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**MEDITERRANEAN ACTION PLAN (MAP)  
REGIONAL MARINE POLLUTION EMERGENCY RESPONSE CENTRE FOR THE  
MEDITERRANEAN SEA (REMPEC)**

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Thirteenth Meeting of the Focal Points of the Regional  
Marine Pollution Emergency Response Centre  
for the Mediterranean Sea (REMPEC)

REMPEC/WG.45/INF.11  
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Agenda Item 11

**TECHNICAL FEASIBILITY STUDY FOR THE IMPLEMENTATION OF  
AN EMISSION CONTROL AREA (ECA)  
IN EU WATERS WITH FOCUS ON THE MEDITERRANEAN SEA**

**Note by the European Commission**

**SUMMARY**

**Executive Summary:** The density of maritime traffic in the European Union's waters and of the population living in coastal areas justifies the need to act on related air pollution from ships. Such action is based on impact studies to assess the costs and benefits of additional emission control areas (ECAs). This document presents, in the Annex, a study<sup>1</sup> procured by the European Commission covering all EU waters with focus on the Mediterranean Sea. The study shows that the designation of an ECA for Sulphur Oxides (SO<sub>x</sub>) and for Nitrogen Oxides (NO<sub>x</sub>) under MARPOL in the Mediterranean Sea could, by 2030, cut emissions of SO<sub>x</sub> and NO<sub>x</sub> from international shipping by 80 and 20 %, respectively, compared to current legislation, and that monetised benefits would largely outweigh costs in all conservative scenarios. The study also explores additional options for enhanced reduction to abate both NO<sub>x</sub> and fine particulate matters (PM<sub>2.5</sub>) through retrofits of existing ships.

**Action to be taken:** Paragraph 15

**Related documents:** REMPEC/WG.45/11, REMPEC/WG.45/INF.9, REMPEC/WG.45/INF.11, MEPC 73/13/1, MEPC 74/INF.5

**Introduction**

1 Air pollution continues to be a major health and environmental concern at European level. Despite decreases in emission of air pollutants over the last decades and improved air quality, the European Environment Agency still estimate more than 400,000 premature deaths each year in the EU due to air pollution and poor air quality.

2 Still today, 20 out of 28 EU Member States exceed EU air quality thresholds, especially for PM and nitrogen dioxide (NO<sub>2</sub>), including in more than 130 European cities (many of which include ports). While EU air quality standards for sulphur dioxide (SO<sub>2</sub>) are widely met, more than a third of all

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<sup>1</sup> The EC-funded research study "The potential for cost effective air emission reductions from international shipping through designation of further Emission Control Areas in EU waters with focus on the Mediterranean Sea" can be found at [http://www.iiasa.ac.at/web/home/research/researchPrograms/air/Shipping\\_emissions\\_reductions\\_main.pdf](http://www.iiasa.ac.at/web/home/research/researchPrograms/air/Shipping_emissions_reductions_main.pdf)

monitoring stations across Europe report levels above levels recommended by the World Health Organization.<sup>2</sup>

3 EU legislation requires further decreases of emission of air pollutants, both to achieve the concentrations levels established via the Ambient Air Quality Directives<sup>3</sup> and meet the national emission reduction targets for SO<sub>x</sub>, NO<sub>x</sub>, PM<sub>2.5</sub> as well as for ammonia (NH<sub>3</sub>) and volatile organic compounds (VOC) set via the National Emission Ceilings Directive<sup>4</sup> for the years 2020, 2025 and 2030. The latter also recommends the EU Member State to pursue multilateral cooperation with third countries and coordination with international organisation, including the IMO, to collectively address international shipping.

4 Ships are a major source of this pollution, especially in densely populated coastal areas and port cities, and their cumulative emissions continue to increase as the sector grows<sup>5</sup>. Around 12,000 premature deaths annually in the European Union were caused by air pollutant emissions from international shipping in 2015<sup>6</sup>. To comply with EU legislation on air quality<sup>5,6</sup>, many European coastal States are increasingly considering the cost effectiveness of acting on the maritime transport sector as compared to action of land sources. Although the sector is a very significant contributor in coastal and port areas but as pollution travels large distances it can even deteriorate air quality in the mainland.

5 Even if several studies show that shipping emissions in European seas may remain stable from 2000 to 2030 yet they will become larger than those from land sources as of 2030. Half of the EU population lives within 50 KM distance from the sea. Therefore there is a collective interest to explore the balance between the stringencies of the current emission control regulations for land-based sources in the EU versus those for the shipping sector, and to assess the feasibility and potential impacts of further emission reduction initiatives for the maritime sector.

## **Context**

6 Currently the EU law regulates the sulphur content of marine fuels via Directive (EU) 2016/802, in order to reduce sulphur oxides (SO<sub>x</sub>) emissions of from maritime transport, and broadly transposes MARPOL Annex VI legal provisions into EU law. In April 2018, the European Commission adopted a report on the implementation and compliance with this Directive<sup>7</sup>. The report shows that a high rate of compliance by the maritime transport sector, driven also by a robust enforcement of the EU sulphur standards, have led to a significant reduction of sulphur dioxide concentrations in port cities and coastal regions bordering the the North Sea and Baltic Sea.

7 With the aim to extend the success of the SO<sub>x</sub> - ECAs - established in the North Sea and Baltic Sea - to all EU waters, the European Commission is actively engaging with relevant counterparts that are considering to possibly create ECAs for SO<sub>x</sub> (and NO<sub>x</sub> as appropriate) in all the the sea waters under the jurisdiction of the EU Member States as well as in sea areas shared with non EU states such as the Mediterranean Sea.

## **Study**

8 In light of the above, the European Commission has procured a study<sup>1</sup> in 2017, building upon current knowledge, methodologies and models that have been used previously by the Commission to prepare EU legislation addressing air pollution<sup>8</sup> to ensure consistency. International Institute for Applied Systems Analysis (IIASA) was designated the to lead the consortium carrying out this study.

9 As a central tool, the study employs the GAINS (Greenhouse gas – Air Pollution Interactions and Synergies) model, complemented by more detailed computations with Norwegian Meteorological

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<sup>2</sup> European Environment Agency (2018). Air Quality in Europe- 2018 Report, pag. 51.

<sup>3</sup> Directives 2008/50/EC and 2004/107/EC

<sup>4</sup> Directive (EU) 2016/2284

<sup>5</sup> Furthermore, impacts of the maritime transport sector are also on the marine environment and climate change and there are increasing indications of impacts as well on sea-related economic activities (tourism, fisheries, protection of cultural heritage).

<sup>6</sup> [www.iiasa.ac.at/.../Final\\_Report\\_VITO\\_International\\_Shipping-main-16042013.pdf](http://www.iiasa.ac.at/.../Final_Report_VITO_International_Shipping-main-16042013.pdf)

<sup>7</sup> COM(2018)188.

<sup>8</sup> 2013 Clean Air Policy Package (EC 2013) also assessing the feasibility and the potential benefits of the implementation of additional ECAs in EU waters and, most recently, for the Clean Air Outlook of the European Commission (Amann et al. 2017)

Institute (MET.NO) EMEP atmospheric chemistry-transport model. Subsequently, Ecometrics Research and Consulting (EMRC)'s ALPHA-RiskPoll model provided full benefit analyses<sup>9</sup>.

10 This study covers the whole of the EU waters under the Member States' jurisdiction and explores the effects of additional measures that could be taken to reduce shipping emissions to air, with a focus on the Mediterranean Sea. Furthermore the study:

- updates the projections of the likely development of maritime transport activities based on current literature on emission inventories and fuel demand,
- provides new assessments of costs of compliance with current sulphur legislation,
- improves the understanding of the role of emissions from vessels in ports, and the options for reducing these emissions,
- develops new scenarios of future emissions that would result from different policy interventions, including additional Emission Control Areas for SO<sub>x</sub> or for NO<sub>x</sub> or both under IMO rules. Additional options for enhanced reduction of NO<sub>x</sub> and PM<sub>2.5</sub> through retrofits of existing ships or taking into account upcoming climate policies are explored.
- assesses their impacts on ambient air quality and resulting population exposure, and
- estimates the associated benefits to human health, and quantifies these benefits in monetary terms.

