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Final Report:

Specific evaluation of emissions from shipping including assessment for the establishment of possible new emission control areas in European Seas

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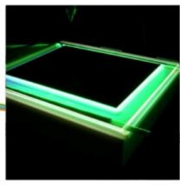
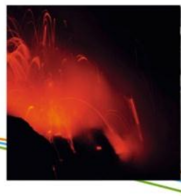
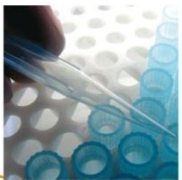

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LIST OF ABBREVIATIONS

AE	Auxiliary engine
BAS	Baltic Sea
BLACK_SEA	Black Sea
BG	Bulgaria
bln	billion (10^9)
CARB	Air Resources Board of California
CO_2	Carbon dioxide
CH_4	Methane
CLE	Current legislation on emissions of air pollutants
CO	Carbon monoxide
CONCAWE	The oil companies' European association for environment, health and safety in refining and distribution
ECA	Emissions control area
EE	EX-TREMIS/Eurostat
EEZ	Exclusive economic zone
EMEP	European Monitoring and Evaluation Programme
EMMOSS	Vlaams emissiemodel voor scheepvaart en spoorwegen (Flemish emission model for shipping and rail)
EU	European Union
GAINS	Greenhouse Gas and Air Pollution Interactions and Synergies model
IIASA	International Institute for Applied Systems Analysis
IMO	International Maritime Organization
kt	kilotons
kW	kilowatt
LMIU	Lloyd's Marine Intelligence Unit
LNG	Liquefied natural gas
LOSC	Law of the Sea Convention
M	million
MARPOL	International Convention for the Prevention of Pollution from Ships
MCE	Maximum Control Efforts
MD	Marine distillates
ME	Main engine
MED	Mediterranean Sea
MTFR	Maximum Technically Feasible Emission Reductions
NECA	NOx emission control area
nm	nautical miles
NOS	North Sea with English Channel
NO_x	Oxides of nitrogen
OSPAR	The Convention for the Protection of the marine Environment of the North-East Atlantic
PM	Particulate matter
PM2.5	Fine particulate matter
RO	Residual oil
ROM	Romania
Sc	Scenario
SCR	Selective catalytic reduction
SECA	Sulfur emission control area
SO_2	Sulfur dioxide

SSS	Short Sea Shipping
TML	Transport and Mobility Leuven
TNO	Nederlands Instituut voor Toegepaste Geowetenschappen (Netherlands Organisation for Applied Scientific Research)
UNCTAD	United Nations Conference on Trade and Development
vkm	vehicle kilometers
VITO	Vlaamse Instelling voor Technologisch Onderzoek (Flemish Institute for Technological Research
VLIZ	Vlaams Instituut voor de Zee (Flemish Institute for the
VOC	Volatile organic compounds

CHAPTER 1 EXECUTIVE SUMMARY

This report describes the results of one of the sectoral studies undertaken in connection with the Service Contract on Monitoring and Assessment of Sectorial Implementation Actions (ENV.C3/SER/2011/0009) of DG Environment of the European Commission. The study presents scenarios of air emissions from international shipping on the seas surrounding Europe. The approach adopted was to develop further the EX-TREMIS/ EUROSTAT/ EUROMOSS (EEE) database and integrate this information with a digital European shipping routes map. Emissions have been estimated for the medium-term (up 2030) and for the long-term (2050). Results of this study will be used within the work on the revision of the EU Thematic Strategy on Air Pollution (TSAP).

Analysis starts with the Baseline projection, which combines current expectations regarding development of maritime transport with the effects of existing legislation on ship emissions. Scenarios explore effects of measures that go beyond the current legislation. These include establishing additional emission control areas (ECAs) on sea regions and zones with particularly high impact on land-based receptors, reducing cruising speed of vessels (slow steaming) as well as switching to cleaner fuels (LNG).

Available options have been combined into nine scenarios. Scenario 1 explores effects of implementing the NECA standards (on top of the existing SECA legislation) in the Baltic and North Seas (with English Chanel), together with SECA and NECA within the territorial waters of the EU Member states. Scenario 2 assumes the extension of ECA legislation to Exclusive Economic Zones (EEZ). Scenarios 3 to 5 consider various ways to reduce emissions from the Mediterranean and Black Seas. Scenario 6 and its variants explore the effects of slow steaming. Scenario 7 demonstrates the possible reduction of fine particles emissions through fitting vessels with particle filters. Finally, the Maximum Technically Feasible Reduction (MTFR) case (Scenario 8) demonstrates the potential to reduce emissions through implementation of all technical measures on new and existing vessels in all European seas. Scenario 9 (Maximum Control Efforts - MCE) combines the MTFR assumptions with slow steaming. In a separate sensitivity, the effects of using LNG for short sea shipping are demonstrated.

In 2005, ships emitted about 1.7 million tons of SO_2, which was about 20 % of the emissions form land-based sources in the EU-27. Emissions of NO_x (2.8 million tons) were equivalent to 25% land-based emissions. About 30 % of these emissions occurred on the Territorial Seas of the EU Member States, i.e., within 12 nm from the coast. Emissions from the Exclusive Economic Zones (200 nm) were approximately 75% of the total.

Contribution of shipping to air pollution in coastal zones is high. In 2005, 35% of sulfur deposition in coastal areas originated from international shipping and exceeded 0.2 g/m^2/year, with maximum values up to 0.5 to 1.0 g/m^2.

Recent changes in legislation on emissions from shipping (IMO MARPOL Annex VI) will importantly reduce air pollution from ships. Under the Baseline assumptions, the emissions of SO_2 from the European seas will decrease by 82% in 2020 compared to 2005. Emissions of NO_x

will drop by 13%. After 2020 the Baseline emissions increase due to the increase in transport volume and are in 2030 12 to 13% higher than in 2020.

Implementation of NECA legislation in the Baltic Sea and the North Sea (with English Channel) and ECA for sulfur and nitrogen oxides in the territorial waters of the EU-27 would reduce the emissions in 2030 by 23 kt of SO_2 and 460 kt of NO_x. Extension of NECA and SECA to Exclusive Economic Zones (200nm) would cause a drop in emissions by 160 kt of SO_2 and 970 kt of NO_x compared with the Baseline.

Implementation of slow steaming (speed restrictions) within the Exclusive Economic Zones (200 nm) of the EU Member States has a potential to reduce fuel consumption and emissions in 2030 by approximately 20%.

Implementation of MTFR scenario, in which SECA and NECA standards are implemented in all seas surrounding Europe, would reduce the emissions of sulfur in 2030 by about 73% and nitrogen oxides by 69% compared with the Baseline. PM emissions would drop by 66%. If combined with slow steaming (as in the MCE case), these reductions would be about one quarter higher.

Replacement of oil with LNG as a fuel for shipping reduces air pollution. If 50% of vessels involved in international short sea shipping[1] in the Baltic Sea and the North Sea would use LNG in 2030, the emissions from these two sea regions would decrease by about 25%.

Environmental impacts of international shipping are high. In 2005, air pollution from shipping was responsible for about 14 million life years lost (YOLL), 700 cases of premature deaths due to ozone, and 17 thousand km^2 of ecosystems with acid deposition above critical loads. Area of ecosystems endangered by eutrophication, which can be attributed to the emissions from shipping, was 30 thousand km^2. For the Baseline situation, negative impacts will persist also in the future and – without further strengthening of legislation - will even increase after 2020.

Described in this report scenarios importantly contribute to mitigating these impacts. Implementation of ECA for sulfur and nitrogen in Territorial Seas and the Exclusive Economic Zones of the EU Member States reduces the health effects caused by shipping emissions in 2030 by one third. Area of ecosystems affected by acidification and eutrophication due to shipping activities decreases by about 45%. The MTFR scenario reduces shipping contribution to air pollution by about two thirds.

Costs of scenarios depend on the spatial coverage and the type of measures applied. Establishing NECA in the Baltic and the North Sea (with English Channel) costs in 2030 about 270 million €. Extension of SECA and NECA to all EU territorial waters increases these costs to about 740 M€. Costs are about 270 M€ lower in case scrubbers were used instead of low sulfur fuel. Establishing NECA and SECA in the EU territorial and EEZ waters would cost 3.2 bln € (for low S fuels option) or 1.3 bln € (for the case of application of scrubbers). Using PM filters on top of SECA and NECA legislation in in the Baltic, Black, Mediterranean and the North Sea (with English Channel) would be relatively inexpensive – about 66 million €. Finally, MTFR over the whole area of European seas costs 5.4 billion €(low S fuels case) or 2.4 billion € (with scrubbers).

[1] Short sea shipping (SSS) is defined in this study as movements between ports of the EU Member States)

Assessment of cost-effectiveness of measures on shipping in the context of minimization of the costs of achieving targets from the TSAP will be done with the use of the GAINS model when developing cost-efficient scenarios for the revision of the TSAP.

CHAPTER 2 INTRODUCTION

Within the work on the revision of the Thematic Strategy on Air Pollution (TSAP), the European Commission is interested in exploring measures to reduce emissions from international shipping. In particular, the Commission wishes to assess the effects of establishing new emission control areas (ECAs) for sulfur and nitrogen oxides (NECAs and SECAs) and the implementation of emission limit values for fine particulate matter (PM2.5). To provide quantitative input to such an assessment, this study has revised and updated emission inventories from maritime shipping and developed several mid- and long-term scenarios of reduction of ship emissions with different spatial coverage. Gridded emission inventories were used by EMEP in their atmospheric chemistry model to determine the contribution of international shipping to concentrations and depositions of air pollutants in Europe. EMEP developed the so-called pollution transfer matrices, which were used in the assessment of environmental impacts of the scenarios. For each of the scenarios we also assessed emission control costs. Results of this analysis are being used in the on-going assessment of cost-effectiveness of measures on shipping in relation to the measures on land-based sources within the work on TSAP.

The **scope of this report** is as follows:

- First, we present the methodology of building up the emissions inventory for international shipping.
- Next, we describe assumptions chosen for developing of the baseline emission scenario, including the changes in shipping activities and the current legislation (CLE) on emissions from shipping.
- Further, we explore the effects of different policies with regard to control emissions form shipping that go beyond the current legislation. We also estimate the costs of each scenario.
- Finally, we determine effects of the scenarios on air pollution impact indicators, including effects on human health and ecosystems.

Scenarios described in this report are used by IIASA in the assessment of the costs and benefits of European air pollution control policies in the context of the revision of the TSAP. In this assessment IIASA uses its integrated assessment model GAINS (Amann et al., 2011).

Current version of the report includes several revisions, which take into account comments and suggestions to the draft version from September 2012. Comments were made by the Commission staff, stakeholders from industry, NGOs and the representatives of the EU Member States.

CHAPTER 3 METHODOLOGY AND INPUT DATA

3.1. EXTREMIS/EUROSTAT/EMMOSS (EEE) APPROACH TO ESTIMATE SHIPPING EMISSIONS

The approach adopted for estimating international shipping emissions was to develop further the EX-TREMIS/EUROSTAT (EE) dataset used in the MBI-Lot2-Shipping project for DG ENV (Campling et al, 2010) and to integrate this information with a digital European shipping routes map[2] within (what call) the TNO grid. The TNO grid area is used to study air pollution in Europe (Figure 3.1). The European Commission was also interested in the emissions occurring in the Bay of Biscay and the Celtic Sea – so we use the borders of these sea regions as defined by the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention) (Figure 3.2).

The EX-TREMIS/EUROSTAT database uses a combination of publically available data, and restricted national data. It consists of a fleet module, which defines the ship categories and their segmentation and the transport activity module, which calculates the Origin-Destination (O/D) matrix of shipped tons and ton-miles. These volumes are converted into ship-equivalent traffic, expressed as distance travelled by ships (ship-km), thus representing the sea activity database. The information stored in the database makes a distinction between six vessel types, 3 size-classes and destinations to over 250 countries or regions.

EUROSTAT New Cronos database is used to derive the port activity database, as there is information on the number and gross tonnage of vessels at the main EU-27 ports (port-callings). Emissions are calculated for main engines (ME) and auxiliary engines (AE) using the detailed EMMOSS[3] emissions model, developed for marine traffic to and from Belgian ports.

The EEE activity database includes only ship movements to- or from EU-27 ports. Movement of ships in passage, i.e., sailing on seas surrounding Europe but not entering the EU ports is not included. This causes some underestimate of shipping movements and emissions. To minimize these underestimates, corrections were made to activity data in the Mediterranean Sea where movement of free passage is particularly important. Approach adopted is described in Section 3.4.5.

This report concentrates on emissions from international shipping. The GAINS model includes emissions from the so-called national sea traffic (i.e., from trips between ports located in the same country) in national emission estimates. To ensure that these emissions are not double counted, we have removed from our database all routes that that had an origin and destination in the same Member State.

[2] *Source: RRG Spatial Planning and Geoinformation*
[3] *Flemish emission model for inland shipping, maritime transport and rail (http://www.tmleuven.be/project/emmoss/home.htm)*

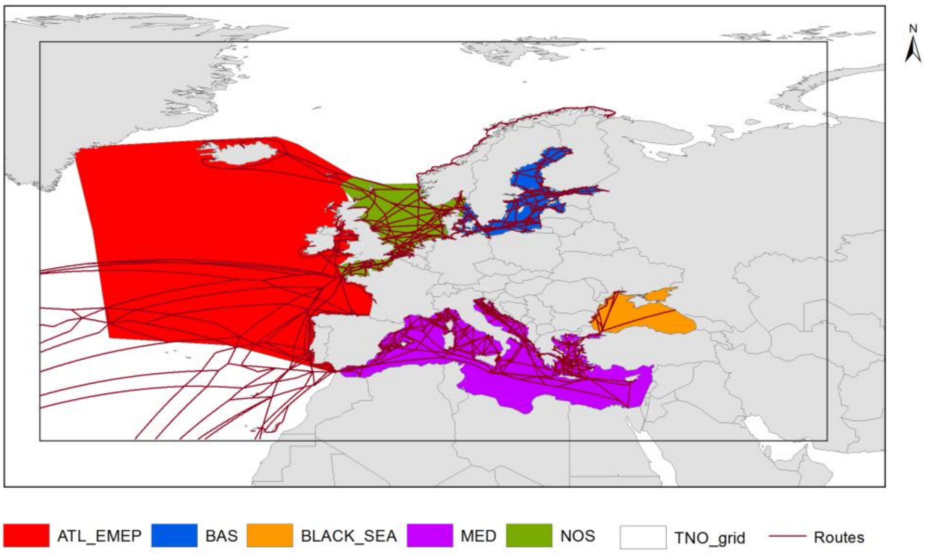


Figure 3.1 Shipping routes and the regional seas within the TNO grid borders

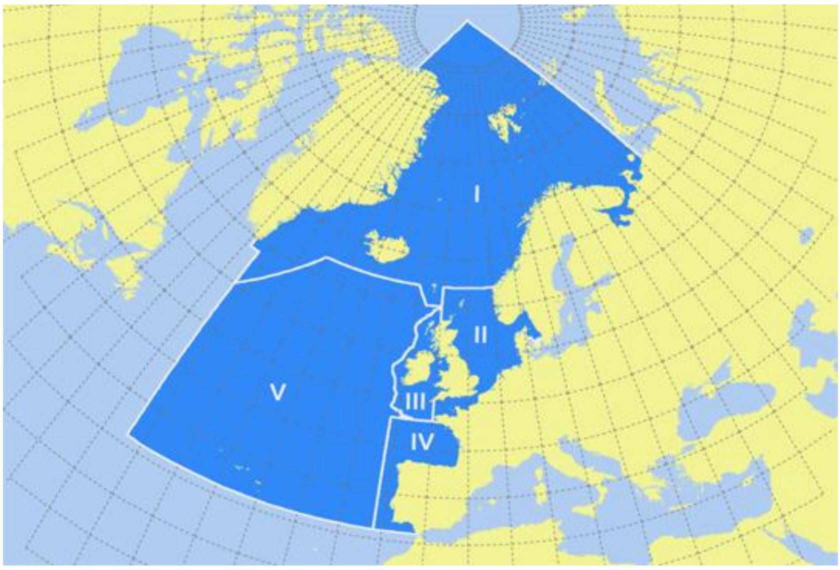


Figure 3.2 Boundaries to map emissions in the Celtic Sea (III) and the Bay of Biscay (IV)

3.2. EMISSION FACTORS

Emission estimates, as developed in our study, take into account (1) fleet dynamics (fleet renewal, size increase), (2) fuel consumption based on activity data, and (3) emission factors, in terms of kg/kg fuel. Fleet dynamics are important as vessels of different age have different emission profiles.

(1) Fleet dynamics include mainly the rate of fleet renewal and the increase of size. The increase of size is taken into account by the transport activity calculation with different growth rates for vessels of the same type but different sizes. The rate of fleet renewal is based on the EU-active fleet in the last 5 years (source: LMIU). This allowed us to construct an age distribution for different vessels types and size-classes. We see that container vessels are

typically very young, while dry bulkers are typically old. This age distribution is the starting point to estimate future age distributions. In the EMMOSS project (Vanherle et al., 2007) estimated Weibull survival functions from the UNCTAD yearly maritime review (UNCTAD, 1997-2006) allowing us to calculate fleet renewal rates.

(2) Fuel consumption is calculated from energy needed and vessel efficiency. Operational speed is important in this calculation; the propeller law determines the relation between speed and propulsion energy as follows:

(energy) ~ (speed) ^ 2.7

This means that the required propulsion energy is not linearly proportional to vessel speed. From the vessel data (source: LMIU), we were able to estimate the operational speed and installed (propulsion and auxiliary) power of the different vessel types. This has allowed us to determine the propulsion energy required per kilometer, given an assumption on the percentage of installed power used at cruising speed. While in the literature a ratio of 75-85% is common (Whall, 2002, Endresen, et al., 2003), recent empirical evidence suggests a lower estimate (Vanherle and Zeebroeck, 2008). As a conservative estimate, we have therefore used 75%.

(3) For the development of emission factors, several data sources exist. We used the emission factors calculated by (Oonk, 2003) as these are more recent than Whall (2002). Next, we applied the emission factors from the EMMOSS-study and were able to refine them further with respect to the relation between sulfur content of fuel and particulate emissions.

The emission factors distinguish several ship age and category classes, engine types (auxiliary vs. main engines) and fuel types. Thus, further disaggregation of the transport activity in terms of engine type rather than just vessel type was required. For this purpose a compatibility matrix was prepared, which linked propulsion technology with the different vessel types and size classes. In general, two stroke engines are more common for larger vessels. For tankers, a minor share uses steam turbines as the main propulsion technology. An overview of the emission factors used in our study is provided in Annex I.

Since black carbon (BC) emission factors were not included in the EMMOSS model database, we derived these factors from other sources. Measurements carried out in the US and in Europe (Lack et. al., 2009; Cappa et. al., 2011; Jayaram et. al., 2011) reported an increase in BC factors for some vessel types following reduction of S content. According to other studies (Petzold et. al., 2010; Agrawal et. al., 2010) BC factors are rather independent from sulfur content of fuel. Recently published review of BC measurements (Lack and Corbett, 2012) suggests a 30% reduction of BC emissions when switching from residual oil to low sulfur marine distillates. Recognizing significant uncertainties in the BC emission factors and their relation to the sulfur content of fuels, we decided to use a constant emission factor of 5 mg/MJ for residual oil and 3.5 mg/MJ for low sulfur marine distillates.

3.3. COSTS CHARACTERISTICS OF ABATEMENT MEASURES

3.3.1. GENERAL ASSUMPTIONS

We assess costs of implementing emission reduction measures based on information about available technologies from literature sources. We calculate annual costs for each technology, including both: investment, operation, and maintenance costs associated with measures that reduce emissions of SO_2, NO_x, and PM. All costs are given in Euro 2005. We present the costs per unit of fuel used (MWh or GJ) by a given ship category. For measures that require investments, we assume a four percent real discount rate to convert investment outlays into annual costs.

In the literature, investment costs are expressed per unit of rated power of vessel engines. These costs are recalculated into costs per unit of fuel used assuming 4000 annual operating hours per year. Cost assessments are done for 2020 and 2030 and include costs of technologies after their full commercialization and production at high enough scale. We did not attempt to assess the costs for 2050 because in such a long time horizon cost characteristics of measures are likely to importantly change compared with the values relevant for the period 2020 to 2030.

Calculated scenarios assume different packages of measures for existing (pre-2016) and new vessels. Based on the age distribution of the fleet (compare Figure 6) we assume that 30 % of all vessels in 2020 are new ships. This share increases to 60 % in 2030. We assume a 20 years lifetime of control equipment for new vessels and – in case of retrofits - 15 years for existing ones. Further, we assume that retrofitting of existing vessels can be performed only on a fraction of all existing vessels due to technical constraints and due to a limited remaining lifetime of vessels. We assume maximum penetration rates for retrofits to be 40 % in 2020 and 60% in 2030. We assume that by 2050 all existing vessels are scrapped. The potentials are based on expert judgment and take into account that: (1) older vessels with short remaining lifetime are unlikely to be retrofitted and will be scrapped; and (2) in many cases it is simply not possible to retrofit due to technical reasons and space limitations (mainly small & older vessels).

3.3.2. MEASURES TO REDUCE SULFUR EMISSIONS

Scenarios developed in this report assume that reduction of SO_2 emissions is achieved by implementing successive sulfur caps on fuel under the auspices of the IMO[4] and the European Union's Sulphur Directive[5]. Reduction in SO_2 emissions needs to be achieved either using low sulfur marine fuels or by taking equivalent measures (exhaust gases scrubbing). Costs of these two alternatives are discussed below.

→ **Use of low sulfur fuels**

Report by Purvin & Gertz (2009) for the European Commission provides an assessment of the expected fuel premiums when ships change marine fuel grades (from 2020 onwards). These

[4] Annex VI to MARPOL Convention
[5] Directive 2005/33/EC

figures (originally given in 2009 prices) have been converted to costs expressed in Euro 2005 with assumptions as in the Table 3.1. Results are presented in Table 3.2. For further assessment we use the average estimate (106 €/t fuel for the step down to 0.5% S) and 117 €/t fuel for the step from 0.5% to 0.1% S). This translates to about 2.5 k€/t SO_2 abated for switching to fuel with 0.5%S and about 14 k€/t SO_2 for switching from 0.5% to fuel with SECA quality (0.1 % S). According to the same study, the cost of residual oil with 2.94% sulfur is projected to be $420/ton (in 2009 prices). This suggests 413 €/ton for fuel with 0.5% S and 530 €/ton for fuel with 0.1% S.

Table 3.1 Conversion rates assumed to derive fuel premiums

1 euro=	0.8045	dollar
1 joule=	0.278	MWh
1 ton of fuel Residual Oil (RO) =	40.7	GJ
1 ton of fuel RO =	11.53	MWh
1 ton of fuel Marine Distillate (MD) =	43.3	GJ
1 ton of fuel MD =	12.03	MWh

Table 3.2 Cost premiums for changing fuel standards

Fuel shift	Low cost	High cost	Average	Average	
unit	$/ton	$/ton	$/ton	€/ton	€/MWh
2.94 to 0.5	120	170	145	106	9.2
2.94 to 0.1	280	330	305	223	19.4
0.5 to 0.1	160	160	160	117	10.2

In comparison to the Purvin & Gertz (2009) study, the US and Canada submission to designate their coast lines as ECAs (MEPC 59/6/5) estimates the costs of switching from residual fuels to distillates and their subsequent desulfurization to be USD 145/ton. Considering the higher energy content of distillates, they estimate that the real cost is USD 123/ton, which is about half of the costs given by Purvin & Gets. However, the US/Canada assessment is based on different assumptions (availability of fuel in the shorter-term and in limited quantities needed for the North American market only) whereas Purvin & Gets study takes into account the European and the longer-term perspective, including required investments.

Current price differentials between high sulfur residual oil (600 USD/t) and low sulfur distillates (900 USD/t) - see www.bunkerworld.com correspond well with the differential implied by the Purvin & Getz study (305 USD/t fuel in 2009 prices, or about 330 USD/t in 2013 prices). It needs to be stressed that Purvin & Getz assessment refers to the prices as expected after 2020 and take into account investments necessary to meet the demand for low sulfur fuel resulting from the new fuel quality standards for ships.

