from the baseline for the “Ambition level 2” (upper right panel), “Ambition level 4” (lower left panel) and MTFR scenarios of emissions from international shipping (lower right panel)

6.4 Protection of ecosystems against eutrophication

Table 6.11 and Table 6.12 provide estimates of the protection of all ecosystems against eutrophication. These include: forests, semi-natural vegetation, and freshwater catchments. The expected benefits are not as large as for acidification, with an overall EU-wide improvement of about four percent as compared with the NEC baseline for the “Ambition level 2” shipping scenarios, 5 to 6 percent for the “Ambition level 3” and “Ambition level 4” and 12 percent for the MTFR scenario. Figure 6.3 shows the spatial distribution of eutrophication indicator for the baseline situation in 2020 and the improvements achieved by individual scenarios.

Table 6.11: Total ecosystems area with nitrogen deposition above critical loads for eutrophication

		2020		
	2000	National and shipping baselines	Nat. baseline, max. technically feasible red. from shipping	
Austria	35618	29726	27662	-6.9%
Belgium	6730	6463	6323	-2.2%
Bulgaria	45600	41010	38491	-6.1%
Cyprus	3049	3061	1968	-35.7%
Czech Rep.	11162	10926	10878	-0.4%
Denmark	3039	2511	2200	-12.4%
Estonia	12316	6839	879	-87.1%
Finland	112220	78792	45671	-42.0%
France	176710	168575	155628	-7.7%
Germany	101804	96754	94465	-2.4%
Greece	9326	9326	8706	-6.6%
Hungary	10278	8282	7789	-6.0%
Ireland	7403	6165	5716	-7.3%
Italy	87696	70839	52738	-25.6%
Latvia	26781	25724	24521	-4.7%
Lithuania	17651	17651	17643	0.0%
Luxembourg	821	821	821	0.0%
Malta				
Netherlands	4124	3845	3717	-3.3%
Poland	86408	83612	82173	-1.7%
Portugal	20107	19674	17117	-13.0%
Romania	60560	59991	59903	-0.1%
Slovakia	19236	18180	17642	-3.0%
Slovenia	5264	5247	5219	-0.5%
Spain	75050	66975	60000	-10.4%
Sweden	60026	21391	13792	-35.5%
UK	20972	14495	10864	-25.1%
EU-27	1019951	876874	772523	-11.9%
Croatia	3081	2766	2398	-13.3%
Turkey				
Norway	13086	4356	1026	-76.4%
Switzerland	18866	12305	11234	-8.7%

Table 6.12: Total ecosystems area with nitrogen deposition above critical loads for eutrophication, percentage change from 2020 baseline.

	2020 - ambition level				
	Level 1 all ships	Level 2 all ships	Level 2 all + S meas. in 12 miles zone	Level 3 all ships	Level 4 all ships
Austria	-1.4%	-3.4%	-3.4%	-3.9%	-5.0%
Belgium	-0.4%	-0.5%	-0.5%	-0.5%	-0.5%
Bulgaria	-2.4%	-5.7%	-5.7%	-6.0%	-6.0%
Cyprus	-2.5%	-13.8%	-13.8%	-16.4%	-21.4%
Czech Rep.	0.0%	-0.2%	-0.2%	-0.2%	-0.4%
Denmark	-0.9%	-2.8%	-2.8%	-3.7%	-4.7%
Estonia	-2.7%	-23.4%	-23.4%	-40.6%	-54.6%
Finland	-5.7%	-19.4%	-19.4%	-21.3%	-24.2%
France	-0.2%	-1.7%	-1.7%	-2.9%	-3.6%
Germany	-0.2%	-0.6%	-0.6%	-0.8%	-1.0%
Greece	0.0%	0.0%	0.0%	0.0%	0.0%
Hungary	-0.1%	-2.9%	-2.9%	-3.2%	-3.3%
Ireland	-1.0%	-2.6%	-2.6%	-3.3%	-4.3%
Italy	-2.0%	-4.0%	-4.0%	-7.3%	-9.9%
Latvia	0.0%	-0.2%	-0.2%	-0.2%	-0.2%
Lithuania	0.0%	0.0%	0.0%	0.0%	0.0%
Luxembourg	0.0%	0.0%	0.0%	0.0%	0.0%
Malta					
Netherlands	-0.3%	-1.1%	-1.1%	-1.5%	-1.8%
Poland	-0.1%	-0.2%	-0.2%	-0.3%	-0.5%
Portugal	-0.2%	-0.6%	-0.6%	-0.8%	-1.8%
Romania	0.0%	-0.1%	-0.1%	-0.1%	-0.1%
Slovakia	-0.4%	-1.0%	-1.0%	-1.2%	-1.5%
Slovenia	0.0%	0.0%	0.0%	0.0%	0.0%
Spain	-0.9%	-3.9%	-3.9%	-4.6%	-5.6%
Sweden	-5.9%	-14.7%	-14.7%	-15.6%	-17.4%
UK	-4.1%	-7.5%	-7.5%	-8.8%	-12.3%
EU-27	-1.2%	-4.0%	-4.0%	-5.0%	-6.0%
Croatia	-3.0%	-10.4%	-10.4%	-11.6%	-11.7%
Turkey					
Norway	0.0%	-33.5%	-33.5%	-33.5%	-56.6%
Switzerland	-1.1%	-1.4%	-1.4%	-2.4%	-2.6%