## **Results**

11 The study shows that the situation will already improve in 2020, for air quality and human health, thanks to the global reduction in the sulphur content in marine fuels from 3.50% to 0.50%.

12 The ECA zones, by regulating both NO<sub>x</sub> and SO<sub>x</sub> emissions from maritime transport, would provide additional health benefits to the populations of the Mediterranean basin and of other EU waters. The benefits of additional measures on particulate matters are also included in the study. No additional benefits in terms of avoided environment, fisheries, cultural heritage degradation, and tourism loss have been estimated. As the ECA zone would allow an overall improvement in air quality throughout the Mediterranean (as well as in other EU waters) and such benefits significantly outweigh costs to the maritime industry with:

- Avoidance of more than 4,000 cases of premature deaths annually by 2030 and up to 11,000 annual cases by 2050 (1/3 in the EU, 50% in North Africa and the Middle East).
- Additional costs to industry are estimated between 1.1 and 2 billion € per year in 2030. This is aligned with costs on land to implement EU legislation<sup>3</sup> on national emission ceiling 1.3 bn €/y in 2030.
- Benefits of further emission controls outweigh the costs by a wide margin. For the EU waters, on average the monetized benefits exceed costs by a factor of 7 in 2030 and by a factor of 13 in 2050.
- Double benefits when action of EU + non-EU coastal states aligned.
- Climate policies will have significant co-benefits for air quality.

## **Contribution to the work of REMPEC**

13 As presented in the document MEPC 73/13/1, REMPEC, in the current biennium (2018-2019), is working to reduce harmful effects of atmospheric emissions from ships, notably by commissioning and overseeing a study that considers the possible designation of the Mediterranean Sea, or parts thereof, as a SO<sub>x</sub> ECA, under the Annex VI of MARPOL.

14 In the context of the Mediterranean Sea, the European Commission contributes to the ongoing process steered by REMPEC including with the results of the IIASA study which have therefore been made available to REMPEC.

<sup>9</sup> GAINS model (Amann et al. 2011), EMEP model (Simpson et al. 2012), ALPHA-RiskPoll model (Holland et al. 2013)

**Actions requested by the Meeting**

15      **The Meeting is invited to** note the information contained in this document.

## **ANNEX**

### **ECAMED: A TECHNICAL FEASIBILITY STUDY FOR THE IMPLEMENTATION OF AN EMISSION CONTROL AREA (ECA) IN THE MEDITERRANEAN SEA**



# Final Report

## The potential for cost-effective air emission reductions from international shipping through designation of further Emission Control Areas in EU waters with focus on the Mediterranean Sea

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December 2018

## Abstract

This study explores the impacts of alternative emission control interventions for international shipping on the European Seas on relevant air pollutant emissions, examines their consequence on ambient air quality in Europe and the neighbouring regions, and explores the resulting improvements of human health. It estimates the costs of the various policy interventions, and compares them with monetized benefits on human health and other impacts.

It is found that further controls of SO<sub>2</sub> emissions, e.g., through SO<sub>2</sub> emission control areas, could deliver rather fast benefits, and avoid by 2030 up to 4000 cases of premature deaths annually, and 8000 in 2050. In the longer run, by 2050, application of Tier III NO<sub>x</sub> standards could double the health benefits. Even when using the lower (most conservative) health valuation, all reduction measures examined in this report emerged as cost-effective, with monetized benefits exceeding emission control costs typically by a factor of 6 in 2030 and by a factor of 12 in 2050.

Designation of the Mediterranean Sea as an Emission Control Area could by 2030 cut emissions of SO<sub>2</sub> and NO<sub>x</sub> from international shipping by 80 and 20 percent, respectively, compared to current legislation. These additional emission reductions could avoid 4,100 cases of premature deaths in 2030 and more than 10,000 annual premature deaths in 2050. Even with the most conservative assumptions for health valuation, monetized benefits are on average 4.4 times higher than the costs in 2030 and 7.5 times higher in 2050.

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The research project "Assessment of the potential for cost-effective air emission reductions from shipping (SO<sub>x</sub>, NO<sub>x</sub>) through designation of further Emission Control Areas in EU waters with focus on Mediterranean Sea" (Specific Agreement 13 under Framework Contract ENV.C.3/FRA/2013/00131) was funded by the European Commission



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This document reports on work of the International Institute for Applied Systems Analysis and has received only limited review. Views or opinions expressed herein do not necessarily represent those of the institute, its National Member Organizations, or other organizations supporting the work.

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## Executive Summary

**This study explores the benefits and costs of additional measures that could be taken to reduce shipping emissions to air, with a focus on the Mediterranean Sea**

International maritime shipping is an important contributor to poor air quality in Europe. It has particularly large impacts in port cities, but through the long-range transport of pollutants it deteriorates also inland air quality affecting a large share of the European citizens.

After the adoption of the 2013 Clean Air Programme for Europe and the 2016 agreement on the EU National Emission Ceilings Directive, there is interest to explore the balance between the stringencies of the current emission control regulations for land-based sources in the EU versus those for the shipping sector, and to explore the feasibility and potential impacts of further emission reduction initiatives for the maritime sector.

This study explores the effects of additional measures that could be taken to reduce shipping emissions to air, with a focus on the Mediterranean Sea. While maintaining consistency with other recent studies, this report:

- updates the projections of the likely development of maritime transport activities,
- provides new assessments of costs of compliance with current legislation,
- improves the understanding of the role of emissions from vessels in ports, and the options for reducing these emissions,
- develops new scenarios of future emissions that would result from different policy interventions, including additional Emission Control Areas (ECAs) for SO<sub>x</sub> (SO<sub>x</sub>-ECAs or SECAs in this study) or for NO<sub>x</sub> (NO<sub>x</sub>-ECAs or NECAs in this study) or both, in the Mediterranean Sea and other European Sea regions,
- assesses their impacts on ambient air quality and resulting population exposure, and
- estimates the associated benefits to human health, and quantifies these benefits in monetary terms.

As a central tool, this report employs the GAINS (Greenhouse gas – Air Pollution Interactions and Synergies) model (Amann et al. 2011), complemented by more detailed computations with MET Norway's EMEP atmospheric chemistry-transport model (Simpson et al. 2012). Subsequently, EMRC's ALPHA-RiskPoll model (Holland et al. 2013) provided full benefit analyses. By employing the same methodologies and models that have been used for the Impact Assessment and the underlying reports of the 2013 Clean Air Policy Package (EC 2013) and, most recently, for the Clean Air Outlook of the European Commission (Amann et al. 2017), results are directly comparable with the above-mentioned studies.

While current IMO and EU regulations will cut SO<sub>2</sub> emissions from international shipping up to 2030, without further controls emissions will grow again after 2030. After 2030, NO<sub>x</sub> emissions will exceed those from land-based sources in the EU.

The sulphur in fuel requirements that have been agreed by the IMO will cut SO<sub>2</sub> emissions by 50-80 percent up to 2030, but in the absence of additional regulations, emissions will rebound afterwards. CO<sub>2</sub> and NO<sub>x</sub> emissions are expected to further increase without additional measures, and NO<sub>x</sub> emissions will exceed emissions from all land-based emissions in the EU-28 after 2030 (Figure A-1).