→ **Sulfur scrubbers**

An alternative to using relatively expensive low sulfur fuels is the use of sulfur scrubbers to reduce SO_2 emissions by an equivalent amount. Exhaust gas is brought in scrubbers into contact with a buffered alkalinity so that SO_2 is trapped and converted to sulfate ions. Two types of systems are used: open (seawater) scrubbers or closed (freshwater) scrubbers. Bosch et al. (2009) provide an overview of investment and operation costs of new installations and retrofits. These costs are summarized in Table 3.3 and Table 3.4. Unit costs calculated based on these parameters are presented in Table 3.5. Costs were calculated under an assumption that vessels use residual oil with 2.94 % S and that the scrubbers reduce the emissions to the 0.1% S equivalent. For seawater scrubbers the unit SO_2 reduction costs are much lower than the costs of using low sulfur fuels.

Table 3.3 Capital costs of scrubbers

Parameter	Unit	Seawater	Closed loop
Investment, new vessel	€ /kW	100	200
Investment, retrofit	€ /kW	200	400
Fixed O+M (% of investments)	% inv.	2%	2%

Table 3.4 Operational costs associated with running scrubbers

Parameter	Unit	Value
Annual operating hours	h	4000
Engine efficiency	%	50%
Lifetime of scrubbers - new	years	20
Lifetime of scrubbers - retrofit		15
Fuel penalty	%	2%
Fuel cost	€ /t	307
Use of NaOH 2.94 to 0.5 (fuel)	l/MWh	6
Use of NaOH 2.94 to 0.1 (fuel)	l/MWh	15
Use of NaOH 0.5 to 0.1	l/MWh	12
Cost of NaOH	€ /l	0.5
Use of NaOH 2.94 to 0.5 (fuel)	€ /MWh	3
Use of NaOH 2.94 to 0.1 (fuel)	€ /MWh	7.5
Use of NaOH 0.5 to 0.1	€ /MWh	6
Amount of sludge to dispose	l/MWh	1.3
Sludge disposal costs	€ /l	0.12
Sludge disposal costs	€ /MWh	0.156

Table 3.5 Unit costs of sulfur scrubbers

Parameter	Unit	Retrofit closed loop	Retrofit - seawater	New closed loop	New seawater
Investment cost	€/GJ fuel	1.25	0.62	0.51	0.26
O+M fixed	€/GJ fuel	0.28	0.14	0.14	0.07
NaOH	€/GJ fuel	1.04	0.00	1.04	0.00
Sludge	€/GJ fuel	0.02	0.02	0.02	0.02
Energy	€/GJ fuel	0.12	0.12	0.12	0.12
Total	€/GJ fuel	2.71	0.90	1.83	0.47
Cost per ton abated	k€/t SO2	3.96	1.32	2.68	0.68

3.3.3. REDUCTION OF NITROGEN OXIDES EMISSIONS

The technology with the highest capability to reduce NO_x emissions and comply with Tier III standards is selective catalytic reduction (SCR). SCR is an exhaust gas after treatment technology that achieves NO_x abatement of more than 80 %. It has to be installed separately for each engine of a ship and needs urea as a sorbent. We provide an overview of the investment and operating costs to install SCR (Table 3.6), based on the recent study on the introduction of a NECA in the North Sea (Danish EPA, 2012).

Table 3.6 Costs of SCR installations for marine vessels.

Cost item	Unit	New	Retrofit
Capital investment (per kW engine output)	€/kW	49.3	74.0
Interest rate	%	4%	4%
Average shipping hours	h/year	4000	4000
Lifetime of investment	years	20	15
Annuity	-	0.074	0.090
Annualized investment cost	€/MWh	0.91	1.66
Variable cost	€/MWh	5.55	5.55
Cost per MWh engine output	€/MWh	6.46	7.21
Engine efficiency		50%	50%
Cost per MWh fuel	€/MWh	3.23	3.61

Exhaust Gas Recirculation (EGR) is a proven technology for diesel engines in land-based applications, whereby a proportion of the exhaust gas is redirected back into the combustion chamber. EGR for shipping engines can also be applied. Recent experience demonstrates that the performance of EGR is good for two stroke engines and that it might become a standard for this type of engines to achieve Tier III limits. However, EGR is not fully commercialized as yet and thus for costs assessment we assume implementation of SCR.

3.3.4. FINE PARTICULATE MATTER FILTERS

Our assessment of costs of fine PM reduction is based on the performance of the Nauticlean S technology developed by the Hug Engineering (Hug Engineering, 2012). It consists of two reactors with a selective-catalytic-reduction for NO_x and a PM filter, whereby the PM filter is equipped with a diesel full-flow regenerative burner. For efficient PM removal, catalytically coated silicon carbide (SiC) filters are used. These filters consist of several honeycombs made of micro fibres. During operation, the soot particles are retained in the filter. As soon as the regeneration temperature is reached, the soot in the filters is burned off without residue. Due to the catalytic coating, the regenerating temperature is around 450 °C. Information on the performance and costs of particle filters for ship engines is scarce. The 6th Framework Programme funded project “The Cleanest Ship Project” (Schweighofer and Blauw, 2009), discusses the implementation of the Nauticlean System on an inland water demonstration ship. The expected performance is up to 99% reduction in PM emissions. One individual company approached indicated that cost estimates were so specific to the ship’s characteristics that general information was not feasible. Corbett et. al. (2010) indicates that the investment costs of marine diesel particulate filters (DPFs) are about US$ 22/kW and the costs of filter regeneration and replacement are US$ 19.6/kW. This translates to € 15.8/kW and € 14.1/kW respectively, in Euro 2005 prices. Fuel penalties can also occur but for fuels with low sulfur content they are expected to be low. Calculated costs per unit of fuel used are presented in Table 3.7.

Table 3.7 Unit costs of particle filters

	Unit	New	Retrofit
Capital investment (per kW engine output)	€/kW	29.9	44.8
Interest rate	%	4%	4%
Average shipping hours	h/yr	4000	4000
Lifetime of investment	years	20	15
Annuity	-	0.074	0.090
Cost per MWh engine output	€/MWh	0.55	1.01
Engine efficiency		50%	50%
Cost per MWh fuel	€/MWh	0.27	0.50

3.3.5. SLOW STEAMING

In recent years, slow steaming has become an interesting option as a measure to reduce fuel consumption and emissions from vessels. With the global economic crisis, higher fuel prices, and the increase in available vessel capacity, reduction in the sailing speed of maritime vessels has become an increasingly common practice in the sector (Alphaliner, 2010). It helps to absorb vessel overcapacity, as a slower commercial speed requires more vessels to maintain the same service frequency per liner service. It has proven to be an effective way to save fuel costs and to restore shipping companies' profitability (Notteboom and Cariou, 2011). Simultaneously slow steaming brings environmental benefits in terms of reduced air pollution. Slow steaming can be realized at two levels (Psaraftis and Kontovas, 2010): the first level is a ship that is designed to go 26 knots may sail at 14 knots, which entails reconfiguring the engine so that it performs well under a reduced load; the second level is strategic, and involves building ships with smaller engines to sail 14 knots instead of 26 knots. The main difference between the approaches is that the first is reversible whereas the second is not. Also, if the smaller-engine ship attempts to sail at higher speeds or just maintain its speed in bad weather, its fuel consumption and emissions would likely be higher than if its engine were more powerful.

The Air Resources Board of California (CARB, 2009) study assessed the impact of vessel speed reduction to from 22 to 12 knots. It treats separately speed restrictions within the 12 nm zone and in the 200 nm zone and high seas. Reduction in CO_2 emissions is used as a proxy to estimate the reduction in fuel consumption, which is further translated into potential cost savings due to slow steaming. Reduction coefficients assumed for speed restrictions are summarized in (Table 3.8).

Table 3.8 Reduction coefficients assumed for speed restrictions within the 12 nm zone, in the 200 nm zone and high seas

Sea Zone	NO_x	SO_2	$PM_{2.5}$	CO_2	Applied to
24 nm zone	-21%	-13%	-18%	-13%	12 nm zone
40 nm zone	-36%	-29%	-31%	-29%	EEZs (200 nm zone) plus high seas

The CE Delft Study (Faber et al., 2012) gives a procedure to calculate the costs of slow steaming measures. The main cost is that if the ships go slower than more ships are needed to deliver the goods on time. When overcapacity is not taken into account, it can be assumed that an x% reduction in speed will result in a [1/ (1-x)-1] share of additional active ships. This means that a 25% reduction in speed results into a 33% increase in the number of active ships. The Authors of the Study provide the following example: "Assuming that a baseline fleet consists of 3 ships of the same ship type, which make 12 voyages of 1,000 km per year, transporting each 1,000 tons per voyage and each sailing on average at 40 km/hour in the baseline scenario. The baseline productivity of this fleet would then be 36 million ton kilometers per year and each ship would sail 300 hours a year *(unrealistic but used for explanatory purposes)*. When under a 25% speed reduction ships would sail 30 km/hour on average, then a ship would need 33% more time for one voyage. In the 300 hours, a ship could only make 9 voyages and the productivity of the fleet would only amount to 27 million ton kilometers per year. In total 4 ships instead of 3 ships would be necessary to provide the same fleet productivity. Therefore there is an investment cost of purchasing or hiring an extra ship."

As we know that there is an overcapacity at present we therefore examine the fuel cost savings that occur with slower speeds taking into account that fuel costs are different in SECA and non-SECA zones. We use the Purvin & Gertz (2009) assumptions about fuel cost as given in Section 3.4.1 (413 €/t for fuel with 0.5% S and 530 €/t for fuel with 0.1% S). These fuel costs are also used for the 2030 estimates.

3.4. Baseline scenario Assumptions

The base year for our scenarios is 2005, and we develop the baseline projection of emissions for 2020, 2030 and 2050. The baseline takes into account the "Current legislation" emission control requirements, which include recently adopted standards, first of all the amendments of October 2008 to the IMO MARPOL ANNEX VI Convention. These are:

- Sulfur cap on all fuels of 3.50% in 2012;
- In the Sulfur Emission Control Areas (SECA) of the North Sea (including English Channel) and the Baltic Sea: a 1.00% Sulfur cap starting 01/07/2010 and a 0.10% in 2015;
- A reduction of Sulfur content from 3.50% to 0.50% in 2020 in non-SECA waters;
- For NO_x: Tier II standards: maximum 14.4 g/kWh in 2011 for new ships.

The sulfur cap on S content of fuels does not concern vessels that are equipped with scrubbers that reduce SO_2 emissions to equivalent levels.

The amendments to the MARPOL Convention make implementation of the global 0.5% S standard in 2020 dependent on the outcome of the review of availability of low S fuel. Such a review needs to be performed in 2018. In case not enough fuel will be available, the implementation can be postponed by five years.

In our simulations we also take into account the compromise agreement between the EU Member States, the European Parliament and the European Commission that was announced on 23 May 2012 (CEU, 2012). It requires that the sulfur standards be enforced in 2020 on all vessels moving on seas surrounding Europe. This means that no distinction is made between the EU and non-EU flag vessels and no postponement in the introduction of the S standard is possible.

3.4.1. ACTIVITY DATA

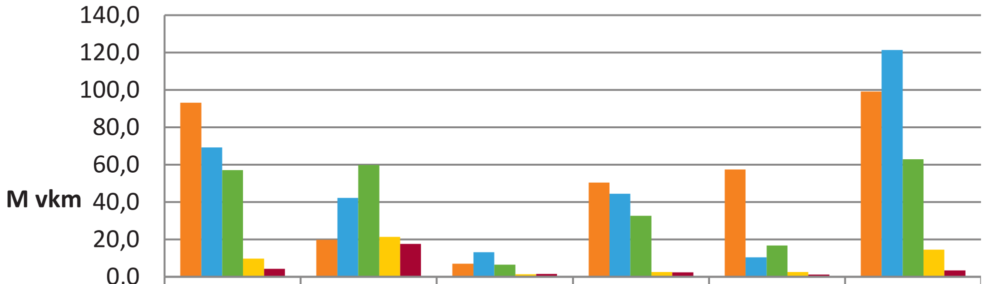
Maritime transport activities in 2005

The maritime transport demand is taken from the MBI project (Campling et al, 2010) which is based on EX-TREMIS database and tools (Schrooten et al., 2009). The core data EX-TREMIS starts from is freely available from EUROSTAT and holds four main datasets:

1. Cargo tonnage (gross weight) handled in all ports of the reporting country, annual data by direction;
2. Cargo tonnage (gross weight) handled in main ports of the reporting country, quarterly data by direction, partner entity and type of cargo (detailed classification);
3. Container cargo volumes handled in main ports of the reporting country, quarterly data by direction, partner entity, container size and loading status; and,
4. Number and gross tonnage of sea-going vessels (>100 GT) calling at main ports of the reporting country, quarterly data by type and size of vessels - Direction: inwards only.

Based on these data, "equivalent ship traffic" is estimated. The concept of equivalent-ship traffic is based on the calculation of the number of loaded equivalent vessels needed to transport by sea the total flow of a certain cargo type to a specific partner country, from just one ideal reference port of the reporting country. The same happens for the opposite direction. Calculations assume an average load factor (i.e. ratio of cargo/passengers transported to the nominal capacity of the vessel) of 90 % (see Schrooten et al., 2009). Details of the approach are described in the EX-TREMIS final report (Chiffi et al., 2007).

Figure 3.3 shows the total maritime transport activity in 2005. Tankers (301 M vkm), bulk cargo (233 M vkm) and container ships (160 M vkm) are the most important contributors to the total transport volume on European waters.



	Bulk cargo	Container	Gas tanker	General cargo	Passenger ship/ferry	Tanker
< 100m	93,1	19,7	6,9	50,3	57,4	99,2
100-150m	69,2	42,2	13,2	44,3	10,4	121,3
150-200m	57,1	59,9	6,5	32,6	16,7	62,9
200-250m	9,6	21,3	1,4	2,5	2,5	14,5
>250m	4,3	17,5	1,5	2,3	1,2	3,4

Figure 3.3 Maritime transport demand in seas surrounding Europe – 2005 (M vkm)

Demand baseline projections:

For the projection period three time intervals are taken:

- 2005 to 2020;
- 2020 to 2030; and,
- 2030 to 2050.

For the period up to 2030, EX-TREMIS reviewed transport demand forecasts available from various studies, which took into account different perspectives on the expected transport demand. Thus a starting point for our projections were forecasts developed within the EX-TREMIS project, that estimated growth for the relevant shipping markets up to 2030 in the EU based on the 2nd IMO Study on Greenhouse Gas Emissions from Ships (IMO, 2009). In this study the growth for future seaborne trade was between 1.5% and 3% annually. The 2009 IMO projections did not include the effects of the recent economic crisis. More recent studies (Hammingh et al., 2012, Danish EPA, 2012 and the study for DG CLIMA - Ricardo-AEA, 2013) assume slower growth. Thus the original EX-TREMIS growth rates (about 2.7%/annum on average for all vessel types) have been revised downwards to 1.1%/annum for the period 2005 – 2020. For the time interval 2020 -2030 a return to the original growth 2.7 %/annum is assumed. These assumptions are approximately consistent with the growth rates adopted in the PBL study for the North Sea (2.1 %/annum for the period 2009 – 2030, compare Hammingh et al., 2012). For the period 2030 to 2050 a lower growth rate is assumed, namely 1.8%/annum. This is consistent with the assumptions of the Ricardo-AEA (2013) study for DG CLIMA that assumes that the demand for maritime transport will slow down by about one percentage point after 2030. Average growth rates for individual periods are presented in Table 3.9. Note that growth rates differ from the average values between ship categories and origin-destination pairs.

Table 3.9 Traffic volume growth rates, %/year

Period	2005- 2020	2020 - 2030	2030 - 2050
Activity growth rate	1.1%	2.7%	1.8%

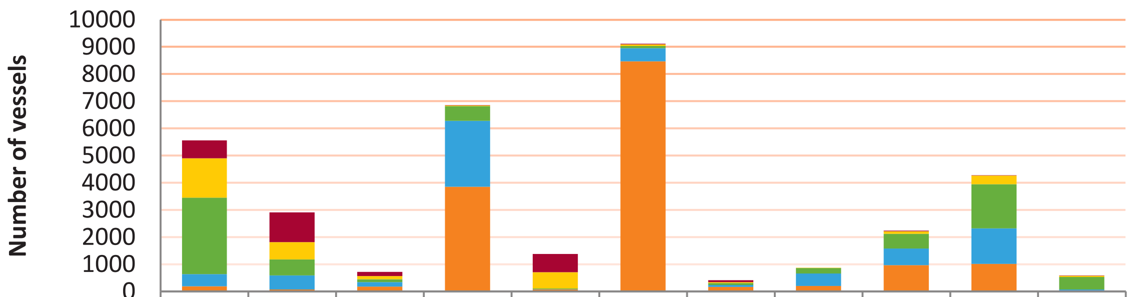
In the projections we did not include the use of the NW-Passage by international shipping. The authors are aware that given climatic changes, the NW-Passage may become a viable trade route for E-W maritime transport flows. It is, however, at this stage impossible to predict to what extent the NW-Passage will attract traffic from other trade lanes. Recent studies acknowledge the viability of the trade route, but argue any intense use of this new option in the near future as still being uncertain (Chøyen, H., & Bråthen, S., 2011). Given that the NW-Passage would relocate and probably reduce the amount of maritime traffic on EU seas, by not taking into account use of the NW-passage, we have opted for a conservative approach when estimating future maritime transport in EU seas.

3.4.2. SHIPPING FLEET

Current fleet

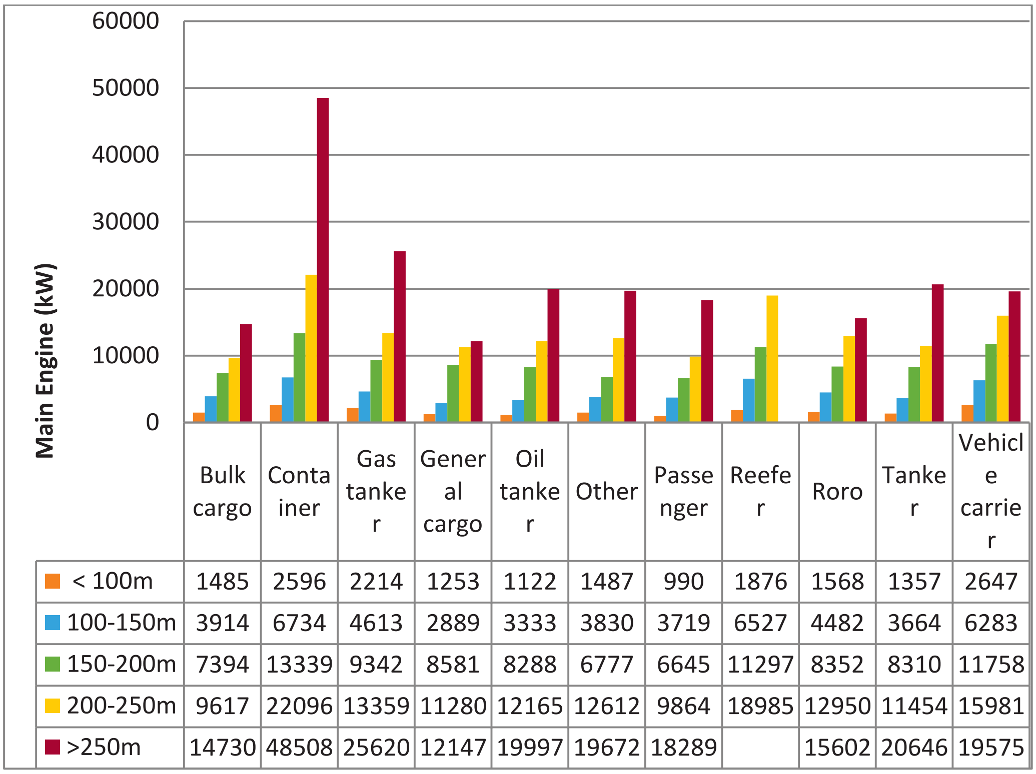
The emissions from international maritime transport do not only depend on the total traffic but also on the characteristics of the fleet, which are at least equally important. In the MBI project the fleet was extensively analyzed with a specific focus on emission reduction potential for NO_x and SO_2 emissions. Fleet data was available (purchased) from Lloyds/IHS. Figure 3.4 and Figure 3.5 provide information on the maritime fleet active in EU as of 2008-2009. In 2010, 35000 vessels were operating in the EU seas. Figure 3.4 illustrates the distribution of the fleet in terms of vessel type and size.

The average engine power, which is the determinant for the vessel's emission, is presented in Figure 3.5. The average engine power installed has the similar characteristics for most vessel types, excluding container vessels. Compared to other ships, container ships are designed for relatively high speeds and thus require stronger engines.



	Bulk cargo	Container	Gas tanker	General cargo	Oil tanker	Other	Passenger	Reefer	Roro	Tanker	Vehicle carrier
>250m	666	1086	144	1	668	29	69		20	8	10
200-250m	1450	646	125	15	596	58	41	7	100	314	43
150-200m	2813	587	97	551	26	86	64	201	532	1623	458
100-150m	448	510	172	2426	15	484	74	457	622	1312	44
< 100m	183	73	172	3842	68	8460	164	194	959	1006	29

Figure 3.4 Number of vessels in the shipping fleet active in EU seas in 2010, by ship type and size



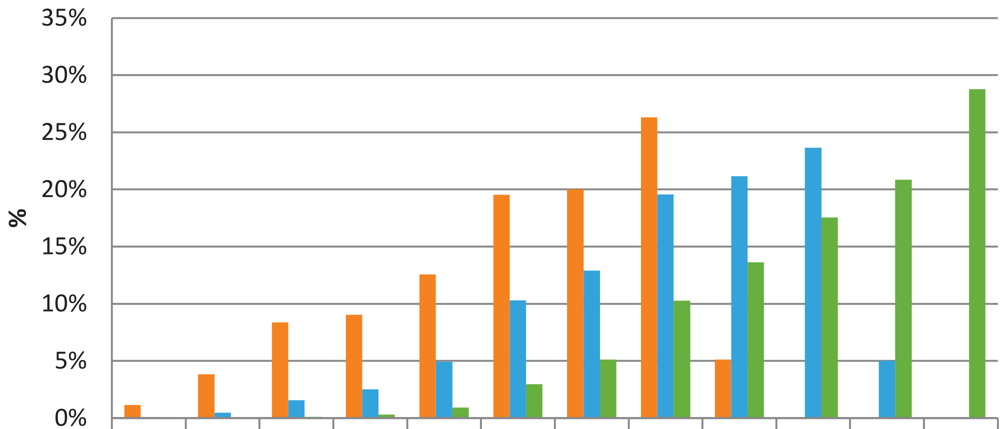
	Bulk cargo	Container	Gas tanker	General cargo	Oil tanker	Other	Passenger	Reefer	Roro	Tanker	Vehicle carrier
< 100m	1485	2596	2214	1253	1122	1487	990	1876	1568	1357	2647
100-150m	3914	6734	4613	2889	3333	3830	3719	6527	4482	3664	6283
150-200m	7394	13339	9342	8581	8288	6777	6645	11297	8352	8310	11758
200-250m	9617	22096	13359	11280	12165	12612	9864	18985	12950	11454	15981
>250m	14730	48508	25620	12147	19997	19672	18289		15602	20646	19575

Figure 3.5 Distribution of the average fleet main engine power installed (kWh) by ship type and size

Fleet projections

Trends observed in past indicate that the fleet will change in the future in some aspects. In the last few decades an increase in vessel size occurred and it is expected that that increase will continue. In addition, demand for some vessel types will be higher compared to others. In particular, one expects that the demand for large container vessels will increase.

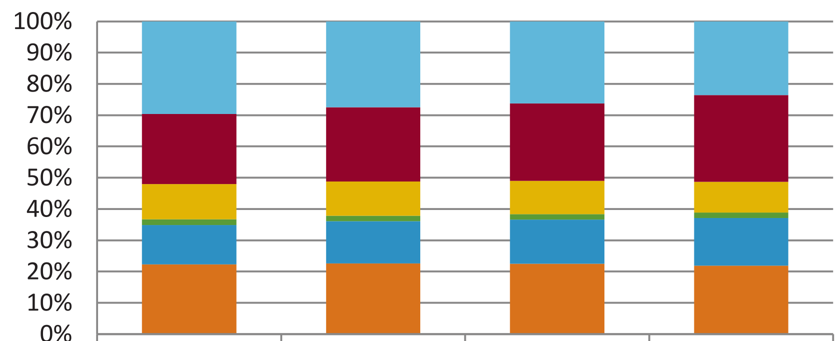
First, the fleet turnover is estimated based on Weibull functions, calibrated on UNCTAD reports. Older vessels have a different emissions profile and worse fuel efficiency compared to newer vessels. The Weibull functions as estimated in the MBI-project, gave the age distributions as in Figure 3.6.