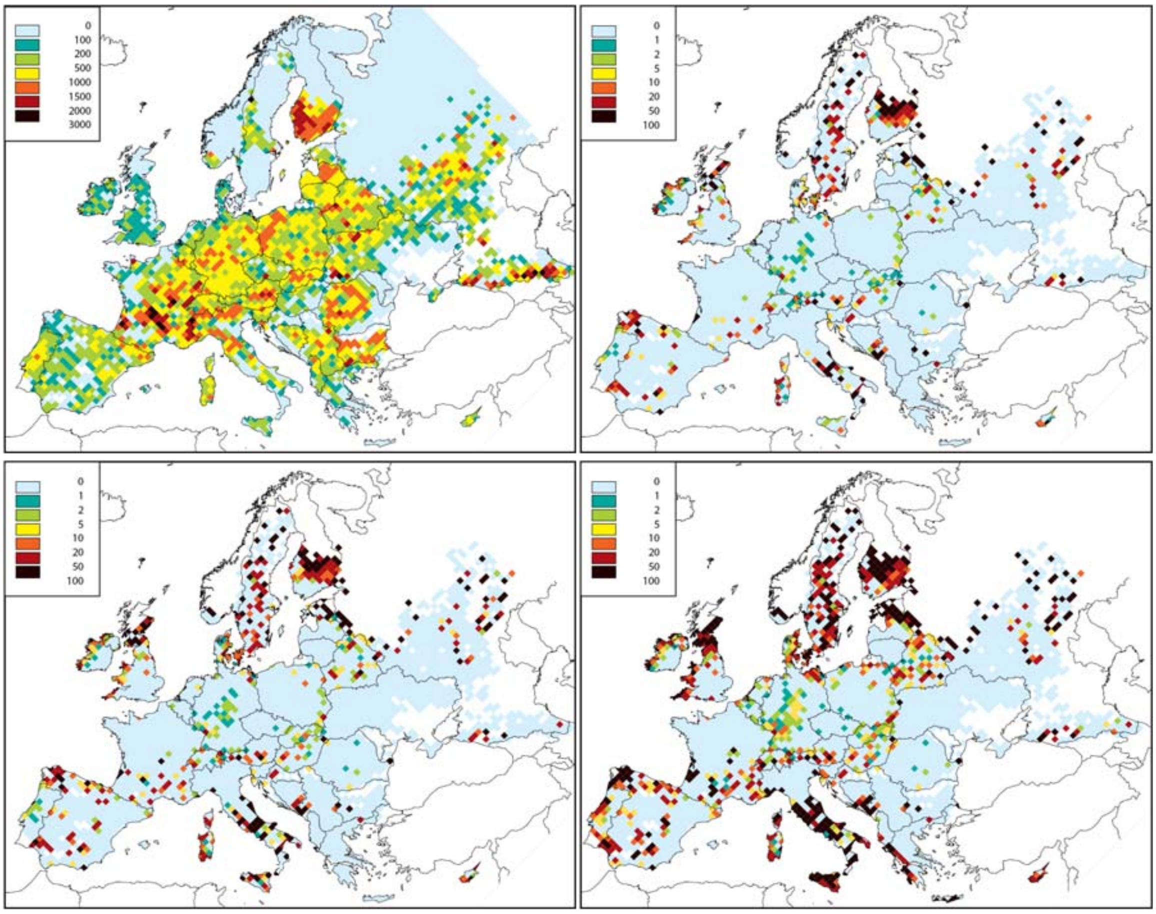

Figure 6.3: Ecosystems area (km^2) with nitrogen deposition above critical loads for eutrophication in 2020 – "Baseline" case (upper left panel) and percentage improvement from the baseline for the "Ambition level 2" (upper right panel), "Ambition level 4" (lower left panel) and the MTFR scenario of emissions from international shipping (lower right panel)