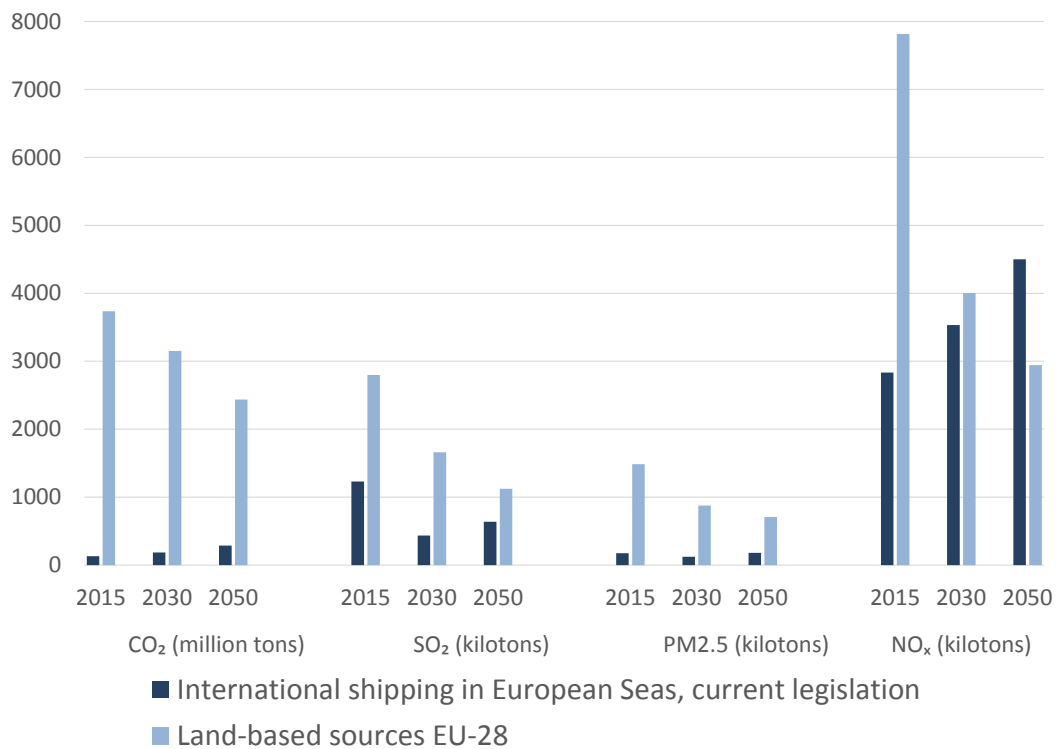


Figure A-1: Projections of greenhouse gas and air pollutant emissions with current emission control regulations, international maritime shipping and land-based sources in the EU-28

## Enhanced emission controls could cut emissions from international shipping in the European Seas by more than 90 percent

There is significant potential for further emission reductions from international maritime shipping in Europe. An extension of the sulphur in fuel controls to all European Sea regions could reduce SO<sub>2</sub> emissions by more than 90 percent, compared to 2015. These measures would also have co-benefits on primary PM<sub>2.5</sub> and black carbon emissions and reduce them by 20 percent. In addition, particle filters could cut PM<sub>2.5</sub> emissions further, up to 95 percent below the 2015 level in 2050. Tier III standards could lower NO<sub>x</sub> emissions in the European Seas by up to 50 percent in 2050 (Figure A-2).

The exact potentials depend on the scope of application (i.e., spatial coverage of emission control areas), from when they would be phased in, and for NO<sub>x</sub> whether existing vessels will be retrofitted.

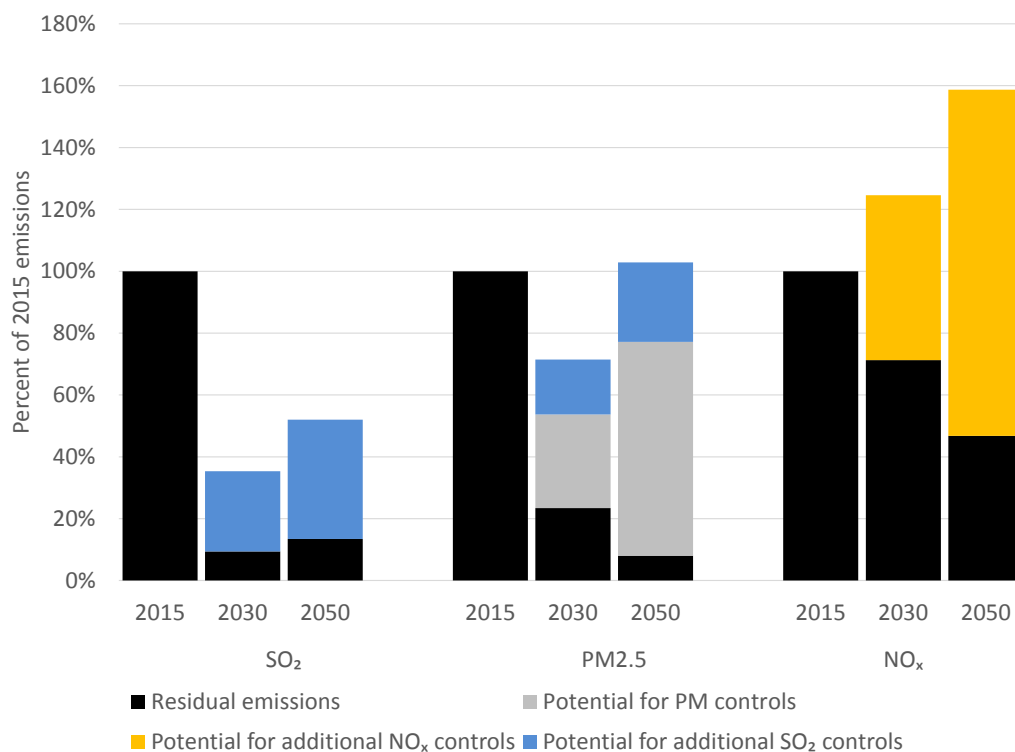


Figure A-2: Emission control potentials in the European Seas, for the baseline projection relative to the 2015 emissions

## Climate policy measures, through their reduction of fuel consumption, have significant co-benefits on air pollutant emissions

The baseline projection of future shipping activities, reflecting current thinking on the evolution of economic growth, global trade volumes and fuel efficiency, indicates for 2050 a 130% increase in CO<sub>2</sub> emissions from international shipping in the European Seas. In contrast, in 2018 the IMO MEPC 72 has agreed on a target to reduce greenhouse gas emissions from international shipping by at least 50 percent in 2050. Measures to achieve such a deep reduction in greenhouse gases will deliver significant co-benefits on air pollutant emissions from shipping. As an illustration, a scenario that assumes climate measures that would stabilize CO<sub>2</sub> emissions by 2050 (but not achieve the 50 percent cut established by the IMO) would allow an additional 50 percent cut in SO<sub>2</sub>, NO<sub>x</sub> and PM<sub>2.5</sub> emissions on top of the reductions achieved with the full set of emission controls in the baseline projection (Figure A-3).