	<= 1974	1975-1979	1980-1984	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014	2014-2019	2020-2024	2025-2030
2010	1%	4%	8%	9%	13%	20%	20%	26%	5%	0%	0%	0%
2020	0%	0%	2%	3%	5%	10%	13%	20%	21%	24%	5%	0%
2030	0%	0%	0%	0%	1%	3%	5%	10%	14%	18%	21%	29%

Figure 3.6 Age distribution of total fleet, historical and future

Given expected demands per maritime transport service (tanker, bulk, container,…), the demand for ship types will develop asymmetrically, meaning that the share of tankers in the total fleet will continue to decline, while the share of container vessels will increase (Figure 3.7).



	2005	2020	2030	2050
Tanker	30%	27%	26%	24%
Passenger ship/ferry	22%	24%	25%	28%
General cargo	11%	11%	11%	10%
Gas tanker	2%	2%	2%	2%
Container	13%	13%	14%	15%
Bulk cargo	22%	23%	23%	22%

Figure 3.7 Share fleet per type - trend 2005-2050

3.4.3. Propulsion technology and vessels' operating efficiency

An important factor determining emissions is the engine type. Typically, a distinction is made between 4-stroke, 2-stroke engines and full turbines. 4-strokes are common among smaller vessels while the more polluting 2-stroke engines are more common among larger vessels (Figure 3.8). A small amount of large vessels use turbines for propulsion

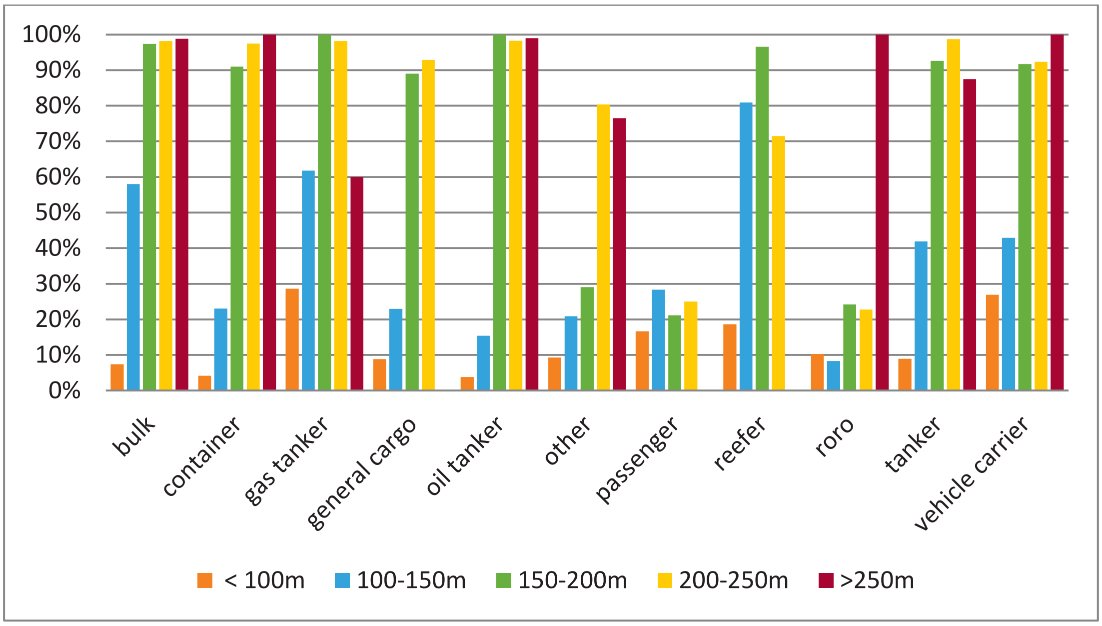


Figure 3.8 Share of 2-stroke engines per vessel type and vessel size

As for fuel efficiency, an improvement of the engine fuel efficiency is assumed over time – compare Table 3.10.

Table 3.10 Vessel engines efficiency improvements over time, by age group

	2 stroke	4 stroke
<=1974	40.3%	37.6%
1975-1979	42.4%	39.4%
1980-1984	44.6%	41.3%
1985-1989	47.1%	43.4%
1990-1994	48.4%	44.6%
1995-1999	49.8%	45.8%
2000-2004	50.4%	46.3%
2005-2009	50.4%	46.3%

In addition, we take into consideration the improvement of operating efficiencies of vessels as required by the Energy Efficiency Design Index (EEDI) for new ships, and reduction of fuel consumption resulting from the implementation of the Ship Energy Efficiency Management Plans (SEEMP) for all ships as recently adopted by the IMO (IMO, 2011). Quantification of the effects of this new IMO legislation is based on the assumptions adopted in the recent study on greenhouse gases emissions from maritime transport commissioned by the DG CLIMA (Ricardo-AEA et al., 2013). No emission abatement technologies have been considered beyond what is required by current legislation. Moderate NO_x emission standards issued by IMO (Tier I and II) are assumed to be achieved with minor engine modifications.

Although small number of vessels are currently being equipped with SCR-technology, in the baseline it is assumed that this is insignificant for the total emissions from European seas. To comply with the NECAs, as will be shown in the scenarios, it is assumed that the required NO_x reduction will be achieved using SCR-technology. This assumption is in line with previous studies for DG ENV (Campling et al., 2010).

Currently some 100 vessels are using LNG as a propulsion fuel. This is a viable alternative to oil-based fuels, but was not considered as an abatement option in the MBI project. A recent study by MEC intelligence (2011) estimates that there is a potential for up to 5% of the new build vessels in 2020 to be able to use LNG in an optimistic scenario in terms of fuel availability, maturity of technology and infrastructure. Given the long turnover rate of maritime vessels (typically 25-30 years), the penetration of LNG in the fleet will not have a significant influence on to Baseline emissions, at least in the near-term. However, in the longer-term the penetration of LNG as energy source for shipping can gain importance. Thus, we assume no penetration of LNG in the Baseline scenario. However, we have prepared sensitivity runs that demonstrate the effects of using LNG as a fuel for short sea shipping in 2030 and 2050. Results are presented in Section 4.6.

3.4.4. OTHER KEY ASSUMPTIONS

Vessels operating within the Sulfur Emission Control Areas (SECAs) need to use marine fuel with sulfur content not higher than 1.5% per mass or take equivalent measures (flue gases cleaning). From 1st January 2015 this S content needs to be further reduced to 0.1% per mass. In the NO_x Emission Control Areas (NECAs) new vessels (i.e., those constructed on or after 1 January 2016) need to adhere to TIER III limits, as specified in the IMO Annex VI of the MARPOL Convention. This means that operation of a marine diesel engine which is installed on a new ship is prohibited except when the emission of nitrogen oxides (calculated as the total weighted emission of NO_2) from the engine is within the following limits, where n = rated engine speed (crankshaft revolutions per minute):

1) 3.4 g/kWh when n is less than 130 rpm;
2) 9 · n(-0.2) g/kWh when n is 130 or more but less than 2,000 rpm; and
3) 2.0 g/kWh when n is 2,000 rpm or more.

The current technology that meet Tier III NO_x emission standards is selective catalytic reduction (SCR) or conversion to gas engine. It is expected that for 2-stroke engines exhaust gas recirculation (EGR) will be also able to meet the Tier III limits. According to Industry experts, in the future EGR can become a major control technique for this type of engines. However, EGR is still in the development phase (Bosch et. al., 2009) and thus in our assessment we assumed that meeting the Tier III standards will require installation of SCR.

As mentioned in section 3.3.5, in scenarios that assume slow steaming, we use the information reported by the CE Delft Study (Faber et al., 2012), which in turn quotes the Air Resources Board of California (CARB, 2009) study. Fuel reduction coefficients due to slow steaming are given in Table 3.8.

We assume that soot particle filters can be installed only together with the SCR to reduce NO_x emissions. Removal efficiency of the filters in 99% for the 20-300 nanometer fine particle fractions. This technology would be similar to the nauticlean system, for which manufacturers claim 99% removal efficiency (HUG, 2012).

3.4.5. Revisions made to the EX-TREMIS Ship Activity and Fuel Consumption data

As stated above, our assessment uses as a starting point the EXTREMIS based Ship Activity and Fuel Consumption dataset. However, we have performed several updates taking into account recent developments in transport volume, changes in the legislation, and the coverage of emission inventories. In particular:

- We account for the impact of 2008 recession and slow recovery, with a faster recovery in period 2020 – 2030 by using the growth rates for shipping activities as in Table 3.9.
- On the basis of the Ricardo-AEA study for DG CLIMA (Ricardo-AEA, et al., 2013) we take account of the increase in vessels' operating efficiencies based on the Energy Efficiency Design Index (EEDI) for new ships, and the Ship Energy Efficiency Management Plan (SEEMP) for all ships (IMO, 2011);
- The EXTREMIS database takes into account only ship movements that either leave or enter the EU ports. Movement of ships in passage is not included. This is of particular importance for the Mediterranean Sea, where many ships travelling from the Suez Canal to the Straits of Gibraltar do not enter the EU ports. Thus, we have increased fuel consumption in the Mediterranean Sea by about 10% and distributed the resulting emissions along the Suez Canal – Gibraltar route. The correction was based on the updated emission inventory for the Mediterranean Sea by ENTEC/CONCAWE (CONCAWE, 2007).
- The combination of revised growth rates and changed assumptions on vessel operating efficiencies causes a reduction of fuel consumption compared with the original EXTREMIS estimates as in Table 3.11.

Table 3.11 Correction factors applied to fuel consumption as in the EXTREMIS database

Period	2005- 2020	2020 - 2030	2030 - 2050
Correction factor	-22%	-20%	-32%

3.5. Comparison of the base year (2005) emissions with the results of other studies

In recent years several studies have been carried out, which estimated emissions from European seas. These include: ENTEC/IIASA study (Cofala, et al., 2007), TML study (De Ceuster, 2006), the CONCAWE/ENTEC study for the Mediterranean Sea (CONCAWE, 2007), and MARIN, 2011. We made a comparison of our estimates with the emissions reported in earlier work. A clear problem at the start was that the studies do not always use the same definitions of sea regions. This is particularly a case with area designated as the North East Atlantic, as well as with the coverage of the North Sea. The ENTEC/IIASA study combines the North Sea with the English Channel (because the North Sea SECA includes the English Channel), whereas the TML study separates the two. In our comparisons we ensured that the regional differentiation of shipping emissions was consistent. This meant in particular ensuring a proper aggregation of data for the North Sea and the English Channel and using the Atlantic (EMEP) area defined in the ENTEC/IIASA study (see Figure 1).

Table 3.12 provides a summary of NO_x and SO_2 emissions along the international shipping routes and at the ports, and the comparison in terms of percentage differences. There are quite high differences between emissions as estimated in the ENTEC/IIASA study and the current one. The differences among other estimates are within ± 10 to 20%. One obvious reason for differences is that the estimates are for different years. Other are caused by different assumptions about activity levels, fuel consumption and emission factors used in the inventories. Recent work by MARIN (MARIN, 2011) for the North Sea and the English Channel used data on ship movement form the Lloyd's Maritime Intelligence Unit (LMIU) Automatic Information System (AIS). Their estimate is quite consistent with our assessment, which is based on the EXTREMIS database. The difference between the MARIN and the ENTEC/IIASA estimates is mainly due to lower sailing speed in MARIN and thus lower fuel consumption compared with the assumptions adopted by ENTEC. Also the CONCAWE/ENTEC update of the emission inventory for the Mediterranean Sea came up with lower emissions than the earlier ENTEC/IIASA study. The CONCAWE/ENTEC estimate is in line with the EEE approach, which was a basis for estimates used in our study.

One needs to stress quite high uncertainties related to the assessment of emissions from maritime activities, which is at least ± 20%.

Table 3.12 Comparison of SO_2 and NO_x emissions from different sources

Source	year	Pollutant	Atlantic (EMEP)	Baltic Sea	Black Sea	Mediterranean Sea	North Sea + English Channel	Total
kilotons								
ENTEC/IIASA (Cofala et al., 2007)	2000	NOx	706	312	90	1813	755	3676
		SO2	482	223	66	1274	541	2586
TML (De Ceuster, 2006)	2005	NOx	537	236		1348	429	2549
		SO2	375	172		990	312	1849
EEE (Chiffi et al., 2007)	2005	NOx	551	220	47	1170	518	2505
		SO2	326	130	27	691	309	1482
CONCAWE, 2007	2005	NOx				1447		
		SO2				863		
MARIN, 2011	2009	NOx					471	
This study	2005	NOx	550	220	47	1294	518	2629
		SO2	327	130	27	764	309	1557
Relative difference, %								
ENTEC/IIASA (Cofala et al., 2007)	2000	NOx	-22%	-29%	-48%	-29%	-31%	-28%
		SO2	-32%	-42%	-59%	-40%	-43%	-40%
TML (De Ceuster, 2006)	2005	NOx	3%	-7%		-4%	21%	3%
		SO2	-13%	-24%		-23%	-1%	-16%
EEE (Chiffi et al., 2007)	2005	NOx	0%	0%	1%	11%	0%	5%
		SO2	0%	0%	1%	11%	0%	5%
CONCAWE, 2007	2005	NOx				-11%		
		SO2				-11%		
MARIN, 2011	2009	NOx					10%	

3.6. Scenario Analysis

3.6.1. Scenario definitions

In consultation with the European Commission, we explored nine different scenarios to assess the impact of technical and non-technical measures on the emissions of air pollutants from European seas and their spatial distribution (Table 3.13). We begin with the Baseline scenario, which takes into account the "Current legislation" emission control requirements, including IMO MARPOL ANNEX VI standards for fuel quality and NO_x emissions. The current legislation takes into account existing SECAs in the Baltic Sea and the North Sea[6]. Next, we simulate the effects of new SECAs and ECAs with different spatial coverage. We also look at the effects of controlling PM emissions through installing PM filters. Finally, we look at the potential emission reductions through implementation of speed restrictions (slow steaming) in various sea zones. We have also prepared a sensitivity that demonstrates the effects of using liquefied natural gas (LNG) as a fuel.

There are different marine zones identified by the United Nations Convention on the Law of the Sea (LOSC): the internal waters (ports), the territorial sea, archipelagic waters (for archipelagic States), the contiguous zone, the exclusive economic zone (EEZ) and the continental shelf. Beyond these maritime zones are the high seas (Figure 3.9). The scope of a coastal State's enforcement and legislative jurisdiction generally diminishes the further a ship is from the coast. For the scenario analysis we distinguish between the following sea zones:

- within the internal waters and the territorial seas (12nm from the internal waters' boundary),
- within the exclusive economic zones (200nm from the internal waters' boundary),
- outside the exclusive economic zones (high seas).

Most coastal States have adopted legislation concerning all the maritime zones they can establish. It is important to note that the Member States with coasts in the Mediterranean have not established EEZs there. For the scenario work we use the unofficial EEZ boundaries as in the GIS databases developed by Flanders Marine Institute (VLIZ) - http://www.vliz.be/vmdcdata/marbound/).

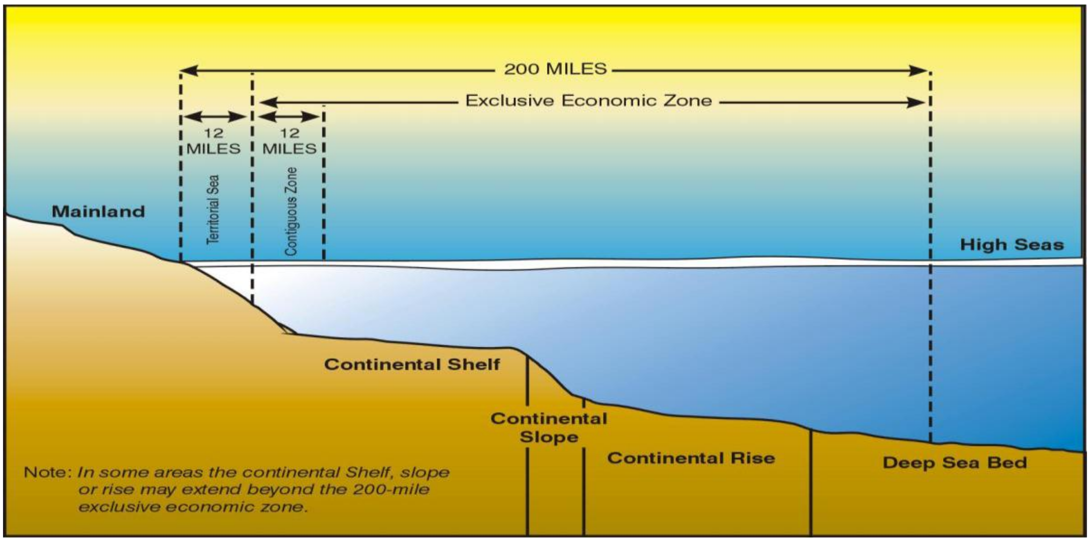


Figure 3.9 The divisions of the seas and oceans pursuant to United Nations Convention on the Law of the Sea (LOSC)

Scenarios 1 and 2 explore effects of implementing SECAs and NECAs in 12 nm and 200 nm zones of European seas. **Scenarios 3 to 5** look at the effects of controlling emissions in the

[6] In our simulations the North Sea region always includes the English Channel

Mediterranean Sea and the Black Sea. **Scenario 6** and its variants look at the effects of slow steaming, leaving emission control requirements at the current legislation level. **Scenario 7** demonstrates the scope for PM reduction through installing PM filters. **Scenario 8** is the Maximum Technically Feasible Reductions scenario (MTFR). In this case, all technically possible control measures are installed not only on new marine vessels but also on existing ones up to the applicability limits. **Scenario 9** (Maximum Control Efforts – MCE) combines the MTFR assumptions with slow steaming in all regions of the European seas.
It needs to be stressed that all scenarios take into account only measures on top of “Current legislation”. Overview of the scenarios is presented in Table 3.13.

Table 3.13 Scenarios to explore the impact of measures on international shipping emissions

Scenario number	Short description	Long description
1	NECA in BAS, NOS, and Territorial Seas (12 nm); SECA in Territorial Seas (12 nm)	NECA added to existing SECA in the Baltic (BAS) and the North Sea (NOS), combined SECA + NECA in Territorial Seas (12 nm) in the Celtic Sea, the Bay of Biscay, the Mediterranean Sea (MED) (without Turkey), and the Black Sea (BLACK_SEA) along the (BG and ROM coast line - Figure 3.10. plus variant 1 – NECA only in the Baltic and North Seas
2	NECA and SECA in EEZ (200 nm)	NECA added to existing SECA in the Baltic and North Seas, combined SECA + NECA for in the EEZs (200 nm) in the Celtic Sea, the Bay of Biscay, the Mediterranean Sea (without Turkey), and the Black Sea (BG and ROM coast line) Figure 3.11
3	NECA in EEZ (200 nm) except MED; SECA in EEZ (200 nm)	NECA added to existing SECA in the Baltic and North Seas, combined SECA + NECA in EEZs (200 nm) in the Celtic Sea, the Bay of Biscay and the Black Sea (BG and ROM coast line); for the Mediterranean Sea only a SECA in the EEZ (200 nm) (Figure 3.12)
4	NECA in EEZ (200 nm); SECA in EEZ (200 nm) except MED	NECA added to existing SECA in the Baltic and the North Sea, combined SECA + NECA in EEZ (200 nm) in the Celtic Sea, the Bay of Biscay, the Mediterranean Sea (without Turkey), and the Black Sea (BG and ROM coast line); for the Mediterranean Sea only a NECA in the EEZs (200 nm) of EU countries (Figure 3.13)
5	NECA and SECA in MED and BLACK_SEA	SECA and NECA for the whole Mediterranean Sea and the Black Sea (Figure 3.14)
6	Slow steaming	Steaming restrictions within the Territorial Seas (12 nm) (Figure 3.15), plus variant 1: restrictions within the EEZs (200 nm) (Figure 3.16) and variant 2: - restrictions in the Mediterranean and Black Seas (Figure 3.17)
7	PM filters and NECA in BAS, NOS, MED, and BLACK_SEA; SECA in MED and BLACK_SEA	Particle filters and NECA in the Baltic, Black, Mediterranean, and North Seas, new SECAs in the Mediterranean and Black Seas (Figure 3.18)
8	MTFR	Maximum Technically Feasible Emission Reductions (MTFR): SECA and NECA limits, and PM filters are introduced for the entire TNO maritime area grid. This scenario assumes retrofitting of pre-2016 vessels up to available potential (Figure 3.19)
9	MCE	Maximum Control Efforts scenario (MCE), whereby steaming restrictions are added to the MTFR measures for the entire TNO maritime area grid (Figure 3.20)

3.6.2. SCENARIO MAPS SHOWING THE SPATIAL EXTENT OF MEASURES

The following maps illustrate the spatial extent of the measures assumed for each scenario.

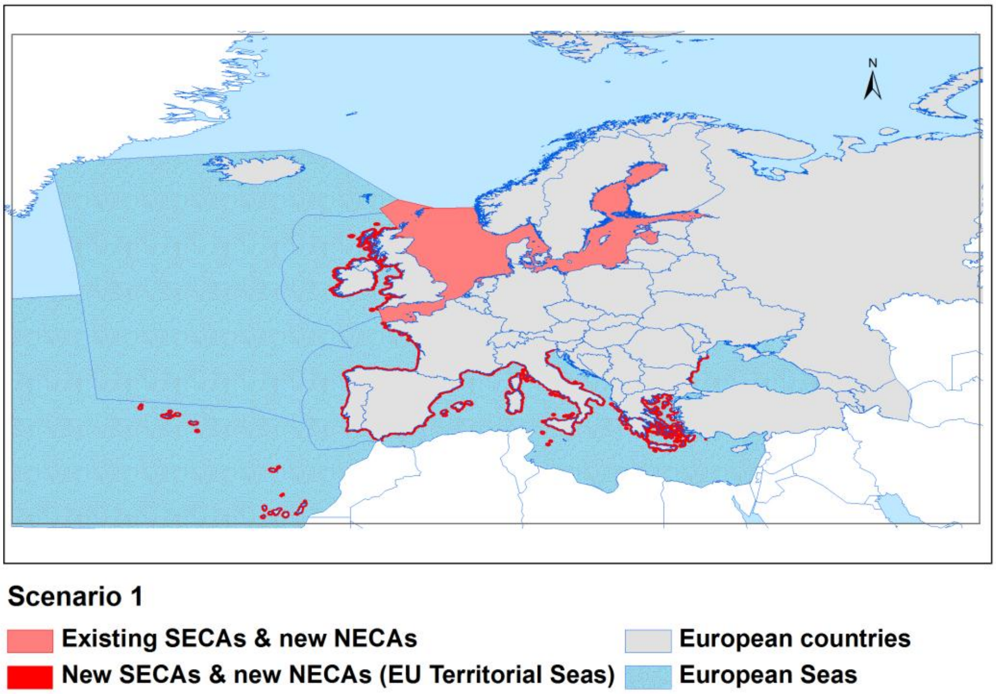


Figure 3.10 Scenario 1 - NECAs for the Baltic and North Seas plus NECAs and SECAs in the 12 nm zone