7 Effects of controlling emissions from shipping on least-cost emission reductions from national sources

The report Amann *et al.*, 2007 presents scenarios of achieving targets of the Thematic Strategy through cost-efficient reduction of emissions from land-based sources. Boundary conditions for those scenarios used the baseline emissions from international shipping. The analysis done for the current report demonstrates how the reduction of emissions from international shipping affects the need to control national sources. Analysis has been performed for shipping scenarios representing four different ambition levels (for all ships, independent of the flag) – compare Section 5. The scenarios assume for national shipping the same type of legislation, as for vessels on international trips. For each of the scenarios GAINS optimization routine was run and determined emission reductions in the EU Member States (EU27) and in Norway that are necessary to reach the objectives of the Thematic Strategy[4].

Aggregated results are presented in Table 7.1. The base case presents the cost-efficient national emissions for land-based sources in Europe computed for the 'Current legislation' case with baseline emissions from international shipping. This scenario determines additional reductions from stationary sources necessary for achieving the objectives of the Thematic Strategy. All scenarios include the effects of implementation of Euro 5 and 6 emission standards on cars and light-duty trucks but do not take into account Euro VI standards for heavy-duty trucks and buses, which are currently under consideration. Reduction of the emissions from shipping allows higher emissions from land-based sources. Aggregated national emissions of SO_2 for EU27 plus Norway are six to 20 percent higher than in the base case (compare scenarios with "Ambition level 2" and "Ambition level 3"). Emissions of NO_x can increase by four to five percent compared with the scenario with only baseline measures on shipping. Cost-optimal emissions of primary PM2.5 can increase by two to seven percent. Although shipping does not emit meaningful amounts of ammonia (NH_3), land-based ceilings for that pollutant are affected by shipping control strategies. That linkage operates, first of all, via the eutrophication target. Lower deposition of oxidized nitrogen due to control of NO_x emissions from ships allow higher levels of reduced N from ammonia emissions. Thus in our scenarios ammonia emissions can be five to eight percent higher.

Inclusion of measures on shipping importantly influences emission control costs. The costs for national sources are 24 percent (Ambition level 1) to 59 percent (Ambition level 4) lower than for the base case. About 30 to 40 percent of that cost reduction is due to lower costs of controlling ammonia emissions from agriculture. Even after including higher costs for the

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[4] The targets for EU27 plus Norway in 2020 are: reduction of years of life lost (YOLLs) due to anthropogenic PM emissions to below 113.6 million; reduction of area of ecosystems endangered by eutrophication to less than 706 thousand km^2; reduction of forest and freshwater areas endangered by acidification to below 68 and 64 thousand km^2; reduction of premature mortality attributable to ozone to below 18 thousand cases – compare Table 5.4 in Amann *et al.*, 2007.

shipping sector, important net cost savings are possible (1.2 and 1.5 billion €/year for "Ambition level 1" and "Ambition level 2", respectively). In spite of quite high costs of reducing emissions from shipping (3.2 billion €/year) for the "Ambition level 4" scenario, the net costs of that scenario are only five percent higher than the baseline costs.

Table 7.2 to Table 7.5 present the emissions by country for our scenarios. Differences in national costs are shown in Table 7.6. Countries with a high proportion of their area located close to the sea coast benefit most from stricter controls on shipping emissions. For the "Ambition level 2" scenario Cyprus, Denmark, Estonia, Finland, Greece, Latvia, Sweden and Norway reduce their national control costs by more than 85 percent. Costs for Bulgaria, Italy, Lithuania, Netherlands, Portugal, and UK are 40 to 70 percent lower.

Emission reductions from shipping are much higher than the corresponding increase in the emissions from land-based sources. For SO_2, the ratio is two to four depending on the scenario. For NO_x this ratio is six to seven. This is because a smaller fraction of emissions from shipping is transported to sensitive receptor areas, than it is a case with the emissions from land-based stationary sources. Nevertheless, since costs of reducing (weekly controlled or uncontrolled) emissions from shipping are low compared with the costs of further cutting emissions from already heavily controlled stationary sources, reducing emissions from shipping is cost-efficient.