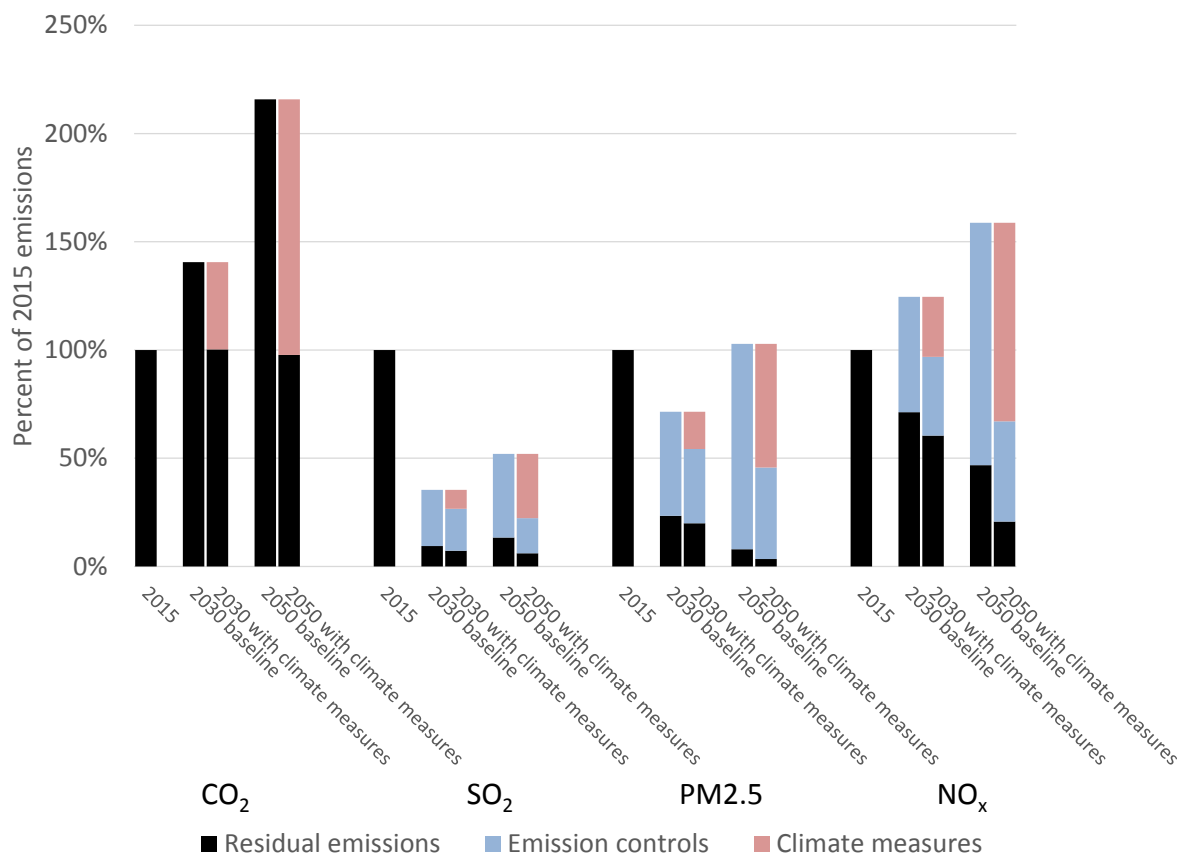


Figure A-3: Emission reductions from climate measures and pollution control legislation, all European Seas, relative to the 2015 levels

**Further emission controls for international shipping would deliver important improvements for air quality throughout Europe, particularly in coastal areas**

Further controls of emissions from international shipping could improve air quality for a large share of European population, given that about half of the EU population lives within 50 km distance from the Sea (Figure A-4). Largest improvements could occur along the coast of Mediterranean countries, and in particular along the North African coast. Here the concentrations of PM<sub>2.5</sub> could decrease by up to 1.2  $\mu\text{g}/\text{m}^3$  in 2030 and up to 1.5  $\mu\text{g}/\text{m}^3$  in 2050 (Figure A-5).

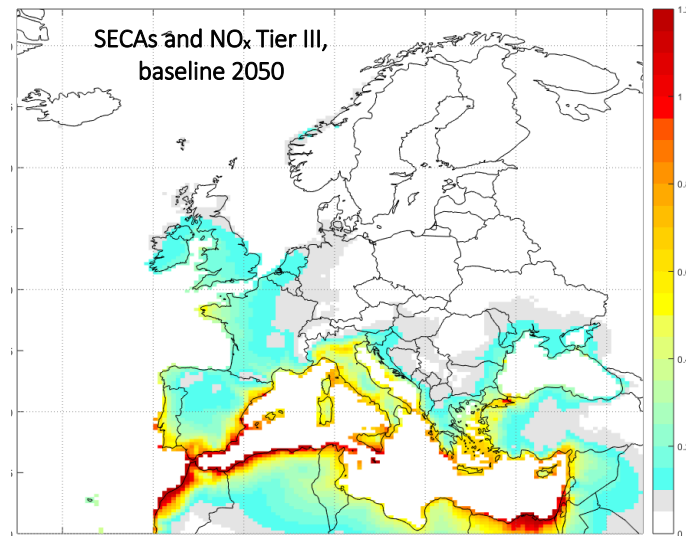


Figure A-4: Decrease of ambient PM<sub>2.5</sub> concentrations ( $\mu\text{g}/\text{m}^3$ ) in 2050 from implementation of SECAs and Tier III standards for NO<sub>x</sub> (including retrofits) in all European Sea regions, for the baseline fuel consumption projection

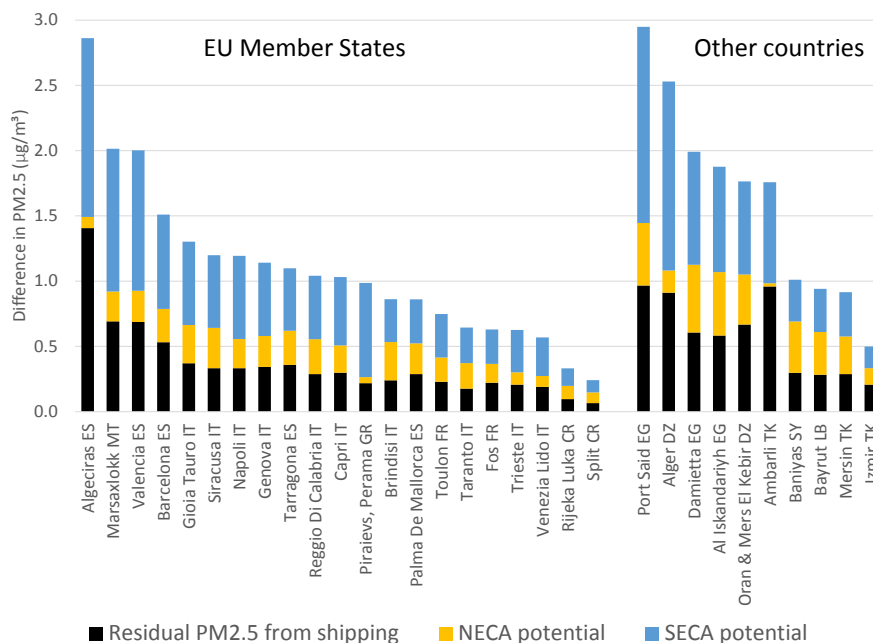


Figure A- 5: Reductions of ambient PM<sub>2.5</sub> concentrations in port cities from SECAs and NECA in the Mediterranean in 2050 (concentrations averaged across the 28\*28km grid cell that contains the port city)

## The air quality improvements of further ship emission controls could save up to 15,000 cases of premature deaths annually

The emission controls examined in this report could avoid up to 15,000 cases of premature deaths annually, about one third of them in the EU-Member States, and 50 percent in North Africa and the Middle East (Figure A-6). Until 2030, sulphur controls that can be introduced in the short term offer the largest potentials for fast improvements, and 40 percent of the full potential of the SECAs could be obtained with measures in the 12 nm zones. Tier III standards for NO<sub>x</sub> will unfold their full benefits in the longer term, and could double the health benefits by 2050.