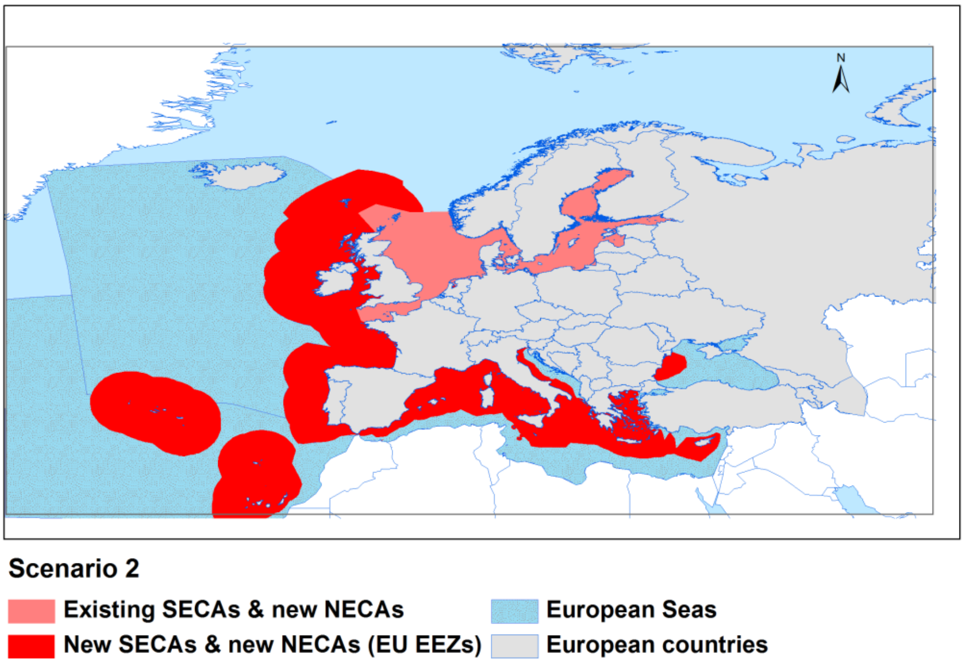


Figure 3.11 Scenario 2 - NECAs and SECAs in 200 nm sea zones of EU-27

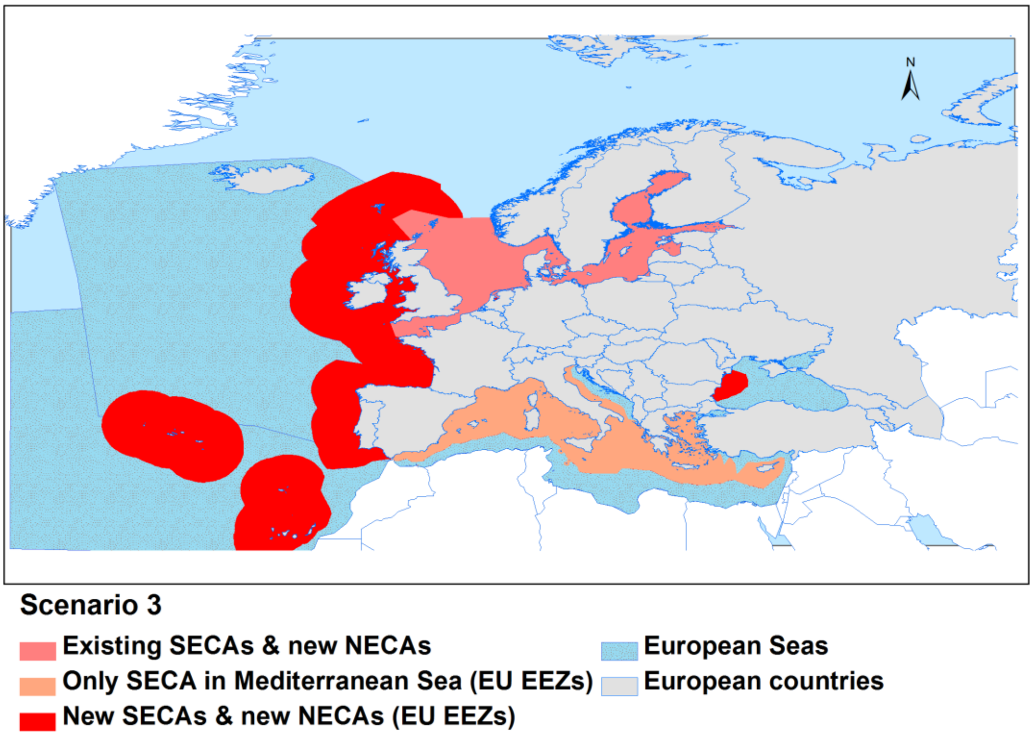


Figure 3.12 Scenario 3 - SECAs + NECAs for 200 nm zones of EU-27. For the Mediterranean Sea only a SECA

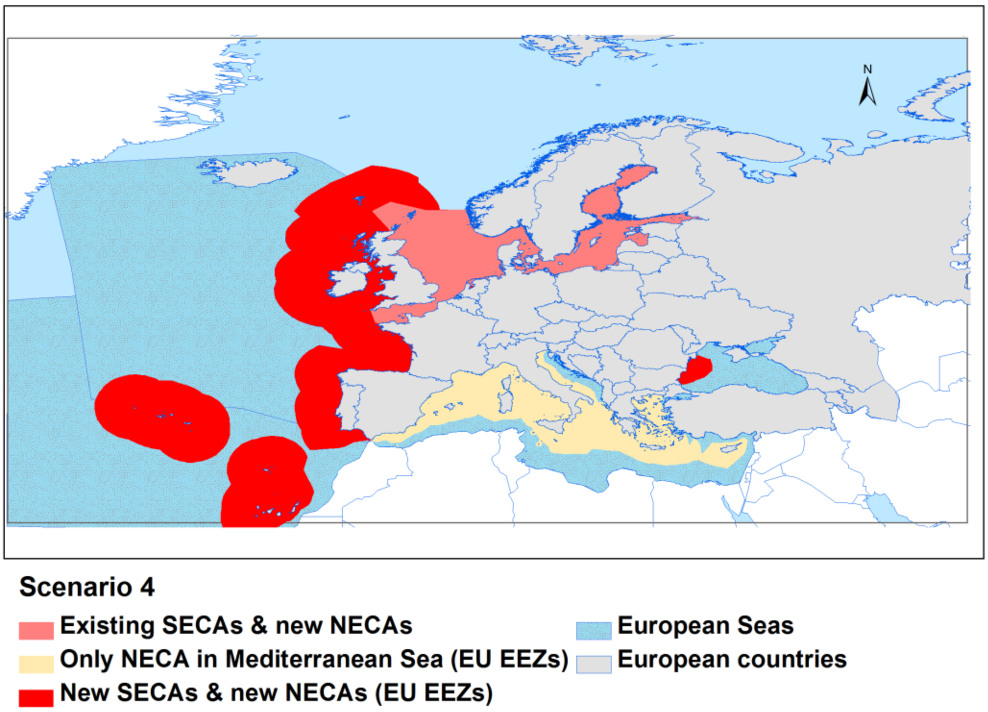


Figure 3.13 Scenario 4 - SECAs + NECAs for 200 nm zones of EU-27. For the Mediterranean Sea only a NECA

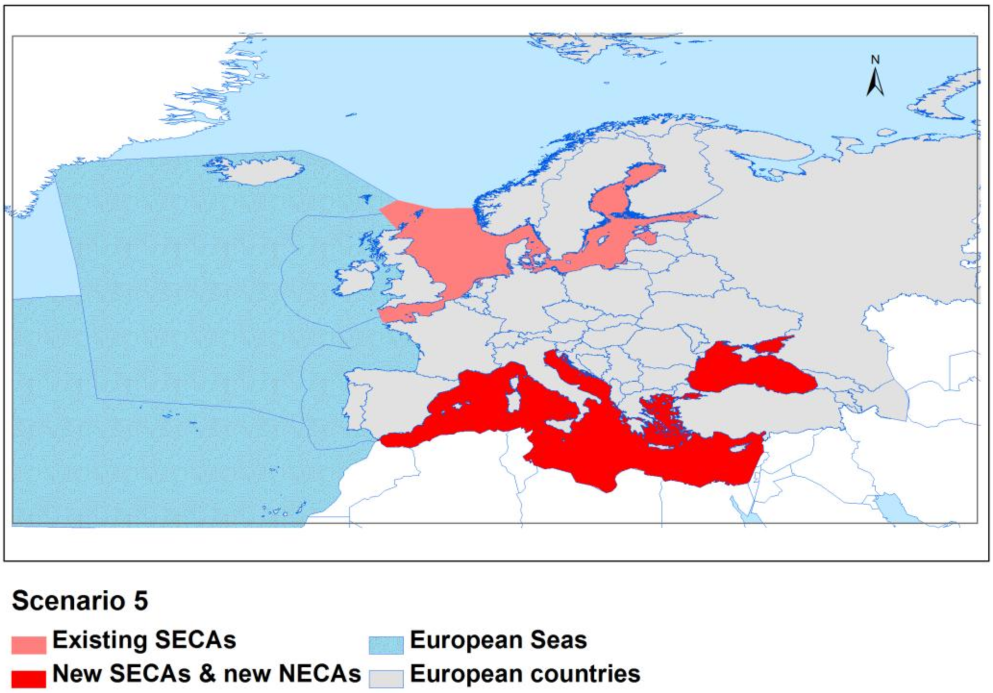


Figure 3.14 Scenario 5 – SECA + NECA for the Mediterranean and Black Seas

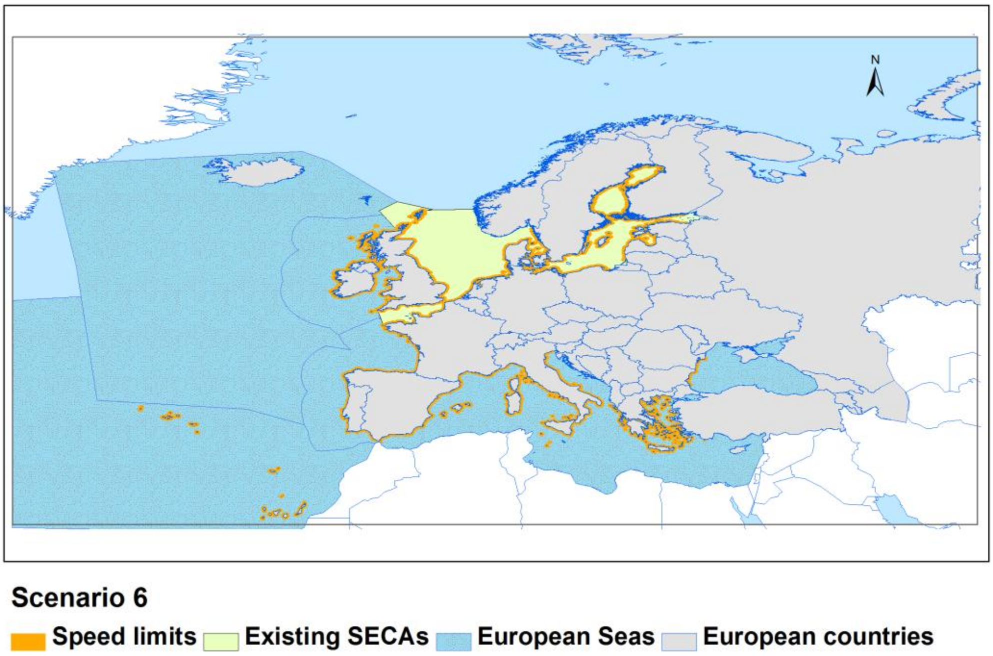


Figure 3.15 Scenario 6 - Steaming restrictions within the 12 nm zone of all seas

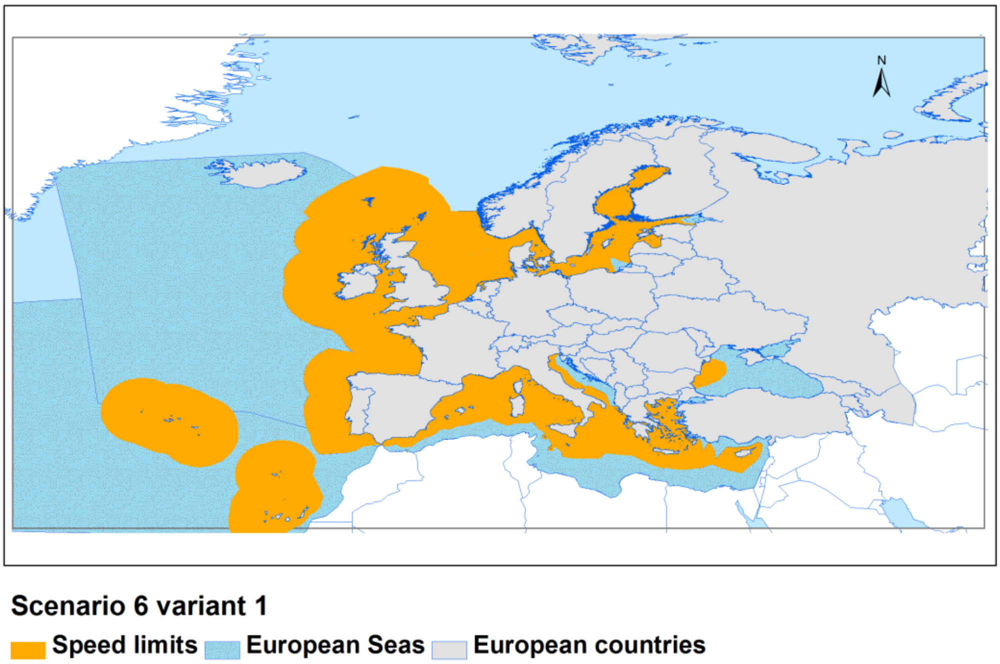


Figure 3.16 Scenario 6 (variant 1) - steaming restrictions within the 200 nm zone of all seas

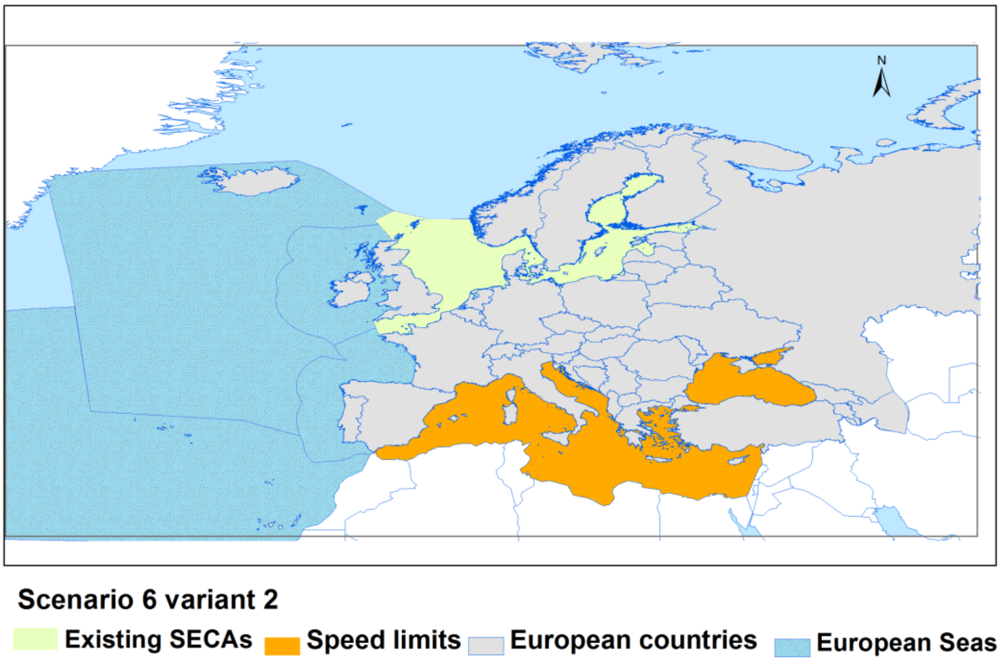


Figure 3.17 Scenario 6 (variant 2) - steaming restrictions in the Mediteranean and Black Seas

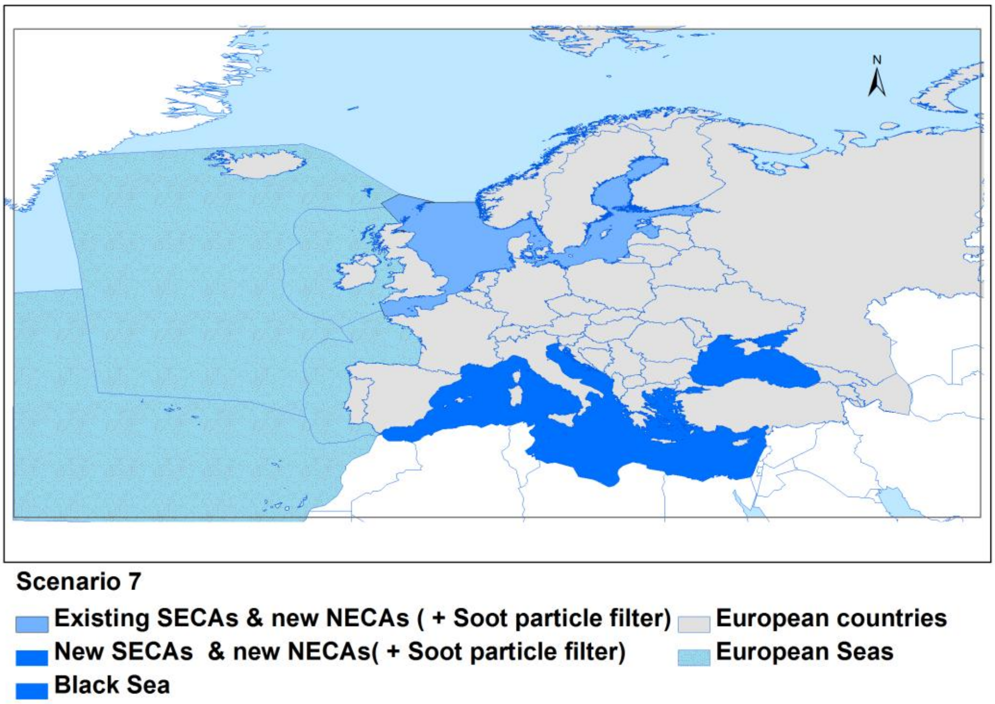


Figure 3.18 Scenario 7 Particle filters for the Baltic, Black, Mediteranean, North Seas on top of SECAs and NECAs

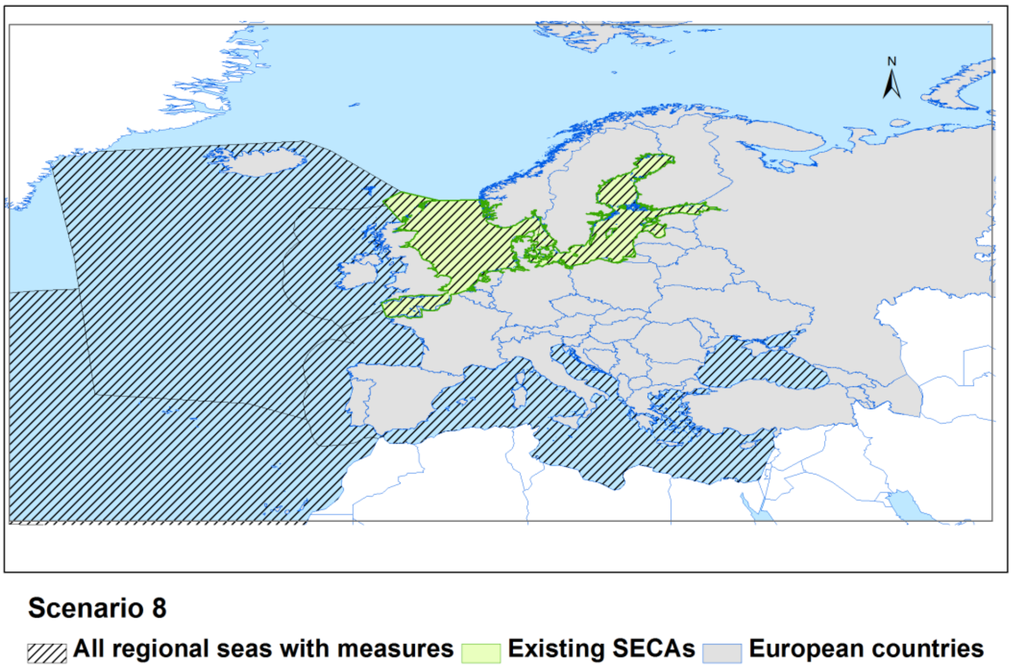


Figure 3.19 Scenario 8 - Maximum Technically Feasible Emission Reductions (MTFR); SECA and NECA limits and PM filters in the entire TNO maritime area grid

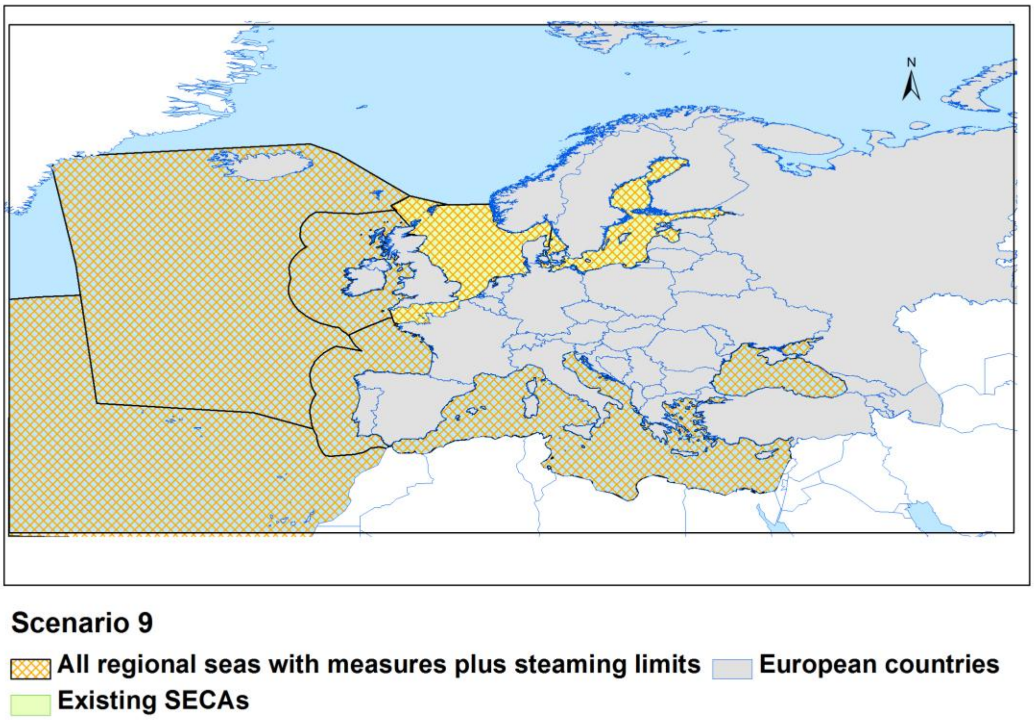


Figure 3.20 Scenario 9 - Maximum Control Efforts (MCE); MTFR measures are combined with slow steaming for the entire TNO maritime area grid

CHAPTER 4 EMISSIONS AND COSTS OF SCENARIOS

4.1. BASELINE PROJECTIONS

In this section, we present the emissions of air pollutants from international shipping for 2020, 2030 and 2050 (Table 4.1 to Table 4.4). The emissions are compared with the emissions in the base year - 2005. We concentrate on emissions of NO_x, SO_2, $PM_{2.5}$ and black carbon (BC). Emissions of other pollutants, which needed to be assessed in order to run the EMEP atmospheric chemistry model, were also calculated assuming emission factors per unit of fuel used, as shown in the Annex I. Details by sea region, year and zone (ports/berthing/12 nm, 200 nm, and open seas) are shown in Annex II.

According to our assessment, ships involved in international maritime transport on European seas emitted in 2005 2.8 million tons of NO_x, 1.7 million tons of SO_2, and 195 thousand tons of fine particles (PM2.5). Assumptions as in the baseline projection, which assumes implementation of measures according to the "Current legislation", cause a decrease of NO_x emissions up to 2020 by 13 %, and a drastic decrease of emissions of sulfur dioxide to less than 300 thousand tons, i.e., by more than 80%. The latter is due to the requirement to reduce sulfur content of marine fuels to 0.1% in SECAs and 0.5% S in other sea regions. Fuel quality improvement causes also a 35% decrease in the emissions of PM2.5. The highest decrease in the emissions of SO_2 and PM2.5 occurs in the SECA regions (the Baltic and North Seas plus English Channel).

After 2020 the baseline emissions increase, which is due to higher fuel consumption caused by increasing activity. In 2030, the baseline emissions of NO_x are 13 % higher than in 2020. The increase in emissions of SO_2 and PM 2.5 (about 19%) is in line with the increase in fuel consumption (compare Table 4.5). Up to 2050, the emissions continue to increase and are approximately 40 – 50% higher than in 2020. Emissions of black carbon slightly decrease up to 2020 and then start to increase proportionally to the increase in fuel consumption.