Table 7.1: Emissions of air pollutants in 2020 and emission control costs for optimized scenarios with different ambition levels of controlling emissions from international shipping

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Emissions, kilotons:					
National sources (EU27 plus Norway)					
SO2	3327	3238	3525	3978	3978
NOx	5782	5946	6022	6054	6091
PM 2.5	923	920	942	986	987
NH3	2763	2794	2902	2933	2977
International shipping					
SO2	3186	3186	2767	758	758
NOx	4828	4383	3511	3212	2732
PM 2.5	396	396	394	338	338
Cost on top of 'Current legislation' baseline, million Euro/year					
National sources (land-based)	5025	3810	2713	2264	2041
Shipping(1)	0	47	828	2523	3232
Total	5025	3856	3541	4786	5273
Difference from base case		-1169	-1484	-238	249

[1] Includes control costs for international and national shipping

Table 7.2: Optimized SO_2 emissions from national sources for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	20	20	20	20	20
Belgium	72	71	72	74	74
Bulgaria	111	111	111	115	115
Cyprus	8	8	8	8	8
Czech Rep.	142	141	142	157	157
Denmark	20	19	21	21	21
Estonia	48	48	48	48	48
Finland	59	59	59	59	59
France	342	339	346	435	435
Germany	420	411	420	426	426
Greece	83	83	83	83	83
Hungary	39	39	45	55	55
Ireland	36	36	36	36	36
Italy	266	266	326	339	339
Latvia	15	15	19	19	19
Lithuania	39	38	39	39	39
Luxembourg	2	2	2	2	2
Malta	8	4	8	8	8
Netherlands	73	73	73	77	77
Poland	551	551	621	855	855
Portugal	75	75	81	86	86
Romania	123	104	133	137	137
Slovakia	58	56	68	81	81
Slovenia	17	17	19	22	22
Spain	398	346	420	446	446
Sweden	41	41	41	41	41
UK	239	239	239	264	264
EU-27	3301	3212	3499	3952	3952
Croatia	62	62	62	62	62
Turkey	911	911	910	910	910
Norway	26	26	26	26	26
Switzerland	18	18	18	18	18

Table 7.3: Optimized NO_x emissions from national sources for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	119	120	119	119	122
Belgium	168	170	173	174	174
Bulgaria	74	73	79	81	82
Cyprus	10	14	15	15	15
Czech Rep.	145	149	156	156	158
Denmark	92	96	102	102	102
Estonia	14	18	21	23	23
Finland	99	113	123	125	125
France	658	672	691	691	691
Germany	711	746	761	765	765
Greece	167	171	169	171	172
Hungary	79	83	87	87	87
Ireland	64	66	69	69	69
Italy	721	721	713	713	713
Latvia	24	26	29	30	30
Lithuania	27	31	33	33	33
Luxembourg	15	15	15	15	15
Malta	5	5	5	5	5
Netherlands	206	222	220	220	220
Poland	351	366	366	378	393
Portugal	129	133	136	136	138
Romania	200	195	189	189	197
Slovakia	56	60	61	61	61
Slovenia	33	33	33	33	33
Spain	677	671	664	665	666
Sweden	132	138	135	135	135
UK	660	696	727	728	732
EU-27	5633	5803	5892	5921	5958
Croatia	53	53	53	53	53
Turkey	731	730	728	728	728
Norway	149	143	130	133	133
Switzerland	49	49	49	49	49

Table 7.4: Optimized emissions of fine particles (PM2.5) from national sources for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	20	20	20	20	20
Belgium	21	21	21	24	24
Bulgaria	21	21	22	31	31
Cyprus	2	2	2	2	2
Czech Rep.	28	28	28	29	29
Denmark	14	14	14	14	14
Estonia	11	11	15	15	15
Finland	22	22	22	24	24
France	115	114	118	119	119
Germany	91	91	92	92	93
Greece	28	28	28	31	31
Hungary	26	25	26	26	26
Ireland	7	7	7	7	7
Italy	90	90	94	94	94
Latvia	10	10	11	11	11
Lithuania	8	8	8	8	8
Luxembourg	2	2	2	2	2
Malta	0	0	0	0	0
Netherlands	16	16	16	17	17
Poland	99	99	99	101	101
Portugal	23	23	25	27	27
Romania	70	70	70	82	82
Slovakia	14	14	15	16	16
Slovenia	4	4	4	4	4
Spain	71	71	72	78	78
Sweden	16	16	16	16	16
UK	52	51	53	56	56
EU-27	881	879	900	944	945
Croatia	13	13	13	13	13
Turkey	290	290	290	290	290
Norway	42	42	42	42	42
Switzerland	7	7	7	7	7