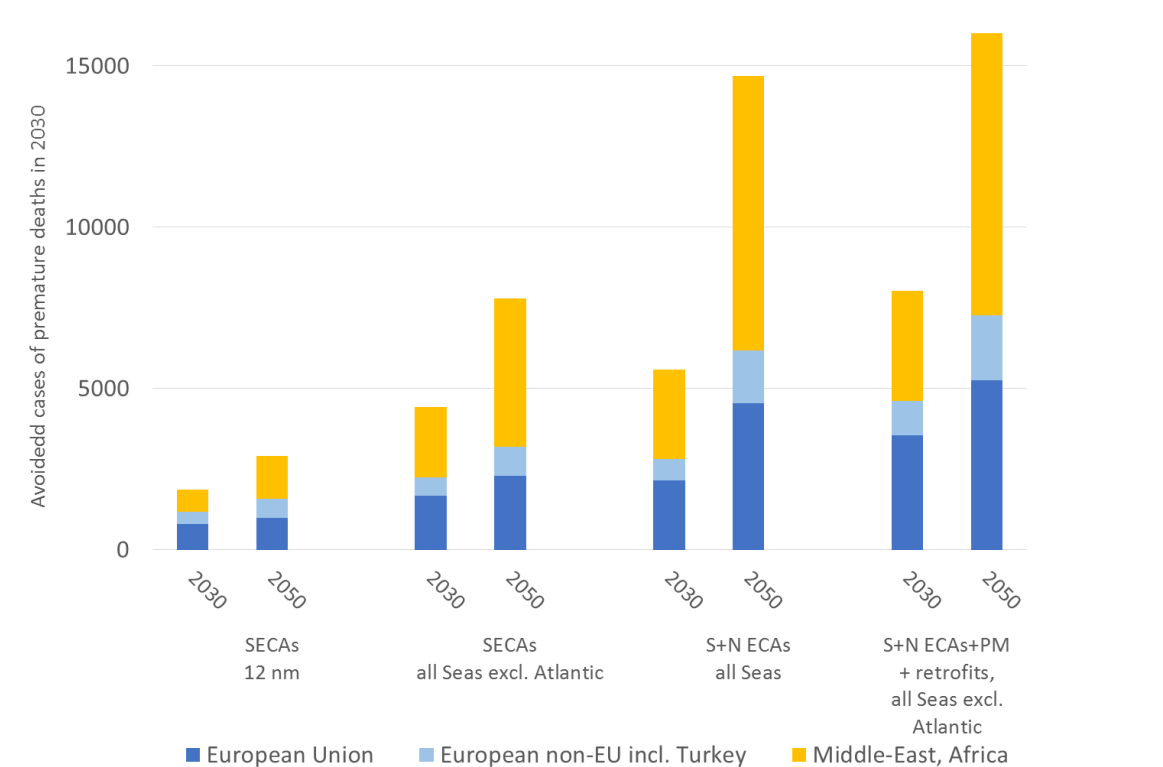


Figure A-6: Avoided cases of premature deaths from the control of shipping emissions in all European Seas in 2030 and 2050

## Benefits of further emission controls for international shipping outweigh the costs by a wide margin

A comparison of costs and monetized benefits of further emission controls for international shipping clearly shows that benefits outweigh the emission control costs by a wide margin for all examined variants of policy interventions, scenario trends, assumptions on cost data and benefits evaluation methods. On average, the monetized benefits exceed costs by a factor of 6 in 2030 (Figure A-7) and by a factor of 12 in 2050.

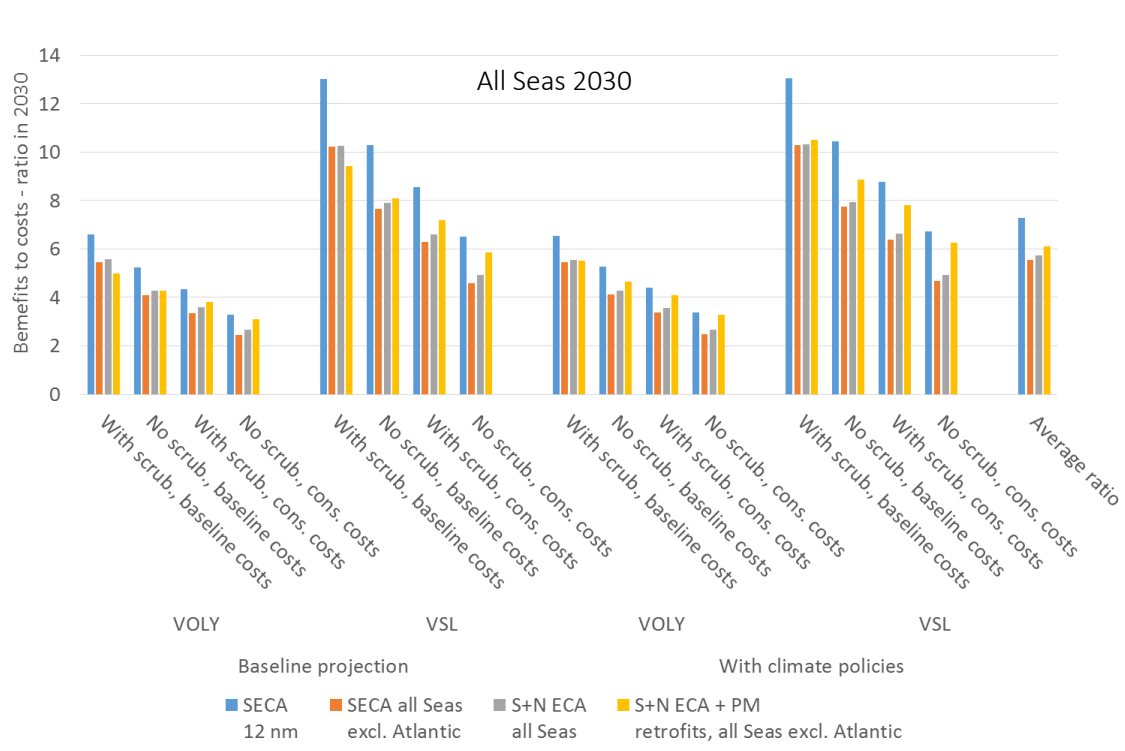


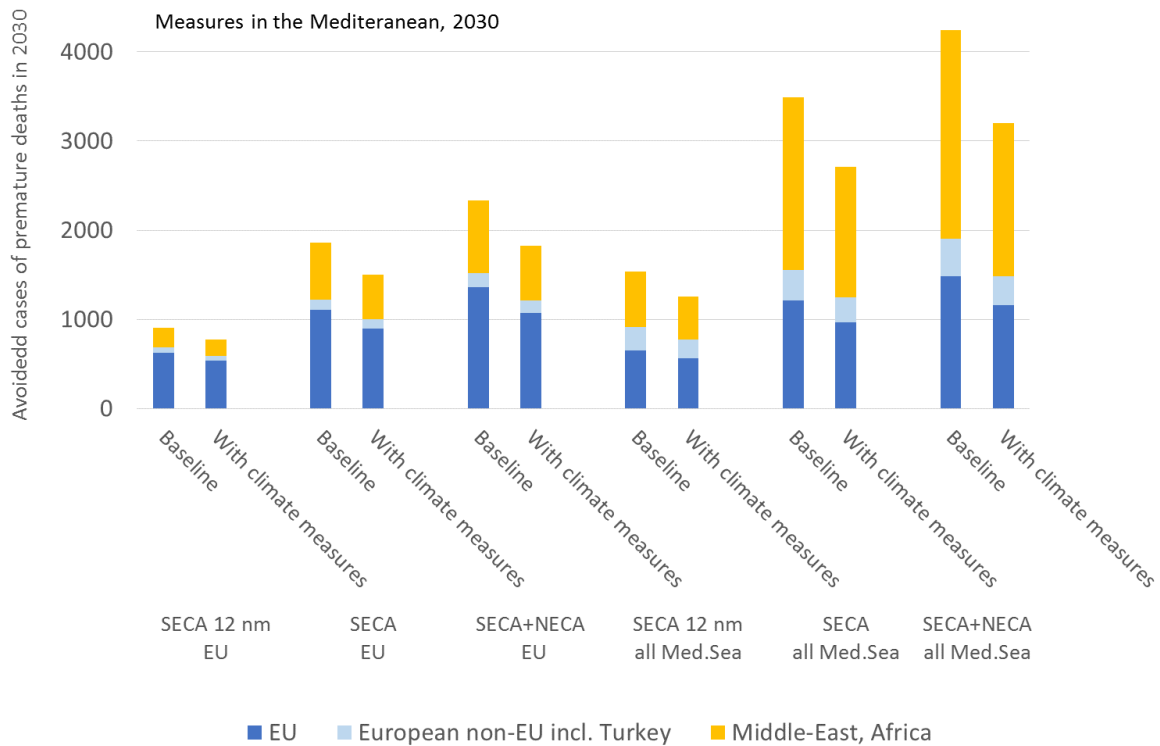
Figure A-7: Benefits-to-costs ratios for the emission control scenarios for all European Seas, 2030 (VSL – Value of Statistical Life; VOLY – Value of Life Year)



## An ECA designation of the Mediterranean Sea could very cost-effectively save more than 4,000 cases of premature deaths annually already by 2030

Designation of the Mediterranean Sea as an ECA could by 2030 cut emissions of SO<sub>2</sub> and NO<sub>x</sub> from international shipping by 80 and 20 percent, respectively, compared to current legislation. These additional emission reductions could avoid 4,100 cases of premature deaths in 2030 (Figure A- 8) and more than 10,000 annual premature deaths in 2050.