Table 4.1 Baseline emissions of NO_x from international shipping by sea region (kt)

Measures applied	Current legislation			
Scenario number or name	Baseline			
Sea regions	2005	2020	2030	2050
Baltic Sea	220	183	202	250
Bay of Biscay	474	425	488	633
Black Sea	47	39	44	54
Celtic Sea	22	18	20	23
Mediterranean Sea	1294	1116	1255	1587
North Sea (+ English Channel)	518	449	503	627
Rest of NE Atlantic (within EMEP grid)	54	48	54	69
Rest of NE Atlantic (TNO grid outside EMEP)	192	172	196	250
Total	2821	2450	2762	3494

Table 4.2 Baseline emissions of SO_2 from international shipping by sea region (kt)

Measures applied	Current legislation			
Scenario number or name	Baseline			
Sea regions	2005	2020	2030	2050
Baltic Sea	130	6	7	9
Bay of Biscay	282	65	78	103
Black Sea	27	6	8	10
Celtic Sea	14	2	2	3
Mediterranean Sea	764	167	198	254
North Sea (+ English Channel)	309	15	17	22
Rest of NE Atlantic (within EMEP grid)	31	7	9	11
Rest of NE Atlantic (TNO grid outside EMEP)	112	26	30	40
Total	1668	293	349	452

Table 4.3 Baseline emissions of PM2.5 from international shipping by sea region (kt)

Measures applied	Current legislation			
Scenario number or name	Baseline			
Sea regions	2005	2020	2030	2050
Baltic Sea	14.2	8.7	10.1	12.8
Bay of Biscay	34.0	22.8	27.3	36.0
Black Sea	2.9	1.9	2.2	2.8
Celtic Sea	1.5	0.9	1.1	1.3
Mediterranean Sea	87.4	57.0	67.3	86.3
North Sea (+ English Channel)	36.5	22.5	26.4	33.5
Rest of NE Atlantic (within EMEP grid)	3.7	2.5	2.9	3.8
Rest of NE Atlantic (TNO grid outside EMEP)	13.8	9.2	10.9	14.2
Total	193.9	125.5	148.3	190.7

Table 4.4 Baseline emissions of BC from international shipping by sea region (kt)

Measures applied	Current legislation			
Scenario number or name	Baseline			
Sea regions	2005	2020	2030	2050
Baltic Sea	0.6	0.5	0.6	0.7
Bay of Biscay	1.2	1.3	1.5	2.0
Black Sea	0.1	0.1	0.1	0.2
Celtic Sea	0.1	0.1	0.1	0.1
Mediterranean Sea	3.3	3.4	4.0	5.2
North Sea (+ English Channel)	1.3	1.1	1.3	1.6
Rest of NE Atlantic (within EMEP grid)	0.1	0.1	0.2	0.2
Rest of NE Atlantic (TNO grid outside EMEP)	0.5	0.5	0.6	0.8
Total	7.2	7.1	8.4	10.8

Table 4.5 Baseline fuel consumption by international shipping in different sea regions (kt)

Scenario number or name	Baseline			
Sea regions	2005	2020	2030	2050
Baltic Sea	2,968	3,101	3,659	4,663
Bay of Biscay	6,138	6,565	7,904	10,426
Black Sea	644	670	791	996
Celtic Sea	311	320	368	444
Mediterranean Sea	17,260	18,258	21,861	28,482
North Sea (+ English Channel)	6,791	7,103	8,372	10,608
Rest of NE Atlantic (within EMEP grid)	695	736	881	1,147
Rest of NE Atlantic (TNO grid outside EMEP)	2,459	2,619	3,135	4,079
Total	37,266	39,372	46,971	60,844

4.1.1. COMPARISON OF LAND BASED AND INTERNATIONAL SHIPPING EMISSIONS

In 2005, NO_x and SO_2 emissions from international shipping were equivalent to about 25% and 21% of the land-based emissions from EU-27 (Figure 4.1 and Figure 4.2). Whereas the emissions of NO_x from land sources are expected to decrease up to 2030 by more than 65%, the baseline emissions from shipping decrease only by 2%. Thus, their share in relation to the land-based emissions will increase to 70%. Up to 2050, under the "Current legislation" assumptions, the NO_x emissions from shipping are likely to exceed the emissions from land sources. Implementation of strict sulfur standards on marine fuels causes a decrease of SO_2 emissions by 80 %. Although the land emissions of SO_2 will also fall by 72%until 2030, the relation of shipping emissions to land based is expected to remain lower than in2005.

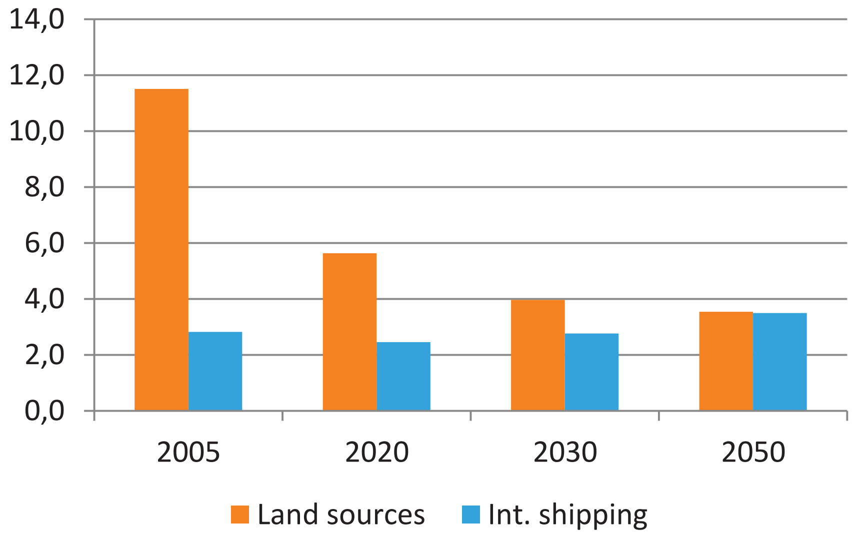


Figure 4.1 Comparison of land based and international shipping emissions of NO_x (kt)

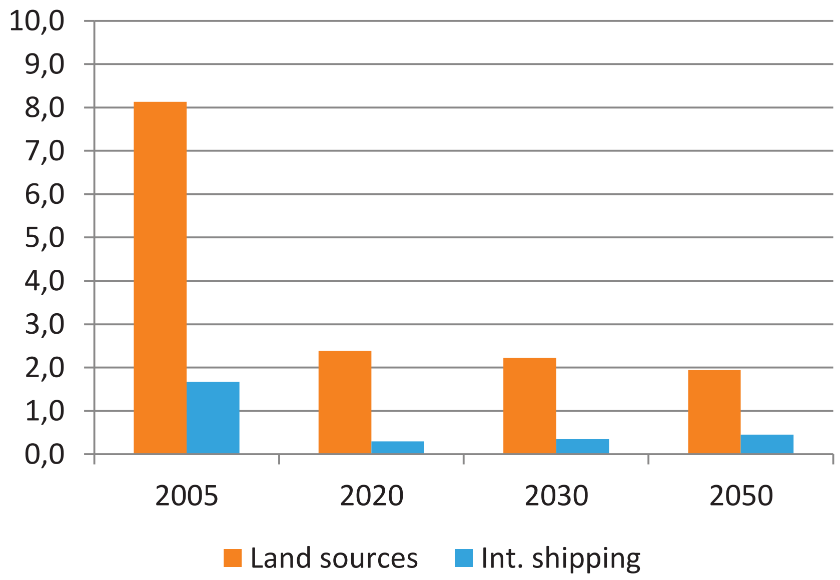


Figure 4.2 Comparison of land based and international shipping emissions of SO_2 (kt)

4.2. SCENARIO RESULTS

4.2.1. SECAS AND NECAS IN TERRITORIAL WATERS AND EXCLUSIVE ECONOMIC ZONES

This section presents the effects of imposing SECA and NECA legislation on territorial waters and exclusive economic zones of the EU Member States - Scenario 1 and 2. Emissions by sea regions are shown in Table 4.6 to Table 4.8. In Scenario 1, we assume that NECA standards are introduced in the Baltic and North Seas, on top of already existing SECA legislation. In all other sea regions the ECAs (for both: sulfur and nitrogen oxides) are implemented in territorial seas of the EU Member States (12 nm zone). This causes a decrease of total emissions of NO_x from the European seas by 6% in 2020 compared with the Baseline and 17% in 2030. In 2050 this decrease – relative to the Baseline - is 27%. SECA sulfur limits cause about 7% decrease in the total emissions of SO_2 from European shipping in all years, and, as a side effect, about 0.5% decrease in the emissions of PM.

Implementation of NECA legislation in the Baltic and North Seas only (Scenario 1 var.1) reduces the emissions of NO_x in those regions by 27% in 2020, 47% in 2030, and 66% in 2050. Finally, SECA and NECA legislation in the 200 nm zones of all EU countries causes a reduction of the total emissions from European seas in 2020 by 12% for NO_x, 47% for SO_2, and 3% for PM2.5 compared to the Baseline case. For NO_x, the reduction increases with time to 35% in 2030 and 56% in 2050. Higher future reductions are due to increasing share of new ships, which need to meet Tier III standards in NECA regions.

Table 4.6 Emissions of NO_x for different variants of NECAs and SECAs (kt)

Measures applied	NECA in BAS, NOS			NECA in BAS, NOS, and 12 NM; SECA in 12 nm			NECA and SECA in 200 nm		
Scenario number or name	Scenario 1 var 1			Scenario 1			Scenario 2		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	154	108	63	154	108	63	154	108	63
Bay of Biscay	425	488	633	420	471	597	357	265	170
Black Sea	39	44	54	39	43	52	37	38	42
Celtic Sea	18	20	23	17	15	15	15	11	6
Mediterranean Sea	1116	1255	1587	1083	1149	1358	1010	916	891
North Sea (+ English Channel)	376	269	159	376	269	159	376	269	159
Rest of NE Atlantic (within EMEP grid)	48	54	69	48	54	69	48	54	69
Rest of NE Atlantic (TNO grid outside EMEP)	172	196	250	170	191	240	153	135	124
Total	2348	2434	2838	2307	2300	2553	2150	1796	1525

Table 4.7 Emissions of SO_2 for different variants of NECAs and SECAs (kt)

Measures applied	NECA in BAS, NOS			NECA in BAS, NOS, and 12 NM; SECA in 12 nm			NECA and SECA in 200 nm		
Scenario number or name	Scenario 1 v.1			Scenario 1			Scenario 2		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	6	7	9	6	7	9	6	7	9
Bay of Biscay	65	78	103	61	74	97	14	17	23
Black Sea	6	8	10	6	7	9	5	6	8
Celtic Sea	2	2	3	2	2	2	1	1	1
Mediterranean Sea	167	198	254	152	180	230	95	113	145
North Sea (+ English Channel)	15	17	22	15	17	22	15	17	22
Rest of NE Atlantic (within EMEP grid)	7	9	11	7	9	11	7	9	11
Rest of NE Atlantic (TNO grid outside EMEP)	26	30	40	25	30	39	12	15	19
Total	293	349	452	274	326	421	156	185	238

Table 4.8 Emissions of PM2.5 for different variants of NECAs and SECAs (kt)

Measures applied	NECA in BAS, NOS			NECA in BAS, NOS, and 12 NM; SECA in 12 nm			NECA and SECA in 200 nm		
Scenario number or name	Scenario 1 v.1			Scenario 1			Scenario 2		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	8.7	10.1	12.8	8.7	10.1	12.8	8.7	10.1	12.8
Bay of Biscay	22.8	27.3	36.0	22.7	27.2	35.8	21.4	25.6	33.7
Black Sea	1.9	2.2	2.8	1.9	2.2	2.7	1.9	2.2	2.7
Celtic Sea	0.9	1.1	1.3	0.9	1.0	1.3	0.9	1.0	1.2
Mediterranean Sea	57.0	67.3	86.3	56.7	66.8	85.7	55.1	65.0	83.4
North Sea (+ English Channel)	22.5	26.4	33.5	22.5	26.4	33.5	22.5	26.4	33.5
Rest of NE Atlantic (within EMEP grid)	2.5	2.9	3.8	2.5	2.9	3.8	2.5	2.9	3.8
Rest of NE Atlantic (TNO grid outside EMEP)	9.2	10.9	14.2	9.2	10.9	14.2	8.8	10.5	13.6
Total	125.5	148.3	190.7	125.0	147.7	189.9	121.7	143.7	184.8

4.3. SECA AND NECA STANDARDS IN THE MEDITERRANEAN AND BLACK SEAS

This series of scenarios looks at the effects of imposing ECA legislation in seas surrounding Southern Europe (the Mediterranean and Black Seas). Three scenarios have been assessed. We simulate the implementation of ECA legislation in EU EEZs making exceptions for the Mediterranean Sea either from the NECA (Scenario 3) or from the SECA legislation (Scenario 4). In Scenario 5, we demonstrate the effects of SECA and NECA standards on the entire area of these two seas. Results are presented in Table 4.9 to Table 4.11. Since the share of the Mediterranean Sea in total European emissions is rather high (45% of SO_2 and 55% of NO_x in the 2030 Baseline), measures applied in this region have an important effect on the totals. In Scenario 3, with no NECA in the EU EEZs of the Mediterranean Sea in 2030, the emissions of NO_x would have been 340 kt higher compared with scenario 2, which assumes enforcing Tier III (NECA) standards. Similarly, the emissions of SO_2 would have been by 85 kt higher in case of missing SECA legislation in the EU EEZs of the Mediterranean Sea.

In Scenario 5 SECA and NECA are assumed for the whole area of the Mediterranean and Black Seas. However, emissions from other regions remain at the Baseline level. Thus, in spite of large reduction of emissions from southern seas (606 kt of NO_x and 160 kt of SO_2 in 2030) total emissions from shipping are higher than in Scenario 2, which assumes SECA and NECA standards in EEZ in all seas.

Table 4.9 Emissions of NO_x for variants of NECAs and SECAs in the Mediterranean and Black Sea (kt)

Measures applied	NECA in 200 nm except MED; SECA in 200 nm			NECA in 200 nm; SECA in 200 nm except MED			NECA and SECA in MED and BLACK_SEA		
Scenario number or name	Scenario 3			Scenario 4			Scenario 5		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	154	108	63	154	108	63	183	202	250
Bay of Biscay	357	265	170	357	265	170	425	488	633
Black Sea	37	38	42	37	38	42	33	23	14
Celtic Sea	15	11	6	15	11	6	18	20	23
Mediterranean Sea	1116	1255	1587	1010	916	891	933	670	401
North Sea (+ English Channel)	376	269	159	376	269	159	449	503	627
Rest of NE Atlantic (within EMEP grid)	48	54	69	48	54	69	48	54	69
Rest of NE Atlantic (TNO grid outside EMEP)	153	135	124	153	135	124	172	196	250
Total	2255	2135	2221	2150	1796	1525	2261	2156	2268

Table 4.10 Emissions of SO_2 for variants of NECAs and SECAs in the Mediterranean and Black Sea (kt)

Measures applied	NECA in 200 nm except MED; SECA in 200 nm			NECA in 200 nm; SECA in 200 nm except MED			NECA and SECA in MED and BLACK_SEA		
Scenario number or name	Scenario 3			Scenario 4			Scenario 5		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	6	7	9	6	7	9	6	7	9
Bay of Biscay	14	17	23	14	17	23	65	78	103
Black Sea	5	6	8	5	6	8	1	2	2
Celtic Sea	1	1	1	1	1	1	2	2	3
Mediterranean Sea	95	113	145	167	198	254	37	44	57
North Sea (+ English Channel)	15	17	22	15	17	22	15	17	22
Rest of NE Atlantic (within EMEP grid)	7	9	11	7	9	11	7	9	11
Rest of NE Atlantic (TNO grid outside EMEP)	12	15	19	12	15	19	26	30	40
Total	156	185	238	227	270	348	158	189	247

Table 4.11 Emissions of PM2.5 for variants of NECAs and SECAs in the Mediterranean and Black Sea (kt)

Measures applied	NECA in 200 nm except MED; SECA in 200 nm			NECA in 200 nm; SECA in 200 nm except MED			NECA and SECA in MED and BLACK_SEA		
Scenario number or name	Scenario 3			Scenario 4			Scenario 5		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	8.7	10.1	12.8	8.7	10.1	12.8	8.7	10.1	12.8
Bay of Biscay	21.4	25.6	33.7	21.4	26.9	35.5	22.8	27.3	36.0
Black Sea	1.9	2.2	2.7	1.9	2.2	2.7	1.8	2.1	2.6
Celtic Sea	0.9	1.0	1.2	0.9	0.7	0.9	0.9	1.1	1.3
Mediterranean Sea	55.1	65.0	83.4	57.0	67.3	86.3	53.5	63.1	81.0
North Sea (+ English Channel)	22.5	26.4	33.5	22.5	26.4	33.5	22.5	26.4	33.5
Rest of NE Atlantic (within EMEP grid)	2.5	2.9	3.8	2.5	2.9	3.8	2.5	2.9	3.8
Rest of NE Atlantic (TNO grid outside EMEP)	8.8	10.5	13.6	8.8	10.6	13.8	9.2	10.9	14.2
Total	121.7	143.7	184.8	123.6	147.1	189.3	121.8	144.0	185.2

4.4. Effects of slow steaming

Table 4.12 to Table 4.14 present the emissions for the cases when slow steaming restrictions are applied to different sea regions and zones. Implementation of speed restrictions to the EEZs (200 nm) bring quite important reductions in emissions from European maritime activities: 22% for NO_x, and about 18 % for SO_2 and PM. In case of introduction of slow steaming in the Mediterranean Sea and the Black Sea the reductions in emissions within the regions are about 30%, which causes a decrease of total emissions from all European seas by more than 15 % for NO_x, 17% for SO_2, and 12% for PM2.5.

Table 4.12 Emissions of NO_x for different slow steaming scenarios (kt)

Measures applied	Slow steaming in 12 nm			Slow steaming in 200 nm			Slow steaming in MED and BLACK_SEA		
Scenario number or name	Scenario 6			Scenario 6 v.1			Scenario 6 v.2		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	170	187	232	143	157	194	183	202	250
Bay of Biscay	420	481	624	282	323	419	425	488	633
Black Sea	39	44	54	36	40	49	26	29	36
Celtic Sea	18	19	23	15	16	18	18	20	23
Mediterranean Sea	1091	1228	1551	932	1049	1326	763	860	1090
North Sea (+ English Channel)	432	484	604	320	357	443	449	503	627
Rest of NE Atlantic (within EMEP grid)	48	54	69	45	52	66	48	54	69
Rest of NE Atlantic (TNO grid outside EMEP)	171	194	248	133	151	193	172	196	250
Total	2389	2692	3405	1906	2144	2709	2085	2351	2979

Table 4.13 Emissions of SO_2 for different slow steaming scenarios (kt)

Measures applied	Slow steaming in 12 nm			Slow steaming in 200 nm			Slow steaming in MED + BLACK_SEA		
Scenario number or name	Scenario 6			Scenario 6 v.1			Scenario 6 v.2		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	6	7	9	5	6	8	6	7	9
Bay of Biscay	64	77	101	46	55	73	65	78	103
Black Sea	6	8	10	6	7	9	5	5	7
Celtic Sea	2	2	3	1	2	2	2	2	3
Mediterranean Sea	163	194	249	141	168	216	119	141	182
North Sea (+ English Channel)	14	17	21	11	13	17	15	17	22
Rest of NE Atlantic (within EMEP grid)	7	9	11	7	8	11	7	9	11
Rest of NE Atlantic (TNO grid outside EMEP)	25	30	39	21	25	32	26	30	40
Total	288	343	444	238	284	367	243	290	376

Table 4.14 Emissions of PM2.5 for different slow steaming scenarios (kt)

Measures applied	Slow steaming in 12 nm			Slow steaming in 200 nm			Slow steaming in MED + BLACK_SEA		
Scenario number or name	Scenario 6			Scenario 6 v.1			Scenario 6 v.2		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	8.3	9.7	12.2	7.2	8.4	10.7	8.7	10.1	12.8
Bay of Biscay	22.7	27.1	35.7	16.7	19.9	26.3	22.8	27.3	36.0
Black Sea	1.9	2.2	2.7	1.7	2.0	2.5	1.4	1.6	2.0
Celtic Sea	0.9	1.0	1.3	0.8	0.9	1.1	0.9	1.1	1.3
Mediterranean Sea	56.3	66.4	85.1	49.7	58.6	75.2	42.5	50.2	64.6
North Sea (+ English Channel)	21.9	25.8	32.7	17.4	20.4	25.8	22.5	26.4	33.5
Rest of NE Atlantic (within EMEP grid)	2.5	2.9	3.8	2.4	2.8	3.7	2.5	2.9	3.8
Rest of NE Atlantic (TNO grid outside EMEP)	9.2	10.9	14.1	7.5	8.9	11.6	9.2	10.9	14.2
Total	123.6	146.0	187.8	103.3	122.0	156.8	110.5	130.6	168.3

4.5. Controls going beyond SECA and NECA standards

In this group of scenarios the effects of implementing particle filters on vessels operating in the Baltic, Black, Mediterranean and the North Seas are studied. The filters are introduced together with SECA and NECA standards in those regions. No retrofit of old vessels (pre-2016) is assumed.

The Maximum Technically Feasible (MTFR) scenario assumes implementation of SECA, NECA and PM filters in all European sea regions. This scenario includes the possibility of retrofitting of the "old" (pre-2016) vessels up to a limit of applicability (compare Section 3.3.1). Finally, the Maximum Control Efforts (MCE) scenario combines assumptions about MTFR controls with slow steaming in all sea regions.

Emission reductions for the three scenarios are shown in Table 4.15 to Table 4.17. Implementation of PM filters on new vessels reduces the emissions of PM2.5 by about 20 % in 2020 and 46% in 2030. The reduction in 2050 is 70%. MTFR scenarios bring quite important reductions compared with the Baseline (Current legislation) measures. SO_2 emissions decrease by 73%. Since the share of new and retrofitted vessels increases with time, the relative reductions of NO_x and PM2.5 also increase with time. In 2020, these reductions are 38% for NO_x and 30% for PM2.5. Up to 2030, they increase to more than two thirds. In 2050, 85% reductions in NO_x emissions and 99% reductions in the emissions of PM2.5 are achieved. The MCE scenario, which includes the effects of slow steaming, allows reducing the emission further. In 2030, the emissions of NO_x and SO_2 are only about 20% of the baseline level, and the emissions of PM2.5 are reduced by about three quarters.

Table 4.15 Emissions of NO_x for scenarios going beyond SECA and NECA standards (kt)

Measures applied	NECA BAS, NOS MED, BLACK_SEA; SECA MED, BLACK_SEA; PM filters in BAS, NOS, MED, BLACK_SEA			MTFR			MCE		
Scenario number or name	Scenario 7			Scenario 8			Scenario 9		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	154	108	63	113	63	38	88	49	29
Bay of Biscay	425	488	633	262	151	95	172	99	62
Black Sea	33	23	14	24	14	8	16	9	5
Celtic Sea	18	20	23	11	6	3	9	5	3
Mediterranean Sea	933	670	401	687	389	238	470	267	183
North Sea (+ English Channel)	382	269	159	277	156	94	197	111	66
Rest of NE Atlantic (within EMEP grid)	48	54	69	29	17	10	19	11	7
Rest of NE Atlantic (TNO grid outside EMEP)	172	196	250	106	61	38	69	40	24
Total	2164	1828	1612	1510	856	524	1040	589	380

Table 4.16 Emissions of SO_2 for scenarios going beyond SECA and NECA standards (kt)

Measures applied	NECA BAS, NOS MED, BLACK_SEA; SECA MED, BLACK_SEA; PM filters in BAS, NOS, MED, BLACK_SEA			MTFR			MCE		
Scenario number or name	Scenario 7			Scenario 8			Scenario 9		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	6	7	9	6	7	9	5	6	8
Bay of Biscay	65	78	103	13	16	21	9	11	15
Black Sea	1	2	2	1	2	2	1	1	1
Celtic Sea	2	2	3	1	1	1	1	1	1
Mediterranean Sea	37	44	57	37	44	57	27	32	46
North Sea (+ English Channel)	15	17	22	15	17	22	11	13	17
Rest of NE Atlantic (within EMEP grid)	7	9	11	1	2	2	1	1	2
Rest of NE Atlantic (TNO grid outside EMEP)	26	30	40	5	6	8	4	4	6
Total	158	189	247	79	95	123	59	70	95

Table 4.17 Emissions of PM2.5 for scenarios going beyond SECA and NECA standards (kt)

Measures applied	NECA BAS, NOS MED, BLACK_SEA; SECA MED, BLACK_SEA; PM filters in BAS, NOS, MED, BLACK_SEA			MTFR			MCE		
Scenario number or name	Scenario 7			Scenario 8			Scenario 9		
Sea regions	2020	2030	2050	2020	2030	2050	2020	2030	2050
Baltic Sea	7	4	0	7	4	0	6	3	0
Bay of Biscay	23	27	36	15	9	0	11	6	0
Black Sea	1	1	0	1	1	0	1	1	0
Celtic Sea	1	1	1	1	0	0	1	0	0
Mediterranean Sea	41	24	1	39	22	1	29	17	1
North Sea (+ English Channel)	17	10	0	17	10	0	13	8	0
Rest of NE Atlantic (within EMEP grid)	2	3	4	2	1	0	1	1	0
Rest of NE Atlantic (TNO grid outside EMEP)	9	11	14	6	4	0	4	3	0
Total	102	80	57	88	50	2	66	38	1

4.6. SENSITIVITY: IMPACT OF THE USE OF LNG ON AIR EMISSIONS

The international shipping emissions database is filtered to select only the trips related to the movement between the EU ports, which for the purpose of this sensitivity we define as short sea shipping (SSS). It represents around a quarter of the total fuel consumption of international shipping on European seas. The Danish Maritime Authority (DMA, 2012) predicts that the demand for new vessels will grow by about 4% per year. This means that by 2030, about 50% of vessels will be new builds (post-2016) and many of them may opt for LNG. Since the exact percentage of vessels that will be using LNG is uncertain, we developed two cases with the following assumptions:

1. In the first one, we adopt a rather conservative assumption that in 2030 about 10% of vessels will be LNG fueled and that this share will increase to 15% in 2050.
2. In the second one, we assume 50% uptake of LNG in 2030 and 100% in 2050.