Table 7.5: Optimized emissions of ammonia (NH_3) from national sources for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	41	41	40	40	39
Belgium	74	74	74	75	75
Bulgaria	57	58	59	59	60
Cyprus	5	6	7	7	7
Czech Rep.	62	60	60	60	60
Denmark	47	51	53	53	53
Estonia	7	8	10	11	11
Finland	27	26	29	30	30
France	462	464	474	479	487
Germany	384	379	383	385	387
Greece	36	39	45	46	46
Hungary	61	61	61	61	61
Ireland	86	87	88	89	90
Italy	287	294	311	316	325
Latvia	9	11	12	12	12
Lithuania	28	30	31	31	32
Luxembourg	5	5	5	5	5
Malta	3	3	3	3	3
Netherlands	123	122	124	125	126
Poland	239	237	243	243	244
Portugal	50	52	57	58	61
Romania	113	113	115	116	115
Slovakia	26	25	25	24	24
Slovenia	14	14	15	15	15
Spain	250	260	279	285	296
Sweden	38	44	50	50	50
UK	214	216	229	235	243
EU-27	2750	2779	2881	2912	2956
Croatia	32	32	32	32	32
Turkey	491	491	491	491	491
Norway	13	15	21	21	21
Switzerland	41	41	41	41	41

Table 7.6: Emission control costs by country for optimized scenarios meeting Thematic Strategy objectives for shipping scenarios with different ambition levels

		Ambition level for shipping			
	Base case	Level 1 all ships	Level 2 all ships	Level 3 all ships	Level 4 all ships
Austria	94	101	115	121	125
Belgium	113	102	69	56	48
Bulgaria	64	55	35	25	21
Cyprus	19	6	0	0	0
Czech Rep.	122	120	102	93	90
Denmark	119	36	11	11	11
Estonia	37	10	1	0	0
Finland	89	41	3	1	1
France	667	597	481	411	387
Germany	614	494	394	362	342
Greece	87	34	11	8	8
Hungary	68	56	43	38	38
Ireland	105	94	74	68	58
Italy	346	316	203	177	145
Latvia	35	11	3	2	2
Lithuania	85	55	42	38	33
Luxembourg	9	8	10	10	10
Malta	0	1	0	0	0
Netherlands	190	76	66	53	49
Poland	398	357	285	138	115
Portugal	89	71	41	33	25
Romania	205	209	182	167	160
Slovakia	50	44	34	30	31
Slovenia	29	28	24	22	21
Spain	541	500	354	311	262
Sweden	187	40	9	8	8
UK	526	315	163	124	97
EU-27	4886	3778	2757	2309	2087
Croatia					
Turkey	0	4	8	8	8
Norway	139	48	2	1	1
Switzerland	0	0	0	0	0

8 Summary and conclusions

Maritime activities constitute a significant fraction of anthropogenic emissions of air pollutants in Europe. It is estimated for the year 2000 that SO_2 and NO_x emissions from international maritime shipping in Europe amounted to approximately 30 percent of the land-based emissions in the EU-25. About 20 percent of these ship emissions are released within the 12-mile zones near to the coast line. The vast majority (approximately 95 percent) of emissions is released from larger vessels (>500 GRT). For these larger vessels, roughly 95 percent of SO_2 and emissions are estimated to be released from cargo ships. About 45 percent of the sea emissions in the region originate from ships with EU flags. Approximately five percent of SO_2 emissions are emitted at berth.

Because of concerns about harmful impacts of air pollution, the European Union has established a comprehensive legal framework to control air quality in their Member States. A wide body of legislation demands stringent emission control measures for land-based sources. As a consequence, land-based emissions in the EU Member States are expected to decline in the coming years. The baseline projections for the revision of the National Emission Ceilings (NEC) directive suggests that current EU legislation for land-based sources would lead by 2020 to a reduction of SO_2 emissions in the EU27 by more than 60 percent compared to the year 2000, and for NO_x emissions by more than 40 percent. Based on an analysis of the costs and benefits of further measures, the European Commission has proposed in its Thematic Strategy on Air Pollution more stringent environmental objectives that imply for the year 2020 emission control measures that bring down SO_2 emissions by 81 percent and NO_x emission by 61 percent.