Figure A- 8: Avoided cases of premature deaths from the control of shipping emissions in the Mediterranean Sea in 2030



Even with the most conservative assumptions for health valuation, monetized benefits are on average 4.4 times higher than the costs in 2030 and 7.5 times higher in 2050.

## Contents

1	Introduction.....	1
1.1	Context .....	1
1.2	Objectives of the report .....	2
1.3	Structure of the report .....	2
2	Approach, method and tools employed for this study .....	3
2.1	Approach .....	3
2.2	Modelling tools.....	3
2.3	Sea regions and zones distinguished in this study .....	3
3	An inventory of shipping emissions in 2015.....	4
3.1	Fuel consumption .....	4
3.2	Emissions in 2015 .....	5
3.3	Comparison with other inventories.....	7
4	Scenarios of future emissions .....	8
4.1	Projections of fuel demand .....	8
4.2	Emission controls.....	9
4.3	Emission projections.....	10
4.3.1	CO <sub>2</sub> emissions .....	10
4.3.2	SO <sub>2</sub> emissions .....	10
4.3.3	PM <sub>2.5</sub> and BC emissions.....	11
4.3.4	NO <sub>x</sub> emissions.....	13
4.4	Emissions in the Mediterranean Sea .....	13
5	Emission control costs .....	16
5.1	Measures in all European Seas .....	16
5.2	Measures in the Mediterranean Sea .....	17
6	Ambient air quality .....	18
6.1	Ambient concentrations of PM <sub>2.5</sub> .....	18
7	Benefits of the emission controls .....	23
7.1	Premature mortality.....	23
7.2	Monetized health benefits .....	25
7.2.1	Measures in all European Seas .....	25

7.2.2 Measures in the Mediterranean Sea..... 27

8 Comparison of costs and benefits ..... 28

8.1.1 Measures in all European Seas..... 28

9 Conclusions..... 33

## List of acronyms

BC	Black carbon
ECA	Emissions Control Area
EMEP	European Monitoring and Evaluation Programme
IMO	International Maritime Organization
kt	kiloton = $10^3$ tons
MARPOL	International Convention for the Prevention of Pollution from Ships
NECA	NO <sub>x</sub> Emission Control Area (NO <sub>x</sub> -ECA)
NH <sub>3</sub>	Ammonia
nm	nautical mile
NO <sub>x</sub>	Nitrogen oxides
PM2.5	Fine particulate matter with an aerodynamic diameter of less than 2.5 μm
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
SECA	SO <sub>2</sub> Emission Control Area (SO <sub>x</sub> -ECA)
SO <sub>2</sub>	Sulphur dioxide

# The potential for cost-effective air emission reductions from shipping through designation of further Emission Control Areas in EU waters with focus on the Mediterranean Sea

## 1 Introduction

### 1.1 Context

In 2013, the European Commission adopted the Clean Air Programme for Europe, with specific measures to achieve the existing air quality targets as soon as possible, and proposals for additional legislation to reduce harmful emissions. In 2016, national emission ceilings for six air pollutants have been adopted in the National Emission Ceilings Directive (OJ L344/1, 2016). These initiatives focused on land-based sources within the European Union, but they do not address emissions from the maritime sector, which contribute significantly to air pollution in port cities and coastal areas in Europe and the neighbouring regions.

For international shipping, the Sulphur in Fuel Directive (2016/802/EU) transposes the 2008 revision of the sulphur in marine fuel requirements of Annex VI to the Marine Pollution Convention (MARPOL 73/78) of the International Maritime Organization (IMO) into EU law. It establishes SO<sub>x</sub> Emissions Control Areas (SO<sub>x</sub>-ECAs) in the Baltic, the North Sea and the English Channel, with a limit on the sulphur content in marine fuels of no more than 0.10 percent as of 1/1/2015. In October 2016, the IMO decided to lower the global sulphur limit in marine fuels to 0.50 percent by 2020 for ships sailing outside the ECAs, and to designate the Baltic, the North Sea and the English Channel as NO<sub>x</sub>-Emission Control Areas (NO<sub>x</sub>-ECAs, NECA in this study) as of 2021, introducing strict (Tier III) NO<sub>x</sub> emission standards for new ships.

Given these recent policy agreements, there is interest to explore the balance between the stringencies of the current emission control regulations for land-based sources in the EU versus those for the shipping sector, and to explore the feasibility and potential impacts of further emission reduction initiatives for the maritime sector, for example through designations of additional ECAs in the Sea areas surrounding Europe, in particular in the Mediterranean Sea.

In addition, after completion of earlier studies which explored the costs and benefits of SECAs and NECAs in the Mediterranean Sea (Campling et al. 2013), new information has emerged on the quantities and locations of emissions from shipping, the likely trends of future land-based and shipping activities, and on compliance costs with recent legislation.

Recently the European Commission assessed the implementation of and compliance with the sulphur standards for marine fuels (EC 2018). It was found that the stricter standards – 0.10 percent S in SO<sub>x</sub>-ECAs or SECAs in the North Sea and the Baltic Sea – delivered an important decrease of sulphur deposition in coastal zones of riparian states and improved air quality. Implementation of the NECA from 2021 will further improve air quality in these regions. The global sulphur standard of 0.5 percent sulphur content in marine

fuel from 2020 will decrease negative impacts from shipping in coastal zones of non-SECA Seas. The Commission will continue to consider the potential for further reducing air pollution from ships, potentially also including other pollutants than SO<sub>2</sub>.

## 1.2 Objectives of the report

This report aims to inform discussions at the international and regional levels on the health benefits and associated costs of designating additional Emission Control Areas (both for SO<sub>2</sub> and NO<sub>x</sub> emissions) in the European Seas other than the Baltic and North Seas.

For this purpose, this report:

- updates the projections of the likely development of maritime transport activities,
- provides new assessments of costs of compliance with current legislation,
- improves the understanding of the role of emissions from vessels in ports, and the options for reducing these emissions,
- develops new scenarios of future emissions that would result from different policy interventions, including additional ECAs in the Mediterranean Sea and other European Sea regions,
- assesses their impacts on ambient air quality and resulting population exposure, and
- estimates the associated benefits to human health, and quantifies these benefits in monetary terms.

Importantly, by employing the same methodologies and models that have been used for the Impact Assessment and the underlying reports of the 2013 Clean Air Policy Package (EC 2013) and, most recently, for the Clean Air Outlook of the European Commission (Amann et al. 2017), results are directly comparable with the above-mentioned studies.

## 1.3 Structure of the report

Section 2 provides a brief introduction to the approach of this study and the tools that have been used for the analyses. The starting point of the assessment is an updated inventory of emissions from maritime activities in 2015, which is described in Section 3. Subsequently, Section 4 explores the future impacts of a range of alternative emission regulations (e.g., SECAs and NECAs) in various Sea regions on emissions of PM2.5 precursors, i.e., SO<sub>2</sub>, NO<sub>x</sub>, primary PM2.5 and black carbon (BC). Costs of these emission controls are discussed in Section 5, and their impacts on ambient air quality in Section 6. Section 7 quantifies the health benefits of these emission control variants in terms of premature deaths and estimates the associated monetized benefits. These monetized benefits are compared against the emission control costs in Section 8. Section 9 summarizes the findings and presents conclusions from the analyses.