Further, we assume that the LNG vessels have 90% lower emissions of NO_x and that the reduction of PM emissions is 98%. We assume that LNG vessels do not emit SO_2.

With these assumptions, we have developed two variants, which differ with spatial coverage of sea zones where LNG could potentially be applied. In the first variant we assume that LNG is used only in the Baltic Sea and the North Sea (with English Channel), i.e., in the regions, where the SSS is particularly dense. In the second one, we demonstrate the effects of using LNG for SSS in all European seas.

Table 4.18 presents the results for 2030 for the variant of LNG use only in the Baltic and the North Seas. With the LNG uptake of 10 %, the emissions would be lower by about 5%. For the 50% uptake, the emissions would decrease by about 25% compared with the Baseline. In 2050, with 100% uptake of LNG for SSS, the decrease in emissions would be more than 45%. (Table 4.19).

Table 4.18 Reduction of air emissions in 2030 in the Baltic Sea and the North Sea due to LNG use for SSS

	Fuel use, kt	Emissions, kt		
		NOx	SO2	PM2.5
Baseline				
Short sea shipping (SSS)	6495	353	13.0	18
Other shipping routes	5536	352	12	19
Total int. shipping	12031	705	25	37
Case 1: 10 % LNG uptake				
SSS-LNG	650	3.5	0.0	0.0
SSS-oil	5846	317.6	11.7	16.2
Total SSS	6495	321.1	11.7	16.2
Total int. shipping	12031	673	23	35
%reduction relative to Baseline	-	-4.5%	-5.3%	-4.8%
Case 2: 50% LNG uptake				
SSS-LNG	3248	17.6	0.0	0.0
SSS-oil	3248	176.4	6.5	9.0
Total SSS	6495	194.1	6.5	9.0
Total int. shipping	12031	546	18	28
%reduction relative to Baseline	-	-22.5%	-26.3%	-24.5%

Table 4.19 Reduction of air emissions in 2050 in the Baltic Sea and the North Sea due to LNG use for SSS

	Fuel use, kt	Emissions, kt		
		NOx	SO2	PM2.5
Baseline				
Short sea shipping (SSS)	8153	431	16.3	22
Other shipping routes	7118	447	15	24
Total int. shipping	15270	878	31	46
Case 1: 15 % LNG uptake				
SSS-LNG	1223	6.5	0.0	0.1
SSS-oil	6930	366.4	13.9	19.1
Total SSS	8153	372.9	13.9	19.2
Total int. shipping	15270	819	29	43
%reduction relative to Baseline	-	-6.6%	-7.8%	-7.1%
Case 2: 100% LNG uptake				
SSS-LNG	8153	43.1	0.0	0.4
SSS-oil	0	0.0	0.0	0.0
Total SSS	8153	43.1	0.0	0.4
Total int. shipping	15270	490	15	24
%reduction relative to Baseline	-	-44.2%	-51.9%	-47.5%

Table 4.20 and Table 4.21 present the emissions of air pollutants in 2030 and 2050 for the variant when LNG is used as a fuel for SSS on all European seas. In the first case (10% and 15% uptake by 2030 and 2050, respectively) the emission reductions relative to the Baseline are rather small – about 2% for NO_x and PM2.5 and 1.5% for SO_2 in 2030. By 2050, the relative reductions are 50% higher. In the second case (50% LNG uptake in 2030 and 100% in 2050), the reductions are about 11% for NO_x and PM2.5 and 7% for SO_2 in 2030 and twice as high in 2050.

Table 4.20 Reduction of air emissions in 2030 due to LNG use for SSS in all European seas

	Fuel use, kt	Emissions, kt		
		NOx	SO2	PM2.5
Baseline				
Short sea shipping (SSS)	12417	640	47.5	32
Other shipping routes	34554	2122	301	116
Total int. shipping	46971	2762	349	148
Case 1: 10 % LNG uptake				
SSS-LNG	1242	6.4	0.0	0.1
SSS-oil	11176	576.0	42.8	29.0
Total SSS	12417	582.4	42.8	29.1
Total int. shipping	46971	2704	344	145
%reduction relative to Baseline	-	-2%	-1%	-2%
Case 2: 50% LNG uptake				
SSS-LNG	6209	32.0	0.0	0.1
SSS-oil	6209	320.0	23.8	16.1
Total SSS	12417	352.0	23.8	16.2
Total int. shipping	46971	2474	325	132
%reduction relative to Baseline	-	-10%	-7%	-11%

Table 4.21 Reduction of air emissions in 2050 due to LNG use for SSS in all European seas

	Fuel use, kt	Emissions, kt		
		NOx	SO2	PM2.5
Baseline				
Short sea shipping (SSS)	16246	802	61.9	41
Other shipping routes	44598	2692	390	149
Total international shipping	60844	3494	452	191
Case 1: 15 % LNG uptake				
SSS-LNG	1863	9.6	0.0	0.1
SSS-oil	10555	544.0	40.4	27.4
Total SSS	12417	553.6	40.4	27.5
Total international shipping	46971	2676	342	143
%reduction relative to Baseline	-	-3%	-2%	-3%
Case 2: 100% LNG uptake				
SSS-LNG	12417	64.0	0.0	0.1
SSS-oil	0	0.0	0.0	0.0
Total SSS	12417	64.0	0.0	0.1
Total international shipping	46971	2186	301	116
%reduction relative to Baseline	-	-21%	-14%	-22%

The future use of LNG for shipping will depend on many factors, like investment premiums, relative fuel prices, development of appropriate infrastructure, etc. There are studies that address specifically these issues (see EMSA, 2011, DMA 2012). These studies indicate that the use of LNG can be competitive compared with other options to comply with the MARPOL ANNEX VI emission standards. They demonstrate that switching to LNG can have a payback time comparable with installing sulfur scrubbers.

Analysis of cost-effectiveness of using LNG as an alternative fuel for shipping was beyond the scope of our study.

4.7. COMPARISON OF EMISSIONS FROM THE ENTIRE TNO MARITIME GRID AREA FOR SELECTED SCENARIOS

Figure 4.3 to Figure 4.5 compare the emissions for selected scenarios. The graphs clearly demonstrate a drastic and immediate reduction of sulfur emissions due to implementation of sulfur standards on marine fuels. From the other side, legislation on NO_x, even if extended to broader areas (200 nm), will give limited effects in the short-run because the limits are binding only for new vessels. Reduction of fuel consumption achieved in scenario 6 v.1, where slow steaming is enforced in 200nm zones, causes important decrease of emissions of all pollutants, also in 2020. In the MTFR and the MCE scenarios, where retrofits are assumed, the reductions of NO_x emissions are achieved faster. In scenarios 1 to 5 the decrease of PM emissions is a side effect of switching to better quality fuels (0.1% S in SECAs and 0.5% in other sea regions). Implementation of particle filters (scenarios 7 to 9) can reduce the PM emissions to the very low values. These reductions occur faster if retrofits of existing vessels are allowed.

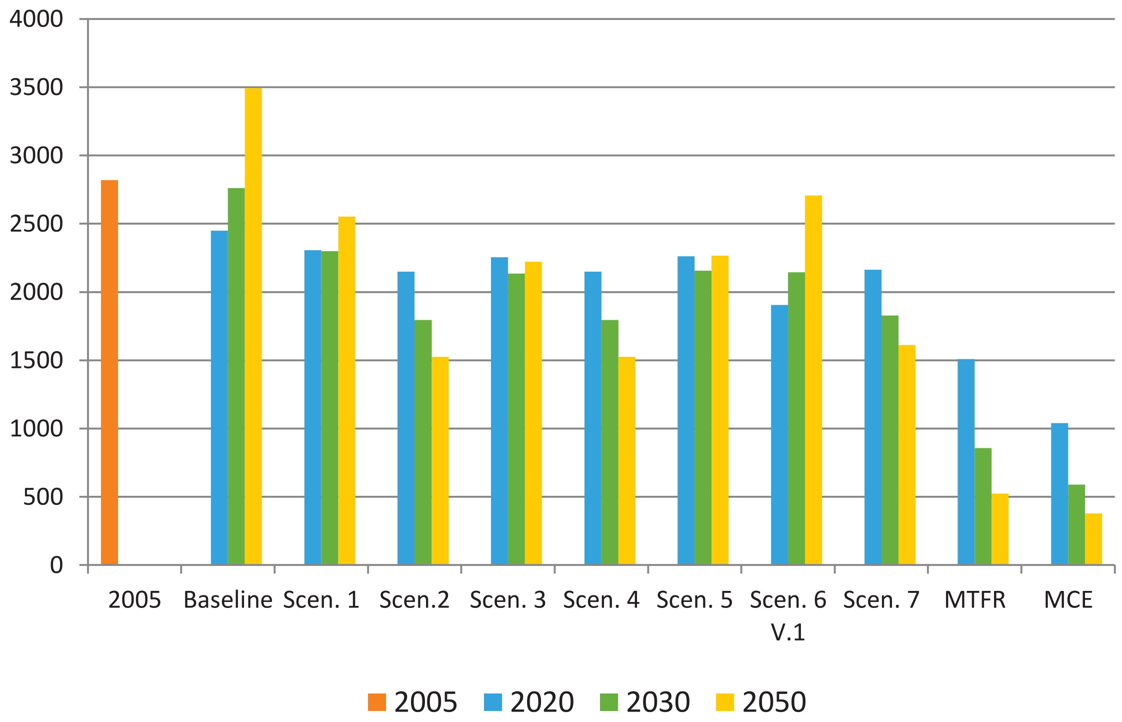


Figure 4.3 Comparison of NO_x emissions for selected scenarios (kt)

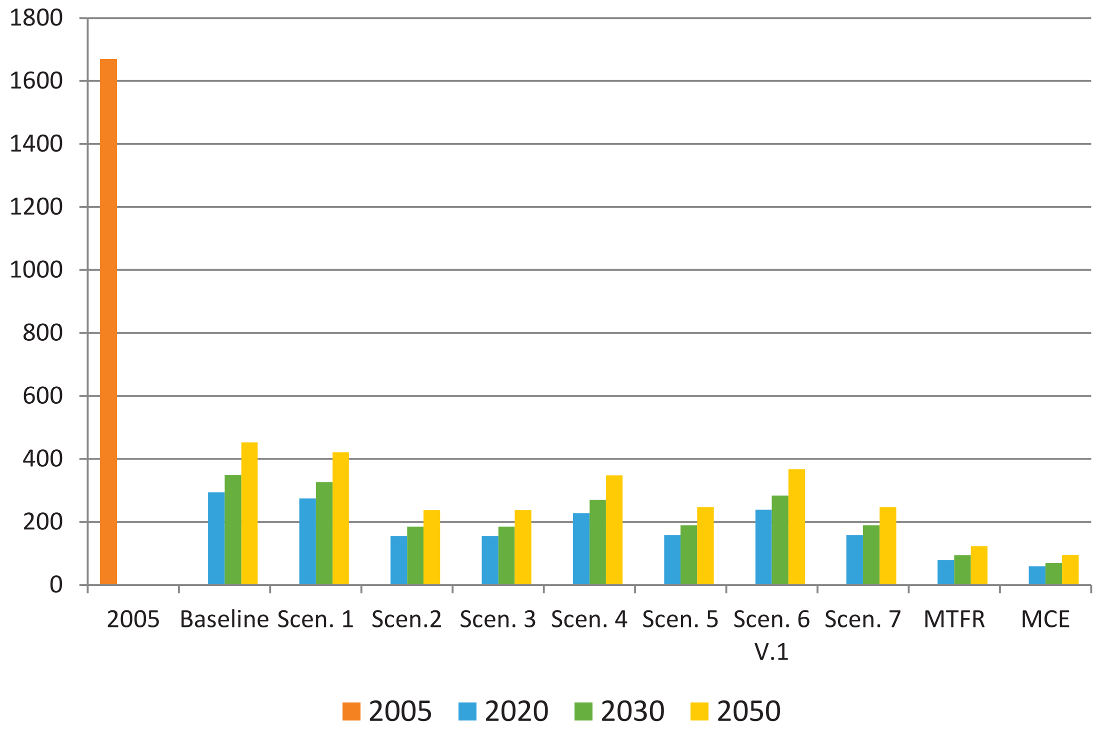


Figure 4.4 Comparison of SO_2 emissions for selected scenarios (kt)

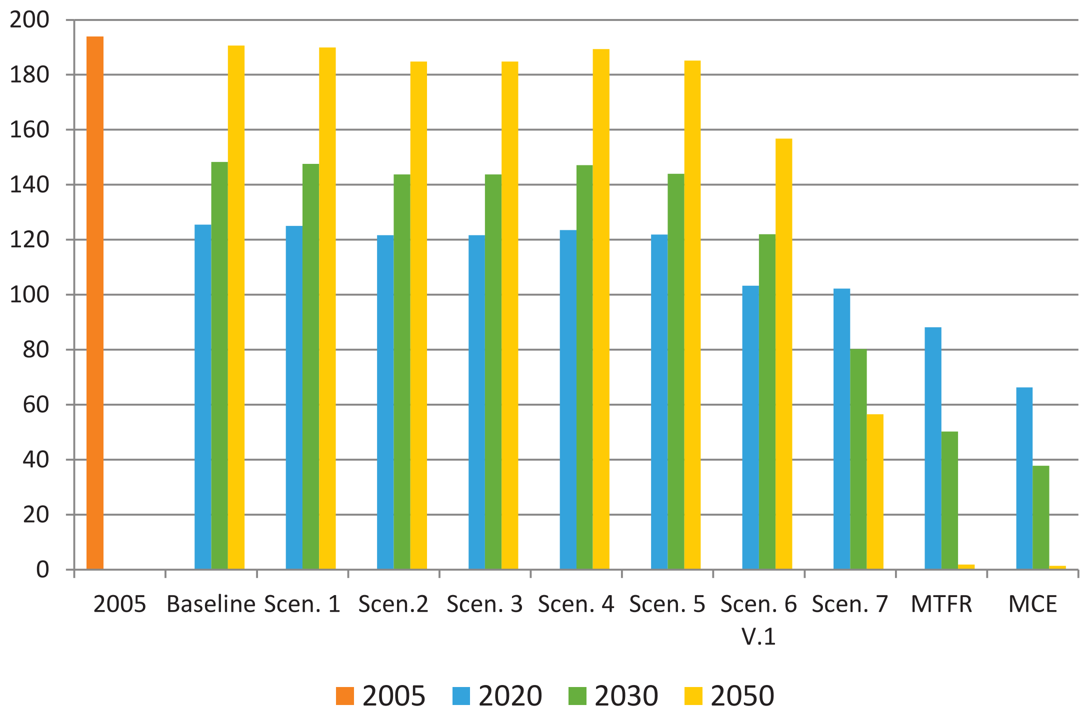


Figure 4.5 Comparison of PM2.5 emissions for selected scenarios (kt)

4.8. SCENARIO COSTS

This section presents emission control costs for selected scenarios for the years 2020 and 2030. Due to the reasons explained in Section 3.3.1, we did not attempt to provide costs for 2050. For slow steaming, we only calculated fuel cost savings. Assessment of other cost components associated with slow steaming (necessity to operate greater number of vessels, longer delivery time of goods etc.) was beyond the scope of our work. We also did not provide estimates of costs of scenarios that demonstrate emission effects of using LNG. This was not possible within the time and budget constraints of our study. Since emissions of SO_2 can be controlled either through using low sulfur fuel or through installing scrubbers, we provided costs for these two alternatives.

4.8.1. COSTS OF NO_x CONTROLS

Table 4.22 and Table 4.23 provide cost estimates for several scenarios to control NO_x emissions in 2020 and 2030 according to the NECA provisions (Scenarios 1 to 5). Scenario 8 presents the costs of implementing the MTFR measures, where all new vessels operating within the TNO grid meet the Tier III standards and also existing vessels are retrofitted to an extent limited by the applicability (retrofitting potential).

Introducing NECA standards for just the North and Baltic Seas would cost 114 M€ per year in 2020 and 268 M€ per year in 2030. If the NECA also includes the 12 nm zones of other EU Member States (as specified by the full Scenario 1) then the annual cost increases to 167 M€ in 2020 and 402 M€ in 2030. The cost of Scenario 2 (NECAs in exclusive economic zones -EEZ of all EU Member States) increases the costs to 333 M€ in 2020 and 795 M€ in 2030. For the MTFR case (Scenario 8), whereby NECA provisions are introduced for the entire maritime TNO grid, and Tier III standards are applied to existing vessels, the costs increase by a factor of 2.5 in 2020 compared with Scenario 2 and by 90 % in 2030.

Reduction of one ton of NO_x costs about 1.1 thousand € in 2020 and 0.8 thousand € in 2030.

Table 4.22 Costs of NO_x emission controls by scenario (2020)

Measures applied	Unit	NECA in BAS, NOS	NECA in BAS, NOS, and 12 nm	NECA and SECA in 200 nm	NECA in 200 nm except MED	NECA in MED and BLACK_SEA	MTFR
Scenario number	-	Scen. 1 v.1	Scen. 1	Scen. 2 & 4	Scen. 3	Scen. 5	Scen. 8
Fuel consumption	Mt	10.2	15	29.8	18.9	18.9	39.4
	TWh	118	173	344	218	218	454
Percentage new ships	%	30%	30%	30%	30%	30%	30%
Baseline emissions	kt/yr	633	891	1840	1192	1155	2451
Decrease in emissions	kt/yr	103	144	301	195	189	940
Scenario emissions	kt/yr	530	747	1539	997	966	1510
Retroffitting potential	%	NA	NA	NA	NA	NA	40%
Cost new ships	M€	114	167	333	211	211	440
Cost old ships	M€	NA	NA	NA	NA	NA	459
Total cost	M€	114	167	333	211	211	899
Unit reduction cost	k€/t NOx	1.1	1.2	1.1	1.1	1.1	1.0

Table 4.23 Cost assessment of introducing NO_x emission controls using SCR for different scenarios (2030)

Measures applied	Unit	NECA in BAS, NOS	NECA in BAS, NOS, and 12 NM	NECA and SECA in 200 nm	NECA in 200 nm except MED	NECA in MED and BLACK_SEA	MTFR
Scenario number	-	Scen. 1 v.1	Scen. 1	Scen. 2 & 4	Scen. 3	Scen. 5	Scen. 8
Fuel consumption	Mt	12.0	18.0	35.6	22.4	22.7	47.0
	TWh	138	208	410	258	262	542
Percentage new ships	%	60%	60%	60%	60%	60%	60%
Baseline emissions	kt/yr	705	998	2075	1345	1299	2762
Decrease in emissions	kt/yr	328	462	966	626	606	1905
Scenario emissions	kt/yr	377	536	1109	719	694	856
Retroffitting potential	%	NA	NA	NA	NA	NA	60%
Cost new ships	M€	268	402	795	500	507	1050
Cost old ships	M€	NA	NA	NA	NA	NA	469
Total cost	M€	268	402	795	500	507	1519
Unit reduction cost	k€/t NOx	0.8	0.9	0.8	0.8	0.8	0.8

4.8.2. COST OF SULFUR CONTROL

Similarly as for $NO_{x,}$ we provide cost estimates of SO_2 controls for cases that assume implementation of SECA standards for different sea regions (Scenarios 1 – 5). We also present costs for the MTFR case (Scenario 8), in which the SECA standard (0.1% S or scrubbing equivalent) is implemented in the entire maritime region covered by the TNO grid.

In all scenarios, we assume that there are no additional investments at a vessel level related to the use of fuels with lower sulfur content. This is because all ships have different storage tanks to store fuels of different quality. Thus, only fuel cost differential is taken into account. Besides, we only assess emission reductions and costs along the shipping routes as it is assumed that already in the Baseline scenario ships use 0.1% S marine fuel in ports.

Costs for the case where the compliance is achieved through the use of low S fuels are presented in Table 4.24 and Table 4.25. Use of fuel of SECA quality in 12 nm zones of all EU countries would increase costs by about 280 M€ in 2020 and 340 M€ in 2030 compared with the Baseline case (SECA in the Baltic and North Sea only). Extension of SECAs to the EEZ of the EU Member States (Scenario 2), increases the costs to 2.0 bln€ in 2020 and 2.4 bln€ in 2030. In both years, the costs increase but a factor of seven but also amount of SO_2 removed increases by the same factor. In Scenario 4, which is similar to Scenario 2 but without a SECA in the Mediterranean Sea, the annual cost is about 970 M€ in 2020 and 1.2 billion € in 2030, which is half of the cost of Scenario 2. Likewise, the amount of SO_2 emissions reduced is halved. In Scenario 5, where a new SECA is introduced only in the Mediterranean and the Black Sea, the annual costs are similar as in the Scenario 2 because of the similar volume of fuel use for which fuel switching occurs. Finally, if the SECA were introduced for the entire maritime TNO grid (Scenario 8), the fuel change would cost up to 3.1 bln € in 2020 and 3.7 bln € in 2030, which in both years is more than 50% higher than the cost of Scenario 2.

Unit cost of reaching the SECA standard with the use of low sulfur fuels according to the Purvin & Getz estimate is 14.6 thousand €/t SO_2 abated, which is quite high. Thus alternative calculations were also performed, which assume the use of scrubbers. Vessels installing scrubbers will continue using residual oil (RO) with high sulfur content (2.94% S) and reduce emissions to a level that corresponds to the sulfur standard in force in a given sea region (0.1% S for SECAs, 0.5% elsewhere). We assume the use of seawater scrubbers, which can be used in all sea regions except the Baltic Sea, which is a SECA region already in the Baseline. We do not attempt to separate costs for the step down to 0.5% and then down to 0.1% S equivalent, because any division of the costs between these two stages would be quite subjective. Thus, we use the average costs, as specified in Table 3.5. Further, we assume that all new ships will be built with scrubbers and existing vessels will be retrofitted to a limit specified by the retrofitting potential. Remaining existing vessels will meet the sulfur standard with low sulfur fuels. Results of calculations are presented in Table 4.26 and Table 4.27. Under such assumptions, compliance costs in 2020 decrease in all scenarios by about 50%. In 2030, the costs are only about 20% of the cost of the low S fuel case.

Table 4.24 Cost of compliance with SECA standards using low S fuels, 2020.

Measures applied	Unit	SECA for 12nm	SECA for 200 nm	SECA for 200 nm except MED	SECA for MED and BLACK_SEA	MTFR
Scenario number	-	Scen. 1	Scen. 2 & 3	Scen. 4	Scen. 5	Scen. 8
Fuel premium, SECA (0.5%S to 0.1%S)	€/MWh	10.2	10.2	10.2	10.2	10.2
Total fuel consumption, new SECAs	Mt	2.4	17.2	8.2	16.9	26.8
	TWh	27.8	198.3	95.1	195.0	308.6
Baseline emissions	kt	24.1	172.0	82.5	169.2	267.7
Decrease in emissions	kt	19.3	137.6	66.0	135.3	214.2
Scenario emissions	kt	4.8	34.4	16.5	33.8	53.5
Total cost	M€	282	2012	965	1980	3133
Unit reduction cost	k€/t SO2	14.6	14.6	14.6	14.6	14.6

Table 4.25 Cost of compliance with SECA standards using low S fuels, 2030.