Whilst measures are in force to address emissions from international shipping, the expected increase in the volume of ship movements will outweigh the positive environmental impacts of these measures and will lead to a further growth in ship emissions overall. Under business-as-usual assumptions, SO_2 emissions from international shipping are computed to increase by more than 40 percent between 2000 and 2020, NO_x emissions by 47 percent and PM2.5 emissions by 56 percent. Under these conditions, emissions from maritime activities would by 2020 come close to the projected baseline emission levels for land-based sources, and surpass the target levels established by the European Commission in its Thematic Strategy on Air Pollution for land based sources, in particular for SO_2 by a factor of two.

Health and environmental impacts of air pollutants are critically determined by the proximity of the emission sources to sensitive receptor sites. This means that, compared to land-based sources, at least some of the maritime emissions have less health and environmental impacts since they are released sometimes far from populated areas or sensitive ecosystems. However, in harbour cities ship emissions are in many cases a dominant source of urban pollution and need to be addressed when compliance with EU air quality limit values for fine particulate matter is an issue. Furthermore, as for all other sources, emissions from ships are transported in the atmosphere over several hundreds of kilometres, and thus can contribute to air quality problems on land, even if they are emitted on the sea. This pathway is especially relevant for deposition of sulphur and nitrogen compounds, which cause acidification of natural ecosystems and freshwater bodies and threaten biodiversity through excessive nitrogen input.

Scientific models are used routinely to describe the atmospheric transport of pollution. These models estimate that for many parts of Europe a significant fraction of sulphur compounds deposited on land originate from ship emissions. While at present emissions from ships are responsible for 10 to 20 percent of sulphur deposition in coastal areas, their contribution is expected to increase to more than 30 percent in large areas in Europe by 2020, especially in the UK, Ireland, Sweden, Denmark, France, Germany, Netherlands, Belgium, Spain, Italy and Greece. In many coastal areas, ships will be responsible for more than 50 percent of sulphur deposition.

The anticipated increase in ship emissions will counteract the envisaged benefits of the costly efforts to control the remaining emissions from land-based sources in Europe. Technologies exist to reduce emissions from shipping beyond what is currently legally required.

This study has identified a set of emission control measures that are technically available which could – if fully applied to all ships on European seas (the MTFR scenario) – reduce some 80 percent of the SO_2 emissions from international shipping and almost 90 percent of the NO_x emissions by 2020. Costs of these measures are estimated at 5.5 billion €/yr (5.1 billion €/year above the baseline). For comparison, the costs of the measures proposed by the Thematic Strategy amount to 7.1 billion €/yr. in 2020 and thereafter.

The study has explored four specific packages of measures with different ambition levels that could reduce emissions at lower costs:

- "Ambition level 1" package includes measures to reduce NO_x emissions through internal engine modifications for all newly built ships after 2010 and retrofitting the slow-speed engines of existing (pre-2000) vessels through slide valves modification. This would reduce in 2020 total NO_x emissions from international shipping by approximately 10 percent compared to the baseline case, which however still leaves a 33 percent increase compared to the year 2000. Costs for these measure are estimated at less than 30 million €/yr.
- "Ambition level 2" set of measures includes the use of residual oil with a maximum sulphur content of 0.5 percent (or seawater scrubbing resulting in equivalent emissions) in the North Sea and Baltic, slide valve retrofits for existing slow-speed engines and humid air motors for all newly built vessels (post-2010). This would, in 2020, reduce SO_2 emissions by 14 percent compared to the baseline and NO_x emissions by 28 percent. In total, implementation of this package involves costs of 770 million €/yr in addition to the baseline costs. A variant of this package (Ambition level 2 with sulphur measures) assumes strengthening the requirements for SO_2 controls by imposing a 1.5 percent limit on the sulphur content of heavy fuel oil for cargo ships within the 12-mile zones (unless stricter regulations are foreseen for the North Sea and Baltic). This would reduce SO_2 emissions by 73 kt further (i.e., 2.3 percent of the baseline emissions) and increase costs by about 60 million €/yr.