## 2 Approach, method and tools employed for this study

### 2.1 Approach

This study explores the impacts of alternative emission control interventions for international shipping on the European Seas on relevant air pollutant emissions, examines their consequence on ambient air quality in Europe and the neighbouring regions, and explores the resulting improvements of human health. It estimates the costs of the various policy interventions, and compares them with monetized benefits of human health improvements and other impacts. For this purpose, the study develops alternative emission control scenarios with different assumptions on the spatial scope, stringency and timing of the introduction of specific emission controls. It employs a suite of well-established modelling tools to estimate for each of these scenarios the changes in emissions and the resulting impacts on air quality and human health, and to determine the costs of measures and the benefits in monetary terms.

### 2.2 Modelling tools

As a central tool, this report employs the GAINS (Greenhouse gas – Air Pollution Interactions and Synergies) model (Amann et al. 2011) developed by the International Institute for Applied Systems Analysis (IIASA). To distinguish the impacts of measures in various Sea regions (see Section 2.3) on population exposure to ambient PM<sub>2.5</sub> concentrations across Europe and North Africa, the GAINS calculations were complemented by more detailed computations with MET Norway’s EMEP atmospheric chemistry-transport model (Simpson et al. 2012). Subsequently, EMRC’s ALPHA-RiskPoll model (Holland et al. 2013) provided full benefit analyses, with detailed estimates of all benefits that can be monetized. By employing the same methodologies and models that have been used for the Impact Assessment and the underlying reports of the 2013 Clean Air Policy Package (EC 2013) and, most recently, for the Clean Air Outlook of the European Commission (Amann et al. 2017), results are directly comparable with the above-mentioned studies.

### 2.3 Sea regions and zones distinguished in this study

The study distinguishes shipping emissions and air quality impacts in eight Sea regions around Europe (Figure 1). Each of these regions is subdivided into four zones, i.e., (i) ports and berth activities, (ii) within internal waters and the territorial Seas (12 nm from the internal waters boundary), (iii) within the exclusive economic zones (200 nm from the internal waters boundary), and (iv) outside the exclusive economic zones (high Seas). Where applicable, EU and non-EU waters are addressed separately (see Annex 1).

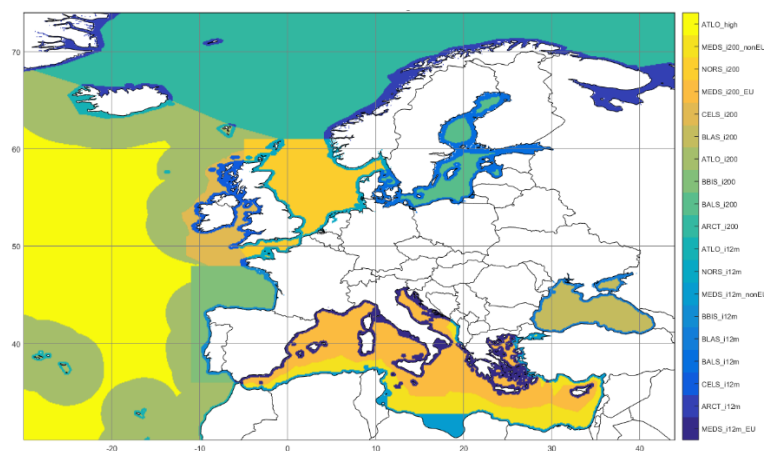


Figure 1: Emission source regions distinguished in this study. Definitions of the zones are provided in Annex 1.

### 3 An inventory of shipping emissions in 2015

As a starting point for the analyses of the effectiveness of further emission controls, a spatially resolved inventory of shipping emissions was compiled for the year 2015 that (i) takes into account most recent statistical data and information on emission factors, (ii) distinguishes the different categories of vessels to the extent that these are relevant for emissions and emission controls, and (iii) considers the Sea regions and zones defined in Section 2.3.

Emissions of air pollutants have been estimated based on the gridded inventory of CO<sub>2</sub> emissions (by vessel type) developed with the STEAM 3 model by the Finnish Meteorological Institute (Johansson et al. 2017), which employed AIS (Automatic Identification System) activity data for the year 2015. Assuming representative emission factors for CO<sub>2</sub>, underlying fuel consumption volumes have then been derived for each of the 28 zones. For further analysis, the 11 vessel categories of the STEAM 3 model have been aggregated into seven types of ships: cargo, container, passenger vessels, RoPax, tankers, vehicle carriers, and others (fishing vessels, service ships, miscellaneous, and other/unknown vessels).

While the STEAM3 inventory includes data for all ship movements, regulations and reporting requirements are different for international shipping and for seagoing ships travelling between ports in the same country. EU emission regulations apply to the latter category, and countries have to report these emissions as part of their national emission inventories. In order to avoid double counting of emissions, fuel volumes used for national shipping have been estimated and subtracted from total fuel consumption, so that the resulting data represent the best estimates for international shipping (see Annex 2).

#### 3.1 Fuel consumption

In 2015, fuel consumption by vessels operating in European Seas amounted to about 1.8 EJ, which corresponds to about 20 percent of the total diesel fuel consumption for road traffic in the EU-28. About 40 percent of the fuel was consumed in the Mediterranean Sea, 20 percent in the North Sea, and about 10 percent in the Gulf of Biscay, the Baltic Sea and the North East Atlantic (within the study domain), respectively (Figure 2). About one third of all fuel was consumed by container ships, 22 percent by tankers and 19 percent by cargo ships.

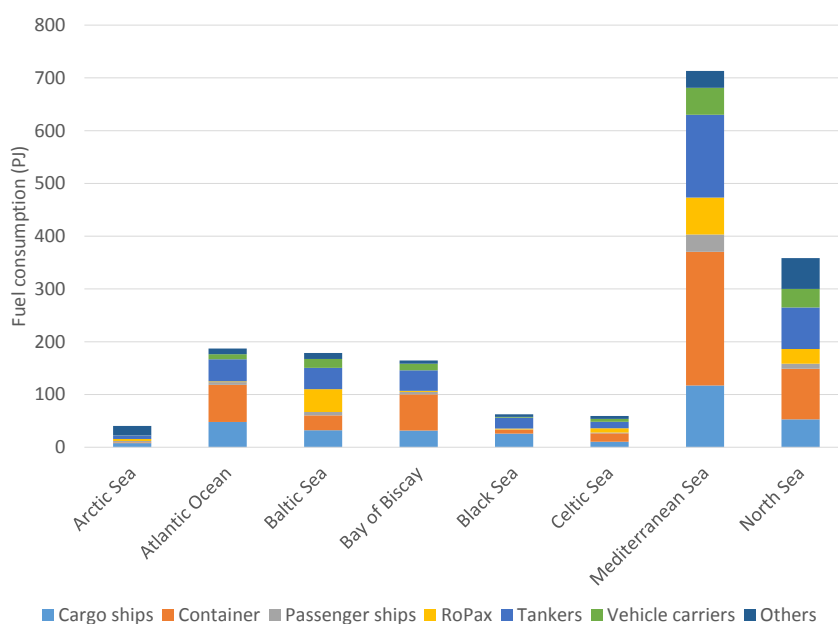


Figure 2: Fuel consumed by international shipping in 2015



### 3.2 Emissions in 2015

It is estimated that international shipping in Europe caused emissions of about 134 million tons of CO<sub>2</sub>, 1,230 kt of SO<sub>2</sub>, 2,830 kt of NO<sub>x</sub> and 175 kt PM2.5. These quantities compare to 3.6 percent of land based CO<sub>2</sub> emissions in the EU-28, 44 percent of land-based SO<sub>2</sub>, 36 percent of NO<sub>x</sub> emissions, and 13 percent of PM2.5 emissions (Figure 3; tables are provided in Annex 2). Based on these data, gridded emissions have been computed for SO<sub>2</sub>, NO<sub>x</sub> and PM2.5 for the various vessel types.