Measures applied	Unit	SECA for 12nm	SECA for 200 nm	SECA for 200 nm except MED	SECA for MED and BLACK_SEA	MTFR
Scenario number	-	Scen. 1	Scen. 2 & 3	Scen. 4	Scen. 5	Scen. 8
Fuel premium, SECA (0.5%S to 0.1%S)	€/MWh	10.2	10.2	10.2	10.2	10.2
Total fuel consumption, new SECAs	Mt	2.9	20.5	9.9	20.0	31.9
	TWh	33	237	114	231	367
Baseline emissions	kt	29.0	205.3	99.2	200.2	318.5
Decrease in emissions	kt	23.2	164.3	79.4	160.1	254.8
Scenario emissions	kt	5.8	41.1	19.8	40.0	63.7
Total cost	M€	340	2403	1161	2343	3728
Unit reduction cost	k€/t SO2	14.6	14.6	14.6	14.6	14.6

Table 4.26 Cost of compliance with SECA standards using scrubbers, 2020.

Measures applied	Unit	SECA for 12nm	SECA for 200 nm	SECA for 200 nm except MED	SECA for MED and BLACK_SEA	MTFR
Scenario number	-	Scen. 1	Scen. 2 & 3	Scen. 4	Scen. 5	Scen. 8
Red. cost - low S fuel	k€/t SO2	14.8	14.8	14.8	14.8	14.8
Red. cost - scrubbers new vessels	k€/t SO2	0.68	0.68	0.68	0.68	0.68
Red. cost - scrubbers retrofits	k€/t SO2	1.32	1.32	1.32	1.32	1.32
Percentage new ships	%	30%	30%	30%	30%	30%
Retrofitting potential existing vessels	%	40%	40%	40%	40%	40%
Decrease in emissions	kt	19.3	137.6	66.0	135.3	214.2
Cost ships using low S fuel	M€	120	853	409	839	1328
Cost ships using scrubbers - new	M€	4	28	13	28	44
Cost ships using scrubbers - retrofit	M€	7	51	24	50	79
Total cost	M€	131	932	447	917	1451
Unit reduction cost	k€/t SO2	6.8	6.8	6.8	6.8	6.8

Table 4.27 Cost of compliance with SECA standards using scrubbers, 2030.

Measures applied	Unit	SECA for 12nm	SECA for 200 nm	SECA for 200 nm except MED	SECA for MED and BLACK_SEA	MTFR
Scenario number	-	Scen. 1	Scen. 2 & 3	Scen. 4	Scen. 5	Scen. 8
Red. cost - low S fuel	k€/t SO2	14.8	14.8	14.8	14.8	14.8
Red. cost - scrubbers new vessels	k€/t SO2	0.68	0.68	0.68	0.68	0.68
Red. cost - scrubbers retrofits	k€/t SO2	1.32	1.32	1.32	1.32	1.32
Percentage new ships	%	60%	60%	60%	60%	60%
Retrofitting potential existing vessels	%	60%	60%	60%	60%	60%
Decrease in emissions	kt	23.2	164.3	79.4	160.1	254.8
Cost ships using low S fuel	M€	55	388	188	378	602
Cost ships using scrubbers - new	M€	9	67	32	65	104
Cost ships using scrubbers - retrofit	M€	7	52	25	51	81
Total cost	M€	72	507	245	494	787
Unit reduction cost	k€/t SO2	3.1	3.1	3.1	3.1	3.1

4.8.3. COSTS OF PARTICLE FILTERS

Table 4.28 provides costs of implementing particle filters for two cases: Scenario 7 – where the filter is introduced on top of NECA requirements in the 200 nm zones of the Mediterranean, Baltic and North Seas, and Scenario 8 - the Maximum Technically Feasible Emission Reductions (MTFR) case. In the later scenario, the filters are introduced for all maritime areas within the TNO grid, including retrofitting of existing vessels. Unit costs of the filters for new vessels and for the retrofit situation are shown in Table 3.7.

Implementation of filters within the EEZ (200 nm) of the Mediterranean, Baltic and North Seas as in the Scenario 7 would cost 28 M€ per year in 2020 and 72 M€ per year in 2030. The amount of emissions reduced is 23 kt $PM_{2.5}$ in 2020 and 68 kt PM2.5 in 2030, respectively, which results in the unit reduction cost of about 1.0 to 1.2 k€/t PM2.5. For the MTFR situation the annual costs increase to 72 and 125 M€, respectively. Unit reduction costs (per ton of PM reduced) are higher than in the scenario 7 because MTFR includes also retrofits of existing vessels, which requires higher capital outlays as for new vessels.

Table 4.28 Cost assessment of introducing fine particulate matter filters (2020 and 2030)

Year		2020		2030	
Measures applied	Unit	PM filters for NECAs in 200 nm	PM filters for entire TNO grid	PM filters for NECAs in 200 nm	PM filters for entire TNO grid
Scenario number or name	-	Scen.7	Scen. 8	Scen.7	Scen. 8
Fuel consumption	Mt	29.8	39.4	34.7	47.0
	TWh	344	454	400	542
Percentage new ships	%	30%	30%	60%	60%
Baseline emissions	kt/yr	90.1	125.5	106.0	148.3
Decrease in emissions	kt/yr	23.3	37.4	68.0	98.0
Scenario Emissions	kt/yr	66.8	88.1	38.0	50.3
Retroffitting potential	%	NA	40%	NA	60%
Cost new ships	M€	28	37	66	89
Cost old ships	M€	NA	35	NA	36
Total cost	M€	28	72	66	125
Unit reduction cost	k€/t PM2.5	1.22	1.94	0.97	1.28

4.8.4. EFFECTS OF STEAMING RESTRICTIONS

Due to the current over capacity of shipping, we can assume that there are enough ships in the fleet to ensure that imports and exports to and from EU ports are transported adequately, so that if steaming restriction measures are introduced investments in new ships are not necessary. The relatively high fuel prices and the pressure to minimize costs mean that many ships have been reducing their speeds recently in any case. We examine here the cost savings that can be achieved for the proposed scenarios in 2020 (Table 4.29) and 2030 (Table 4.30). If steaming restrictions are imposed in the 12 nm zone, fuel consumption is reduced from 4.6 Mt to 3.9 Mt in 2020 and from 6.7 Mt to 5.9 Mt in 2030, meaning a potential fuel cost savings of 276 M€ in 2020 and 410 M€ in 2030. If the steaming restrictions are extended to the 200 nm zone then the fuel consumption is reduced from 24.7 Mt to 18.2 Mt in 2020 and from 29.5 Mt to 21.8 Mt in 2030, meaning the potential fuel cost savings increase to 2.9 bln € in 2020 and 3.5 bln € in 2030. Emissions reductions achieved by slow steaming are much lower than reductions resulting from imposing NECA and SECA legislation. Although these measures bring substantial fuel cost savings, also other issues will need to be taken into account, like the necessity to increase the vessel fleet, their increased operation and maintenance costs, possible late arrival of goods or problems with enforcement and verification of steaming restrictions. All these issues go beyond the scope of this report and thus the full assessment of the costs of slow steaming is not provided.

Table 4.29 Assessment of the effects of steaming restrictions (2020)

Scenario Description	Unit	Slow steaming in 12 nm	Slow steaming in 200 nm	Slow steaming in MED + BLACK_SEA
Scenario number	-	Scen. 6	Scen. 6 v.1	Scen. 6 v.2
Fuel consumption:				
- baseline (SECA)	Mt	2.2	8	0
- baseline (non SECA)	Mt	2.4	16.7	19.7
- scenario (SECA)	Mt	1.9	6	0
- scenario (non SECA)	Mt	2	12.2	17.1
Fuel cost:				
- baseline	M€	2122	11145	8126
- scenario	M€	1846	8253	7070
- cost savings	M€	276	2892	1056
Emissions decrease:				
- NO_X	kt/yr	60.5	530.8	258.9
- SO_2	kt/yr	5.1	53.2	25.6
- $PM_{2.5}$	kt/yr	1.9	21.6	11.4

Table 4.30 Assessment of the effects of steaming restrictions (2030)

Scenario Description	Unit	Slow steaming in 12 nm	Slow steaming in 200 nm	Slow steaming in MED + BLACK_SEA
Scenario number	-	Scen. 6	Scen. 6 v.1	Scen. 6 v.2
Fuel consumption:				
- baseline (SECA)	Mt	3.2	9.5	0
- baseline (non SECA)	Mt	3.5	20	19.8
- scenario (SECA)	Mt	2.8	7.2	0
- scenario (non SECA)	Mt	3.1	14.6	14.4
Fuel cost:				
- baseline	M€	3151	13283	8180
- scenario	M€	2741	9836	5955
- cost savings	M€	410	3447	2226
Emissions decrease:				
- NO_X	kt/yr	85.3	602.5	405.2
- SO_2	kt/yr	5.5	63.6	58.5
- $PM_{2.5}$	kt/yr	3.8	25.6	17.4

4.8.5. OVERVIEW OF THE COSTS TO CONTROL SO_2, NO_X AND $PM_{2.5}$ EMISSIONS

Below we provide a summary of costs of the scenarios considered in this report. They are separated into the costs of SO_2, NO_X and $PM_{2.5}$ measures and are presented for 2020 (Table 4.31) and 2030 (Table 4.32). All costs are in addition to the costs incurred in the Baseline (Current legislation) scenario. For SO_2 costs were calculated for two cases: in the first case the compliance is achieved exclusively with the use of low S fuels; the second case allows the use of sulfur scrubbers.

Adding NECA to the current SECA would be relatively inexpensive – 114 M€ in 2020 and about 270 M€ in 2030. Implementation of SECA and NECA legislation in the 12 miles zone of European seas (Scenario 1) incurs costs of about 0.5 bln €/a in 2020 and 0.7 bln €/a in 2030. These costs increase by a factor of four to five if the legislation were extended to the whole 200 nm (EEZ) of the EU seas (Scenario 2). Implementation of the most stringent legislation (MTFR scenario) would increase costs to 4.1 bln € in 2020 and 5.4 bln € in 2030. The 2020 compliance costs are up to 50 % lower in case controlling sulfur emissions is allowed through flue gases scrubbing. For 2030, this difference becomes even higher – in some scenarios the total costs decrease to only one third of the costs calculated under an assumption that low sulfur fuel is used to comply with S standards.

Table 4.31 Costs of controlling emissions from international shipping in 2020 - a summary, M€

Measures applied	NECA in BAS, NOS	NECA in BAS, NOS, and 12 NM; SECA in 12 nm	NECA and SECA in 200 nm	NECA in 200 nm except MED; SECA in 200 nm	NECA in 200 nm; SECA in 200 nm except MED	NECA and SECA in MED and BLACK_SEA	PM filters and NECA in BAS, NOS, MED, BLACK_SEA; SECA in MED and BLACK_SEA	MTFR
Scenario number	Scen. 1 v.1	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5	Scen. 7	Scen. 8
SO2 cost (low S fuel)		282	2012	2012	965	1980	1980	3133
SO2 cost (scrubbers)		131	932	932	447	917	917	1451
NOx costs	114	167	333	211	333	211	333	899
PM costs							28	72
Total (low S fuel)	114	450	2345	2224	1298	2191	2341	4104
Total (scrubbers)	114	298	1265	1143	780	1128	1278	2422

Table 4.32 Costs of controlling emissions from international shipping in 2030 - a summary, M€

Measures applied	NECA in BAS, NOS	NECA in BAS, NOS, and 12 NM; SECA in 12 nm	NECA and SECA in 200 nm	NECA in 200 nm except MED; SECA in 200 nm	NECA in 200 nm; SECA in 200 nm except MED	NECA and SECA in MED and BLACK_SEA	PM filters and NECA in BAS, NOS, MED, BLACK_SEA; SECA in MED and BLACK_SEA	MTFR
Scenario number	Scen. 1 v.1	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5	Scen. 7	Scen. 8
SO2 cost (low S fuel)		340	2403	2403	1161	2343	2343	3728
SO2 cost (scrubbers)		72	507	507	245	494	494	787
NOx costs	268	402	795	500	795	507	795	1519
PM costs							66	125
Total (low S fuel)	268	742	3198	2903	1956	2849	3204	5371
Total (scrubbers)	268	474	1302	1007	1040	1001	1355	2430

CHAPTER 5 AIR POLLUTION IMPACTS

In this chapter, air pollution effects of the scenarios to control emissions from international shipping are discussed. Four indicators characterize these effects:

- Life years lost due to air pollution by fine particulate matter (PM2.5) from anthropogenic sources (YOLL)
- Premature mortality attributable to human exposure to ground level ozone (O_3)
- Area of ecosystems with depositions of acidifying substances above critical loads for acidification
- Area of ecosystems with nitrogen deposition above critical loads for eutrophication.

The first set of tables (Table 5.1 to Table 5.4) provides the values of indicators by each EU Member State for the period 2005 – 2050 for the baseline situation. The Baseline assumes implementation of “Current legislation” measures for both: land-based sources and for international shipping. Activities for land sources are consistent with the PRIMES Reference 2012 scenario.

Concentrations of fine particles as in 2005 caused a loss of about 370 million life-years and about 27 thousand cases of death could be attributed to elevated ozone levels. Deposition of sulfur compounds at about 195 square km of ecosystems in the EU was above critical loads for acidification. About 1.1 million square km of ecosystems obtained nitrogen deposition above critical loads for eutrophication. Implementation of the emission control measures according to the current legislation causes an important improvement of impact indicators. Compared with 2005, life years lost due to PM pollution in 2030 are reduced by 42%. Premature deaths caused by ozone decrease by 38%. Area of ecosystems endangered by acidification and eutrophication decreases by 69% and 21%, respectively. Little further improvement occurs up to 2050 because the reductions achieved through stricter controls are compensated by higher activity levels. Thus even in the longer-run substantial negative effects from air pollution are expected.

In this report we concentrate on the improvement that can be achieved through measures on international shipping. Table 5.5 provides a summary of impact indicators for EU-28 in the Baseline case and shows the contribution of international shipping to these indicators. In 2005, about 3.6% of YOLLS and 2.6% of premature deaths caused by ozone in the EU Member States were caused by international shipping. Corresponding shares for acidification and eutrophication of ecosystems were 8.4% and 2.7%. Up to 2030, the contribution of shipping decreases for the YOLL and the acidification indicators, and increases for ozone and eutrophication. The last column of the table identifies the scope for feasible improvement through undertaking the maximum control efforts (MCE) on international shipping. In 2020, the MCE scenario can reduce the impacts from maritime activities by about 55%. In 2030, negative effects of emissions from shipping can be reduced by more than three quarters compared with the Baseline situation. In 2050, further reduction, by 85% compared with the Baseline level is possible.

Table 5.1 Life years lost (YOLL) due to air pollution by fine particulate matter (PM2.5) for the Baseline scenario, million

Country	2005	2020	2030	2050
Austria	5.2	3.5	3.1	2.9
Belgium	9.7	5.8	5.4	5.2
Bulgaria	7.9	3.8	3.5	3.4
Cyprus	0.6	0.5	0.6	0.6
Czech Rep.	8.2	5.7	5.2	4.8
Denmark	2.9	1.8	1.6	1.5
Estonia	0.6	0.4	0.4	0.4
Finland	1.7	1.3	1.2	1.2
France	43.0	27.1	24.0	22.5
Germany	54.1	37.0	33.8	30.8
Greece	12.3	6.4	6.0	5.9
Hungary	8.8	5.5	5.1	4.8
Ireland	1.5	0.9	0.8	0.9
Italy	51.2	35.3	30.6	28.0
Latvia	1.1	0.9	0.8	0.8
Lithuania	1.9	1.5	1.3	1.3
Luxembourg	0.4	0.2	0.2	0.2
Malta	0.2	0.1	0.1	0.1
Netherlands	12.7	7.6	7.0	6.7
Poland	40.3	31.4	27.2	24.7
Portugal	7.2	3.9	3.7	3.6
Romania	21.0	12.3	11.2	10.7
Slovakia	4.3	2.9	2.7	2.6
Slovenia	1.5	0.9	0.8	0.8
Spain	32.4	16.9	16.4	16.2
Sweden	2.6	1.9	1.8	1.8
United Kingdom	34.5	21.0	18.5	18.1
Croatia	3.0	1.8	1.7	1.7
EU-28	**370.6**	**238.2**	**214.9**	**202.1**
Non-EU	149.3	128.1	130.8	138.4

Table 5.2 Premature deaths caused by elevated ozone concentrations for the Baseline scenario, cases

Country	2005	2020	2030	2050
Austria	513	342	302	292
Belgium	394	282	261	257
Bulgaria	869	576	518	508
Cyprus	50	43	43	46
Czech Rep.	589	405	363	350
Denmark	184	135	124	123
Estonia	41	30	27	27
Finland	103	76	69	70
France	2,674	1,833	1,653	1,623
Germany	4,120	2,920	2,654	2,594
Greece	922	678	636	636
Hungary	894	581	515	496
Ireland	62	51	49	49
Italy	5,882	3,927	3,559	3,510
Latvia	94	70	64	64
Lithuania	149	109	100	101
Luxembourg	19	13	12	11
Malta	28	20	18	18
Netherlands	489	357	332	328
Poland	1,778	1,261	1,139	1,105
Portugal	613	471	444	445
Romania	1,724	1,148	1,040	1,020
Slovakia	331	220	196	188
Slovenia	146	94	82	79
Spain	2,271	1,694	1,585	1,578
Sweden	249	183	167	167
United Kingdom	1,526	1,226	1,180	1,182
Croatia	384	243	213	208
EU-28	**27,100**	**18,986**	**17,348**	**17,077**
Non-EU	14,615	11,426	10,947	11,228

Table 5.3 Area of ecosystems with acid deposition above critical loads for acidification in the Baseline scenario, sq. km

Country	2005	2020	2030	2050
Austria	63	0	0	0
Belgium	706	40	35	29
Bulgaria	0	0	0	0
Cyprus	0	0	0	0
Czech Rep.	1,903	1,170	907	736
Denmark	1,431	47	33	32
Estonia	12	0	0	0
Finland	20	0	0	0
France	18,086	6,482	5,420	4,899
Germany	33,314	6,711	4,309	2,977
Greece	1,806	298	151	309
Hungary	3,864	1,110	1,087	1,073
Ireland	552	36	33	47
Italy	1,227	95	89	89
Latvia	4,735	1,317	1,001	1,040
Lithuania	6,796	5,862	5,766	5,702
Luxembourg	166	138	118	117
Malta	0	0	0	0
Netherlands	5,025	4,122	3,962	3,796
Poland	56,464	23,219	17,464	15,485
Portugal	982	196	194	218
Romania	3,067	111	69	56
Slovakia	2,171	714	485	405
Slovenia	213	7	5	4
Spain	3,532	64	48	45
Sweden	33,920	18,280	16,920	16,797
United Kingdom	13,117	3,112	2,305	2,683
Croatia	1,399	546	429	489
EU-28	**194,572**	**73,678**	**60,826**	**57,028**
Non-EU	76,017	21,560	20,086	27,497

Table 5.4 Area of ecosystems with nitrogen deposition above critical loads for eutrophication in the Baseline scenario, sq. km

Country	2005	2020	2030	2050
Austria	29,403	19,867	17,223	16,075
Belgium	142	28	26	20
Bulgaria	31,492	16,319	14,250	14,429
Cyprus	2,528	2,528	2,528	2,528
Czech Rep.	2,075	1,819	1,696	1,677
Denmark	4,275	4,245	4,234	4,232
Estonia	9,709	4,817	4,421	4,986
Finland	25,607	9,931	7,284	7,840
France	156,660	133,325	124,849	122,825
Germany	64,092	53,327	50,320	48,943
Greece	58,219	55,971	54,671	55,198
Hungary	23,844	21,038	19,168	18,392
Ireland	1,218	644	636	1,162
Italy	99,239	64,519	58,625	59,057
Latvia	32,423	27,882	26,282	27,538
Lithuania	19,277	18,948	18,897	18,933
Luxembourg	1,156	1,126	1,116	1,116
Malta	0	0	0	0
Netherlands	4,172	3,938	3,897	3,885
Poland	71,968	62,580	59,374	60,740
Portugal	32,721	32,618	32,595	32,638
Romania	93,689	89,134	88,213	87,776
Slovakia	22,104	20,043	19,520	19,378
Slovenia	9,383	3,806	2,332	2,055
Spain	211,492	203,678	202,396	204,624
Sweden	82,366	48,596	42,704	46,478
United Kingdom	8,505	4,134	3,908	5,166
Croatia	28,575	25,390	24,524	24,345
EU-28	**1,126,336**	**930,252**	**885,686**	**892,038**
Non-EU	996,153	868,366	853,455	884,838

Table 5.5 Impact indicators in EU-28 in the Baseline scenario and the contribution of shipping to air pollution effects

Year/Indicator	Unit	All sources	All sources minus shipping	Shipping contribution	Max. reduction of shipping contribution (MCE)
2005					
Life years lost (YOLL) due to PM	million	371	357	3.6%	-
Deaths due to ozone	10^3 cases/year	28	27	2.6%	-
Acidification	10^3 sq. km	195	178	8.4%	-
Eutrophication	10^3 sq. km	1,126	1,096	2.7%	-
2020					
Life years lost (YOLL) due to PM	million	238	234	1.9%	56%
Deaths due to ozone	cases/year	19	18	3.4%	57%
Acidification	10^3 sq. km	74	69	6.7%	53%
Eutrophication	10^3 sq. km	930	892	4.1%	56%
2030					
Life years lost (YOLL) due to PM	million	215	210	2.4%	74%
Deaths due to ozone	cases/year	17	17	4.3%	76%
Acidification	10^3 sq. km	61	56	8.1%	78%
Eutrophication	10^3 sq. km	886	840	5.1%	77%
2050					
Life years lost (YOLL) due to PM	million	202	195	3.3%	86%
Deaths due to ozone	cases/year	17	16	5.5%	85%
Acidification	10^3 sq. km	57	51	9.9%	80%
Eutrophication	10^3 sq. km	892	836	6.3%	88%

Figure 5.1 shows sulfur deposition in Europe in 2005 that originates from international shipping. On average, shipping contributes 35% to the total in coastal zones. For majority of grids these depositions are higher than 0.2 g/m^2/year with maximum values up to 0.5 to 1.1 g/m^2/year. Lowering of sulfur content of marine fuels as required by the current legislation will decrease the depositions in 2030 by about 80%. In the MTFR scenario this decrease is 95%. Depositions in 2030 for the Baseline, MTFR and MCE scenarios are shown in Figure 5.2 to Figure 5.3.

Depositions of nitrogen compounds caused by international shipping in 2005 are shown in Figure 5.4. Changes up to 2030 are illustrated in Figure 5.5 to Figure 5.6. In 2005, about 20 % of nitrogen deposition in coastal areas originated from international shipping with typical values of 50 to 70 NO_x eq/ha/year and maximum values above 100 NO_x eq/ha/year. Little improvement occurs in the 2030 Baseline because slightly lower emission factors from new vessels (Tier I and II) are compensated by the increase in transport volume. Thus, introduction of NECA standards is necessary to decrease the negative impacts of NO_x from shipping. In the MTFR scenario, the depositions decrease by about 70% relative to 2005, in line with the decrease of the emissions.

Finally, Figure 5.7 shows the concentrations (annual averages) of fine particles (PM2.5) in ambient air caused by shipping activities in 2005. In coastal areas, contribution of shipping to the total concentrations is about 25%, which translates into two to four $\mu g/m^3$. These concentrations importantly decrease up to 2030. In the Baseline scenario (Figure 5.8) the concentrations decrease by two thirds and in the MTFR (Figure 5.9) even by 90 % relative to 2005. This is to a large extent due to the reduction of sulfates in ambient air in result of the reduction of sulfur content of marine fuels.