- "Ambition level 3" package explores the reduction of the S content of residual oil to 0.5 percent until 2020, and a 15 percent reduction of emissions of NO_x from existing vessels combined with 50 percent reduction for new (post-2010) vessels. The extra cost of that package is 2.5 billion €/year.
- Finally, the "Ambition level 4" package simulates the effects of implementing (in addition to "Ambition level 3" measures) selective catalytic reduction technology (SCR) on all post-2010 ships. In this case the costs above the baseline increase to 3.2 billion €/year.

A comparison of these options with the candidate measures indicated in the Thematic Strategy for stationary sources reveals that these technical measures for marine sources could reduce approximately three times more SO_2 emissions and seven times more NO_x than what has been proposed for land-based sources. For SO_2, approximately 80 percent of this potential (i.e., excluding the option for 0.5 percent sulphur in residual oil) can be achieved at marginal costs that are below 15 percent of the highest marginal costs of the measures proposed for land-based sources. For NO_x, this low-cost potential comprises about 70 percent of the technical potential considered in this report.

However, any analysis of the cost-effectiveness must consider the impact that emission reductions from the different sources have on human health and environmental effects. A crucial factor in such an assessment is the proximity of the location of emissions to the receptor areas that need to be protected against pollution. As outlined by the emission inventory, approximately 80 percent of ship emissions in the model domain are emitted outside the 12-mile zone. Consequently, the cost-effectiveness of measures for ships relative to land-based measures cannot be judged from marginal abatement costs only, but needs to take into account atmospheric dispersion characteristics too.

To meet this requirement, the RAINS/GAINS integrated assessment framework was used to derive environmental impact indicators for the shipping scenarios. In this context particularly interesting are scenarios with "Ambition level 2" and "Ambition level 3", where a decrease of negative impacts can be achieved at moderate costs. For instance, emission controls according to the "Ambition level 2" scenario reduce the loss in life expectancy of the European population by 3.1 percent (0.17 months) beyond the baseline case. This constitutes approximately 13 percent of the environmental improvement proposed by the Thematic Strategy. This scenario also achieves a 14 percent improvement of acidification indicator. Corresponding numbers for the "Ambition level 3" scenario are: 6.5 percent reduction in loss of life expectancy and a 19 percent reduction in forest area endangered by acidification.

Simulations performed with the RAINS/GAINS model demonstrate that the reduction of emissions from international shipping can substantially lower the costs of additional controls for land-based sources necessary to achieve the Thematic Strategy targets. For three out of four packages considered net cost savings are achieved, even after inclusion of higher cost for shipping sector. The highest cost savings have been identified for the "Ambition level 2" package, where the net costs are reduced by nearly 1.5 billion €/a.

References

Amann, M., Asman W., Bertok I., Cofala, J., Heyes, C., Klimont, Z., R., Posch, M. and Schöpp, W. (2007)., Cost-optimized reductions of air pollutant emissions in the EU Member states to meet the environmental targets of the Thematic Strategy on Air Pollution. NEC Sceanrio Analysis Report No. 3. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Amann, M., Bertok I., Cofala, J., Heyes, C., Klimont, Posch, M. Schöpp, W. and Wagner F. (2006), Baseline Scenarios for the Revision of the NEC Emission Ceilings Directive. Part 1: emission projections. NEC Scenario Analysis Report Nr.1. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, http://www.iiasa.ac.at/rains/CAFE_files/NEC-BL-p1-v21.pdf.

Amann, M., Bertok, I., Cabala, R., Cofala, J., Heyes, C., Gyarfas, F., Klimont, Z., Schöpp, W. and Wagner, F. (2005), Analysis for the final CAFE scenario. CAFE Report No. 6. International Institute for Applied Systems Analysis (IIASA), http://www.iiasa.ac.at/rains/CAFE_files/CAFE-D3.pdf.

Amann, M., Cofala, J., Heyes, C., Klimont, Z., Mechler, R., Posch, M. and Schöpp, W. (2004), The RAINS model. Documentation of the model approach prepared for the RAINS review. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria, www.iiasa.ac.at/rains/review/index.html.

CEC (2005), Communication from the Commission to the Council and the European Parliament on a Thematic Strategy on Air Pollution. SEC(2005) 1132. Commission of the European Communities, Brussels, http://eur-lex.europa.eu/LexUriServ/site/en/com/2005/com2005_0446en01.pdf.