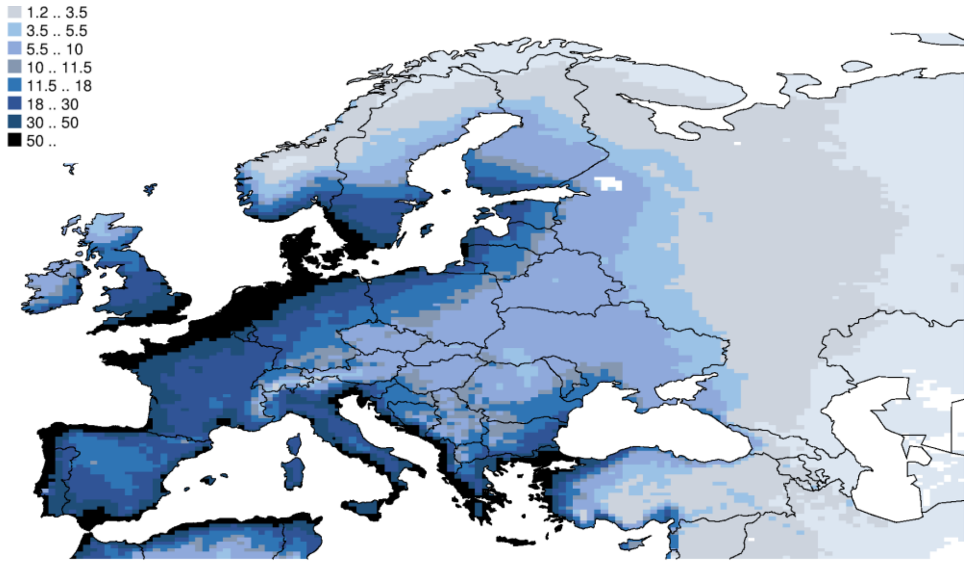


Figure 5.1 Sulfur deposition form shipping sources in 2005, mg/m^2/year

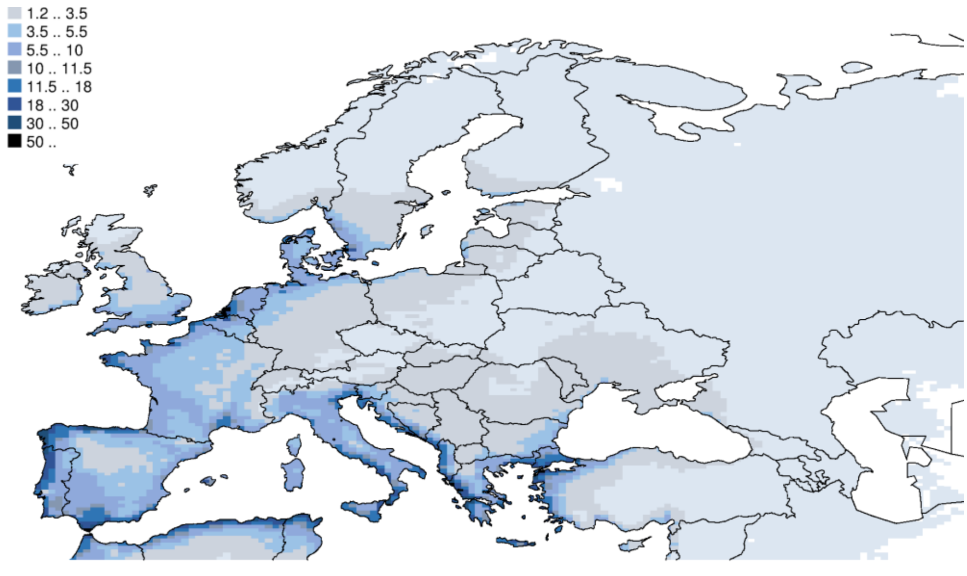


Figure 5.2 Deposition of sulphur from shipping sources, Baseline scenario 2030, mg/m^2/year

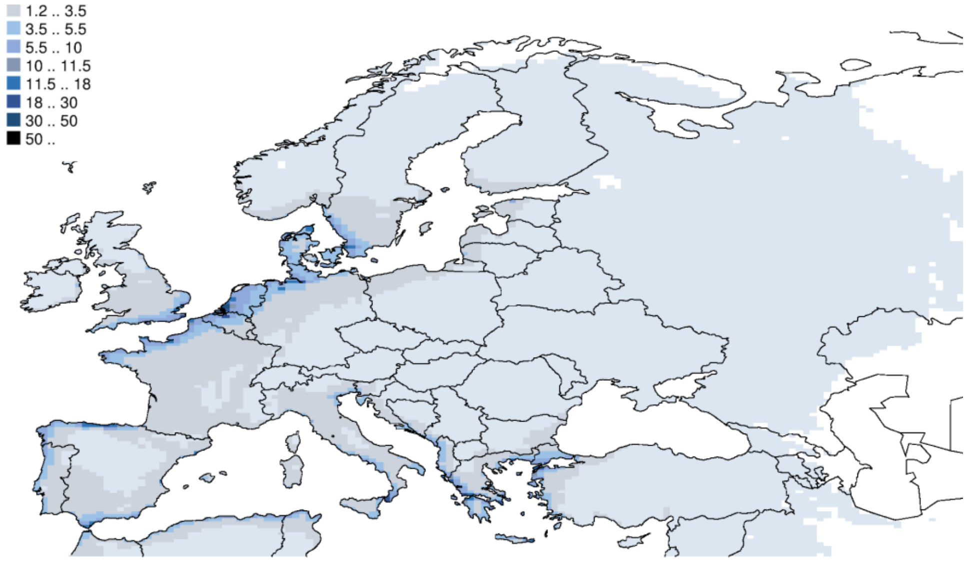


Figure 5.3 Deposition of sulphur from shipping sources, MTFR scenario in 2030, mg/m^2/year

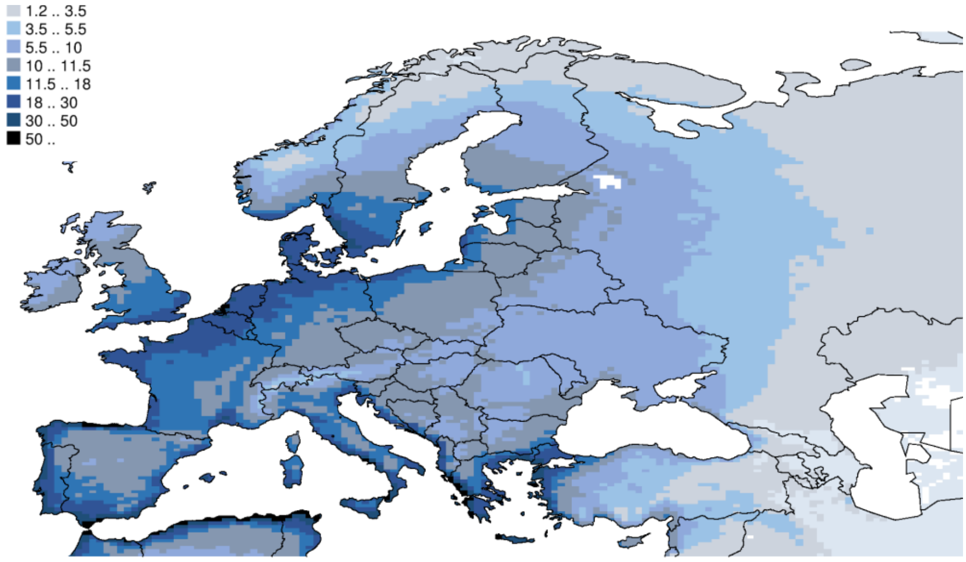


Figure 5.4 Deposition of nitrogen from shipping sources in 2005, eq/ha/year

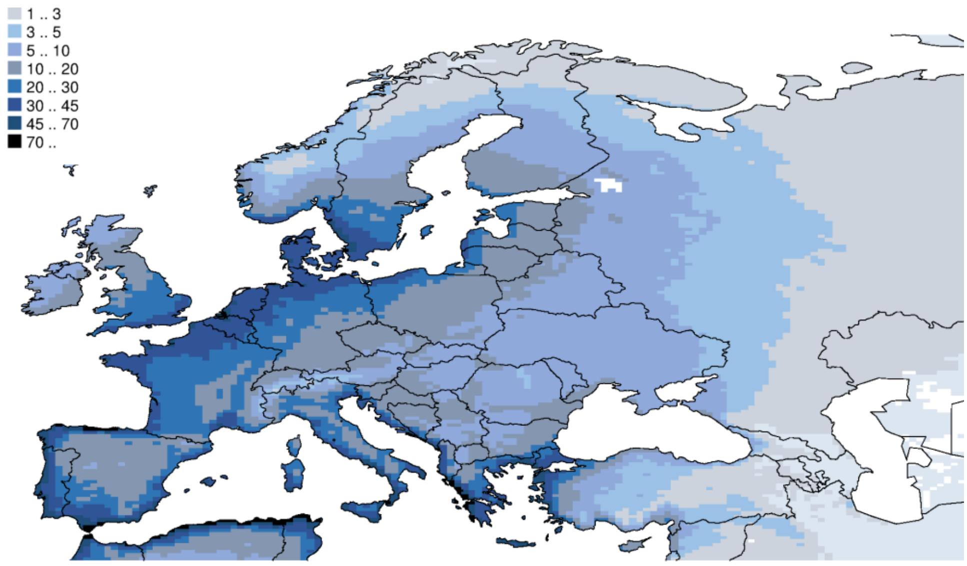


Figure 5.5 Deposition of nitrogen from shipping sources, Baseline scenario in 2030, eq/ha/year

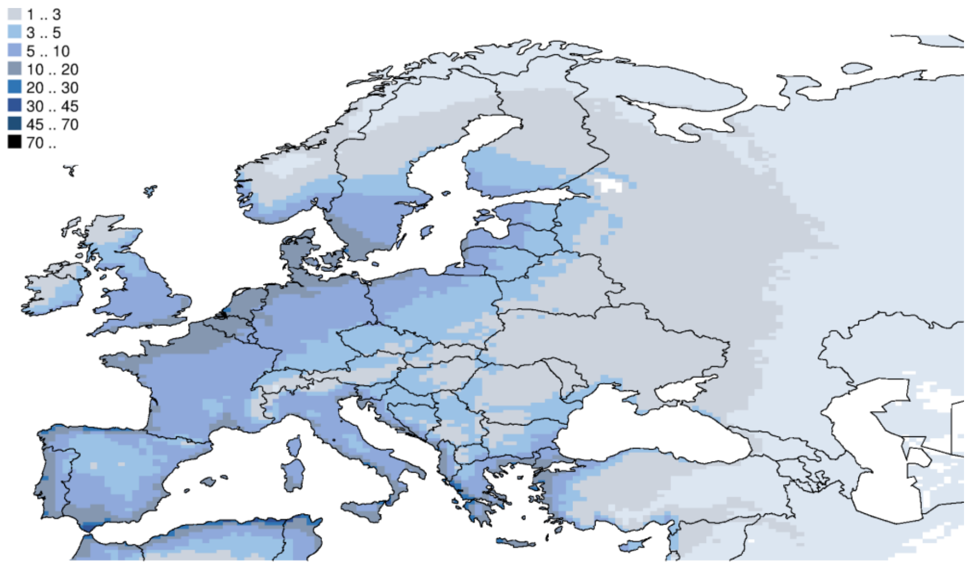


Figure 5.6 Deposition of nitrogen from shipping sources, MTFR scenario in 2030, eq/ha/year

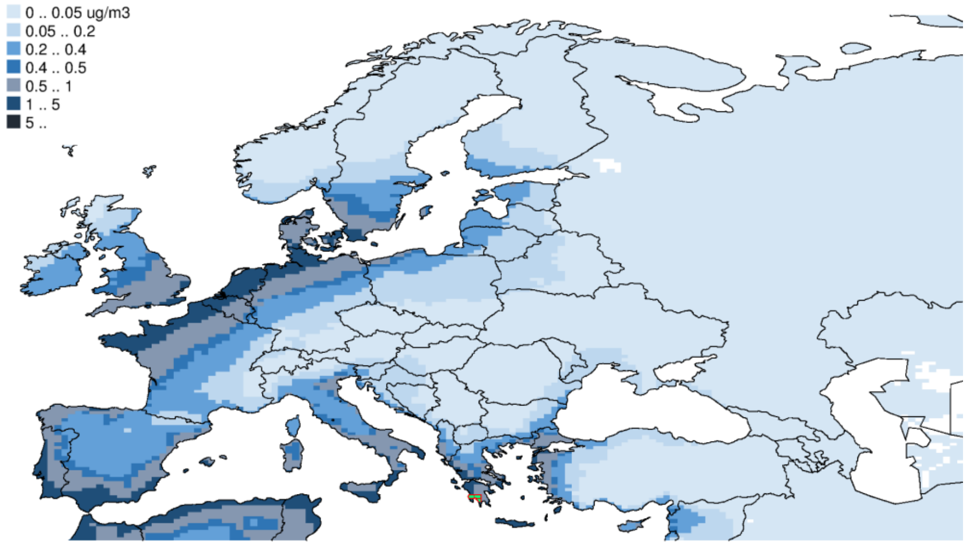


Figure 5.7 Concentrations of PM2.5 from shipping sources in 2005, µg/m^3

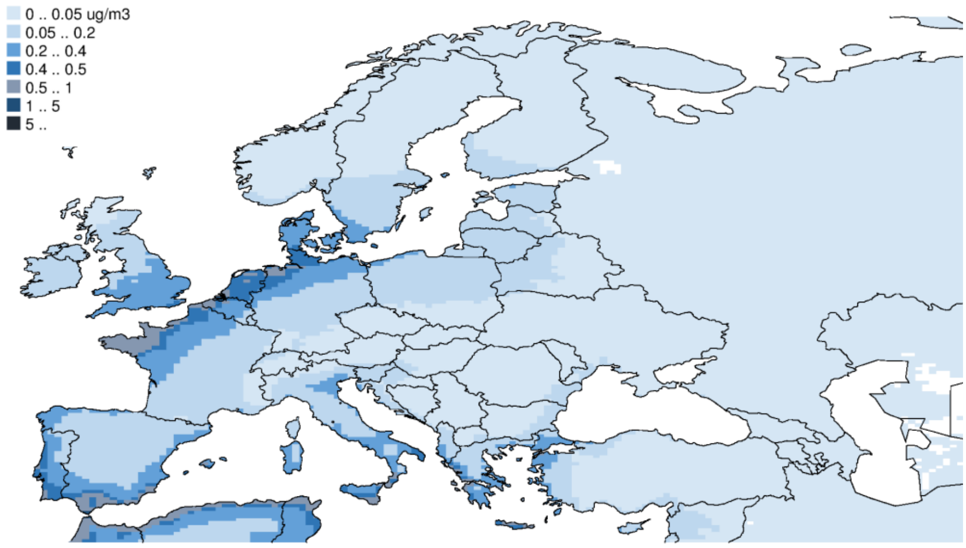


Figure 5.8 Concentration of PM2.5 from shipping sources, Baseline scenario in 2030, µg/m^3

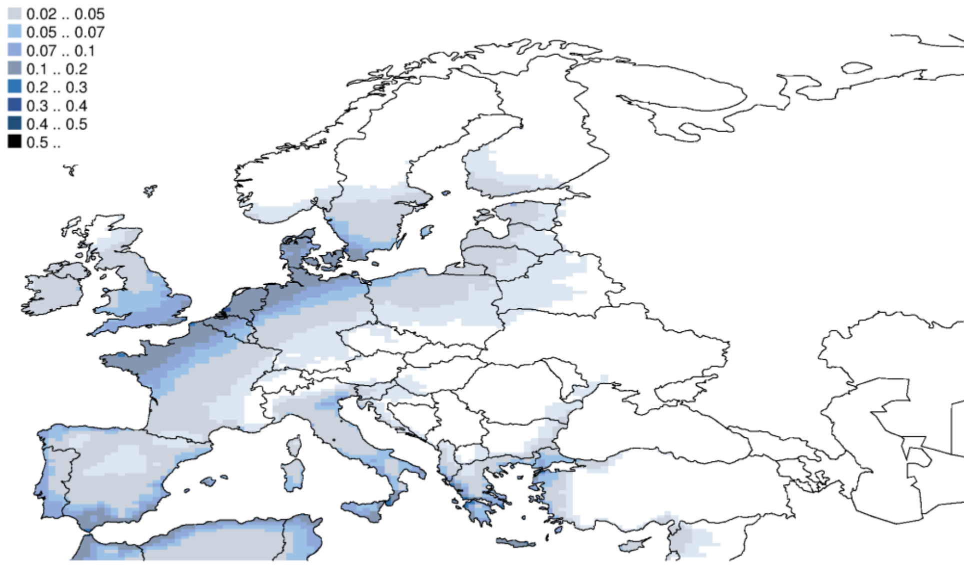


Figure 5.9 Concentration of PM2.5 from shipping sources, MTFR scenario in 2030, µg/m^3

Table 5.6 to Table 5.8 demonstrate the reduction of shipping contribution to individual impact indicators in EU-28 for the scenarios considered in our study. In 2030, scenario 1 (NECA in the Baltic and North Seas combined with ECAs for sulfur and nitrogen in territorial seas of the EU Member States) can reduce the lifeyears lost (YOLL) caused by emissions form shipping by more than 20% (Table 5.7). Areas with exceedances of critical loads for acidification and eutrophication decrease in this scenario by about 30% relative to the Baseline situation. If NECAs and SECAs were extended to the Exclusive Economic Zones, then health effects (from fine particles and ozone) would decrease by one third and the area of ecosystems affected by acidification and eutrophication would have decreased by about 45%. The MTFR scenario reduces the shipping contribution to the indicators by two thirds. Values for individual countries are shown in the Annex IV.

Table 5.6 Reduction of international shipping contribution to impact indicators by scenario in 2020
(% of the total contribution of shipping to impact indicator)

Indicator	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5
YOLL - PM2.5	10	22	20	20	12
Premature deaths - O3	3	12	8	8	6
Acidification	14	21	14	14	5
Eutrophication	13	18	13	13	8

Indicator	Scen. 6	Scen. 6v1	Scen. 6v2	Scen. 7	MTFR	MCE
YOLL - PM2.5	4	24	8	21	41	56
Premature deaths - O3	1	26	14	9	36	57
Acidification	3	27	4	15	39	53
Eutrophication	7	27	12	16	42	56

Table 5.7 Reduction of international shipping contribution to impact indicators by scenario in 2030
(% of the total contribution of shipping to impact indicator)

Indicator	Scen. 1	Scen. 2	Scen. 3	Scen. 4	Scen. 5
YOLL - PM2.5	23	37	32	25	17
Premature deaths - O3	9	35	22	23	18
Acidification	28	46	39	20	11
Eutrophication	31	45	33	27	19

Indicator	Scen. 6	Scen. 6v1	Scen. 6v2	Scen. 7	MTFR	MCE
YOLL - PM2.5	4	24	8	43	66	74
Premature deaths - O3	1	26	14	25	65	76
Acidification	5	20	5	30	72	78
Eutrophication	5	27	9	40	68	77

Table 5.8 Reduction of international shipping contribution to impact indicators by scenario in 2050
(% of the total contribution of shipping to impact indicator)

Indicator	MTFR	MCE
YOLL - PM2.5	81	86
Premature deaths - O3	79	84
Acidification	79	83
Eutrophication	83	87

Cost effectiveness of measures to reduce emissions from international shipping strongly depends on the distance of emission sources form sensitive receptors. Potential role of packages to control emissions from international shipping to achieve the Thematic Strategy targets and the extent to what measures on shipping would allow lowering the costs of controlling emissions from stationary sources will be a subject of a separate analysis using the GAINS model optimization capability.

CHAPTER 6 CONCLUSIONS

International shipping on seas surrounding Europe is an important source of air pollution. In 2005, ships emitted 1.7 million tons of SO_2, 2.8 million tons of NO_x, and about 0.2 million tons of fine particles (PM2.5). SO_2 emissions from shipping were equivalent to 20% of emissions form land-based sources in the UE-27. Corresponding numbers for NO_x and PM2.5 were 30% and 15%. Approximately 20 % of those emissions occurred in the territorial waters of the EU Member States, i.e., within 12 nm from the coast. Emissions from Exclusive Economic Zones (200 nm) were approximately 80% of the total. Contribution of shipping to air pollution in coastal zones is high. In 2005, about 35% of sulfur deposition in coastal areas originated from international shipping and exceeded 0.2 g/m^2/year, with maximum values up to 0.5 to 1.0 g/m^2/year. On average, 20% of nitrogen deposition in coastal areas comes from ships.

Current maritime transport projections assume further growth of transport volume, which is higher than the expected vessel efficiency improvement. This will cause further increase of fuel consumed by international maritime transport. Without strengthening legislation on shipping, this would have caused emissions increase proportional to fuel consumption.

Recently adopted fuel quality and emission standards for sulfur and NO_x according to the revision of the IMO MARPOL Annex VI, will contribute to the reduction of air pollution from ships. Reduction will be particularly high for sulfur. Global reduction of sulfur content of marine fuels to 0.5% and introduction of SECA in the Baltic and North Seas with even more stringent sulfur limits (0.1%) will reduce SO_2 emissions from European seas by 82% in 2020 compared to 2005. Emissions of NO_x will also decrease but that decrease will be moderate (13%). Until 2030, the baseline emissions of all pollutants increase compared with 2020 by about 12 - 13% due to the increase in transport volume.

Implementation of ECA and NECA legislation in the Baltic and North Seas (with English Channel) and in the territorial waters of the EU-27 would reduce the emissions form international shipping in 2030 by 23 kt SO_2 and 460 kt for NO_x. Extension of NECA and SECA legislation to Exclusive Economic Zones (200nm) would cause a drop in emissions by 160 kt of SO_2 and 970 kt of NO_x. compared with the Baseline.

Slow steaming (speed restrictions) brings not only fuel savings but also can importantly reduce emissions of air pollutants. That reduction is immediate, i.e., does not depend on the penetration of new vessels. If implemented in the EEZs (200 nm) of European seas, slow steaming reduces fuel consumption and emissions in 2030 by approximately 20%.

Implementation of measures as in the MTFR scenario, in which SECA and NECA standards are implemented in the whole maritime area, retrofitting of existing vessels in considered, and the emissions of PM are controlled with PM filters, would reduce the emissions of sulfur and nitrogen oxides in 2030 compared with the Baseline by about 73 and 69% respectively. PM emissions would be reduced by 66%. If combined with slow steaming (the Maximum Control Efforts – MCE case) these reductions would be about one quarter higher.

Replacement of oil with liquefied natural gas (LNG) might give important reductions of air pollutants. If 50% of vessels involved in international short sea shipping in the Baltic and North Seas would use LNG in 2030, total emissions would be reduced by about 25%.

Costs of scenarios heavily depend on the spatial coverage of the scenario and a type of measures assumed. Besides, for SO_2, costs depend on how the reduction of emissions will be achieved. With the assumptions adopted in this study compliance with the sulfur standards using low sulfur fuel is much more expensive than installing scrubbers. However, extent to what ship owners will use scrubbers, is uncertain. Thus, the calculations have been performed for two variants: one, which assumes compliance through using of low sulfur fuels and the alternative, which assumes using scrubbers.

Under the assumptions adopted in this study, introduction of NECA in the Baltic and the North Sea (with English Channel) costs in 2030 about 270 million €. Extension of SECA and NECA legislation to EU territorial waters increases these costs to about 740 M€. Costs are by about 270 M€ lower in case scrubbers were used instead of low sulfur fuel. Establishing NECA and SECA on EU EEZ waters would cost 3.2 bln € (low S fuels) or 1.3 bln € (for the case of wide application of scrubbers). Using PM filters on top of SECA and NECA legislation in EEZ would be relatively inexpensive – about 66 million €. Finally, MTFR over the whole area of European seas, which delivers the highest emissions reductions, costs 5.4 billion €(low S fuels case) or 2.4 billion € (with scrubbers).

Negative environmental impacts of international shipping on the European environment are high. In 2005, air pollution from shipping was responsible for 14 million life-years lost (YOLL) and about 700 cases of death due to elevated ozone levels. Shipping emissions caused that critical loads for acidification and eutrophication were exceeded on 17 and 30 thousand km^2, in addition to the exceedances caused by the depositions from land sources. Negative impacts occur mainly in the coastal regions. Although recently revised legislation on international shipping (IMO ANNEX VI to MARPOL Convention) importantly decreases emissions of air pollutants (mainly sulfur), negative impacts will persist also in the future and – without further strengthening of legislation are likely to increase.

Scenarios developed within this study mitigate these impacts. For instance, implementation of NECA in the Baltic and North Seas, combined with ECAs for sulfur and nitrogen in territorial seas (12 nm) of the EU Member States can reduce the shipping contribution to the YOLL indicator in 2030 by more than 20%. Negative impacts on ecosystems can be reduced by 30%.If NECAs and SECAs were extended to the Exclusive Economic Zones, then the health effects caused by shipping would decrease by more than one third and the area of ecosystems affected by acidification and eutrophication would decrease by about 45% relative to the Baseline. This translates into about 1.2 million life years saved and a decrease of the area of ecosystems endangered by acidification by two thousand km^2, and eutrophication by 21 thousand km^2 respectively. The MTFR scenario reduces the shipping contribution to the indicators by about two thirds.

Assessment of cost-effectiveness of measures on shipping in the context of minimization of the costs of achieving targets from the TSAP will be done by GAINS when developing cost-efficient scenarios for the revision of the TSAP.

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