CONCAWE (2006). Techno-economic Analysis of the Impact of the Reduction of Sulphur Content of Residual Marine Fuels in Europe. Concawe Report Nr.2/06., Brussels.

Corbett J.J., Firestone J., Wang Ch. (2007), Estimation, validation and forecasts of regional commercial marine vessel inventories. Final report. Report prepared for the California Air Resources Board and the California Environmental Protection Agency and for the Commission for Environmental Cooperation of North America. University of Delaware, Newark, Delaware, USA, http://www.arb.ca.gov/research/seca/jcfinal.pdf.

De Ceuster G., van Herbruggen B., Logghe S. (2006), TREMOVE - description of model and baseline version 2.41. Report for the European Commission, DG ENV. Chapter VI – The maritime model. Service Contract B4-3040/2002/342069/MAR/C.1. Transport & Mobility Leuven, Leuven, Belgium.

EMEP (2006), EMEP Status Report 1/06. Transboundary acidification, eutrophication and ground level ozone in Europe since 19990 to 2004, Joint MSC-W & CCE & icp-forest & icp-m&m & etc/acc Report.

EMEP (2005), EMEP Status Report 1/05. Transboundary acidification, eutrophication and ground level ozone in Europe 10 2003, Joint MSC-W & CCC & CIAM Report.

Endresen O. *et al.* (2003), 'Emission from international sea transportation and environmental impact', Journal of Geophysical Research, Vol. 108, No. D17, 4560, doi: 10.1029/2002JD002898,2003 (ACH 14 - p.1-22).

Entec (2005a), European Commission Directorate General Environment Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Task 1 -

Preliminary Assignment of Ship Emissions to European Countries. Final Report Entec UK Limited, August 2005.

Entec (2005b), European Commission Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Task 2 – General Report, Final Report, Entec UK Limited, August 2005.

Entec (2005c), European Commission Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Task 2b – NOx Abatement, Final Report, Entec UK Limited, August 2005.

Entec (2005d), European Commission Service Contract on Ship Emissions: Assignment, Abatement and Market-based Instruments. Task 2c – SO2 Abatement, Final Report, Entec UK Limited, August 2005.

Fagerli, H., Simpson, D. and Tsyro, S. (2004), Unified EMEP model: Updates, in: Transboundary Acidification and Eutrophication and Ground Level Ozone in Europe. EMEP/MSC-W Status Report 1.

Jonson, J.E., Simpson, D., Fagerli, H. and Solberg, S. (2006), Can we explain the trends in European ozone levels? Atmos. Chem. Phys, 6, pp 1–16.

Klaassen G., Berglund Ch., Wagner F. (2005), The GAINS Model for Greenhouse Gases - Version 1.0: Carbon Dioxide (CO2). Interim Report IR-05-53. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

OJ L 191/59 (2005), Directive 2005/33/EC of the European Parliament and of the Council on the sulphur content of marine fuels. Official Journal of the European Union.

Simpson, D., Fagerli, H., Jonson, J.E., Tsyro, S., Wind, P. And Tuovinen, J.P. (2003), Transboundary Acidification and Eutrophication and Ground Level Ozone in Europe. Unified EMEP Model Description. EMEP/MSC-W Status Report 1, Part I.

Skjolskvik, K.O., *et al.* (2000), Study of Greenhouse Gas Emissions from Ships (MPEC 45/8 Report to International Maritime Organization on the outcome of the IMO Study on Greenhouse Gas emissions from Ships). MARTINEK Sintef Group, Carnegie Mellon University, Center for Economic Analysis, and Det Norske Veritas, Trondheim, Norway.

UNECE (2004), Review of the Unified EMEP Model, Task Force on Measurements and Modelling, Review of the Unified EMEP Model. Summary Report and Conclusions of the workshop, prepared by the Chairman in collaboration with the secretariat EB.AIR/GE.1/204/6.

US EPA (2003), Final Regulatory Support Document: Control of Emissions from New Marine Compression Ignition Engines at or Above 30 liters per Cylinder,January 2003, EPA420-R-03-004, at pp. 2-5.

Whall, C., Cooper, D., Archer, K., Twigger, L., Thurston, N., Ockwell, D., McIntyre and Ritchie, A. (2002), Quantification of emissions from ships associated with ship movements between ports in the European Community. Final Report. Entec UK Limited.