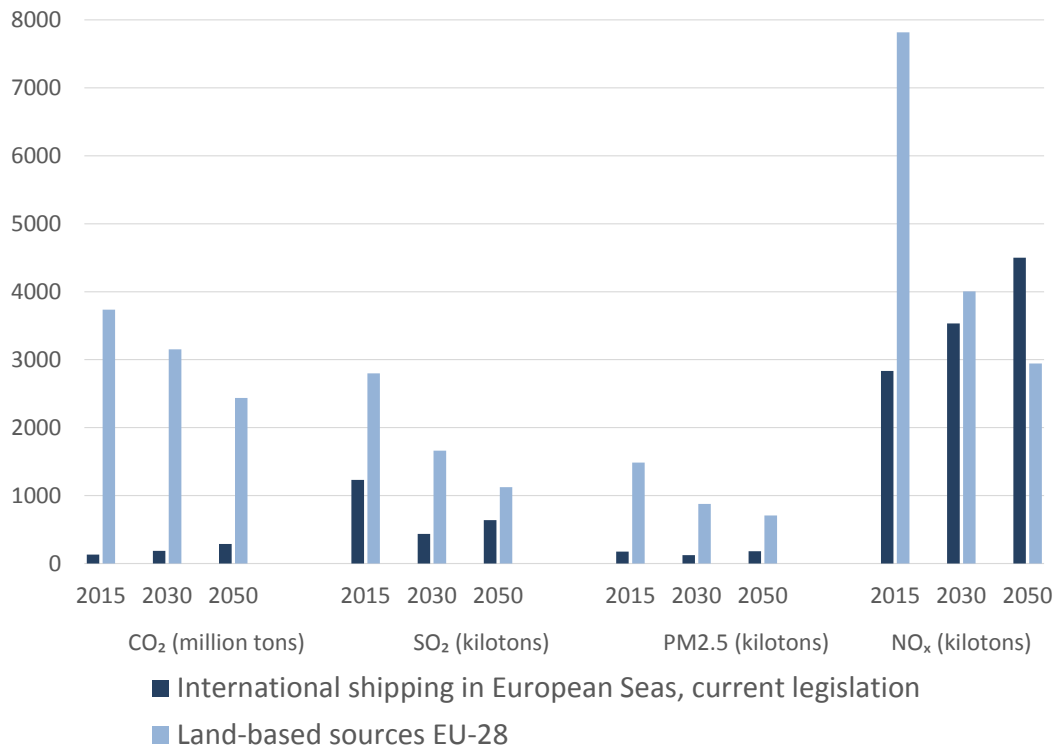


Figure 3: Emissions from maritime shipping in the European Seas and from land-based sources in the EU-28

The largest share of emissions emerges from container ships, followed by tankers and cargo ships (Figure 4).

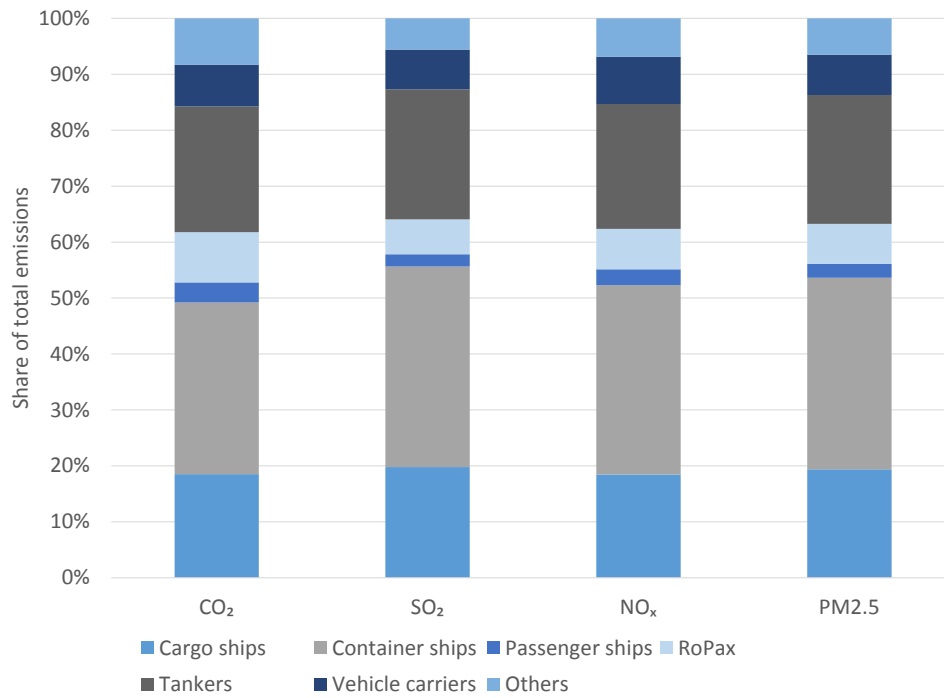


Figure 4: Emissions from international shipping in 2015, by vessel type

The spatial pattern of NO<sub>x</sub> emissions mirrors closely the fuel consumption volumes, while for SO<sub>2</sub> and PM the emission controls in the SECA regions (Baltic Sea and the North Sea) cause large differences. Up to 57 percent of all emissions from international shipping in Europe occur in the Mediterranean Sea (Figure 5).

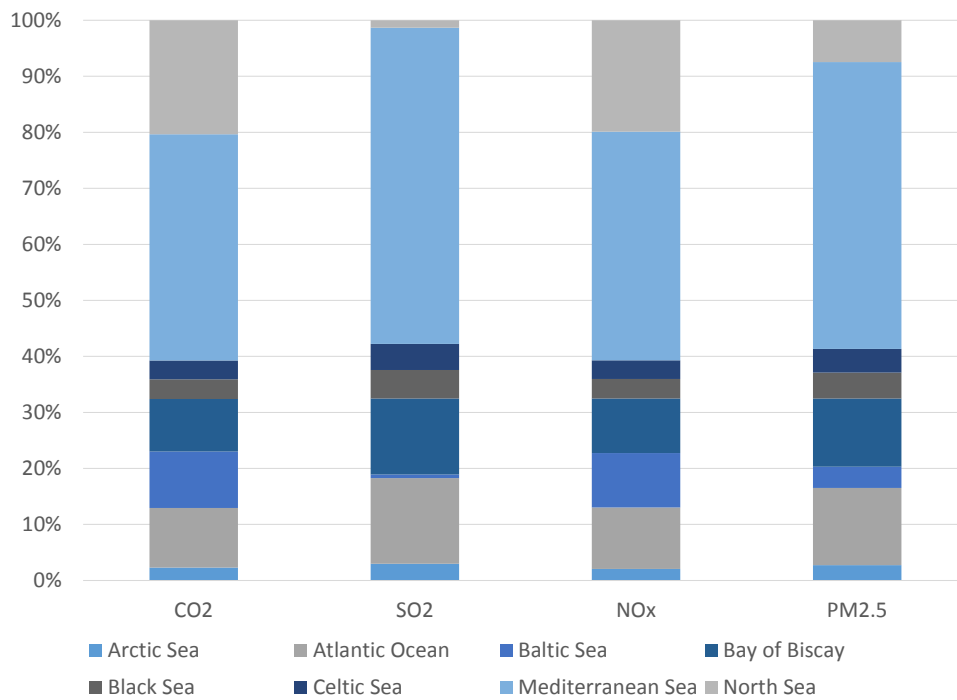


Figure 5: Emissions from international shipping in 2015, by Sea region

Up to one third of emissions is emitted in the 12 nm zones along the coasts, and about two thirds in the adjacent 200 nm zones, most of which in dedicated shipping corridors in variable distances to the coast. Berth or in ports activities account for only a few percent of all emissions from international shipping. In the Mediterranean Sea, about two thirds of emissions originate from the EU waters (Figure 6).

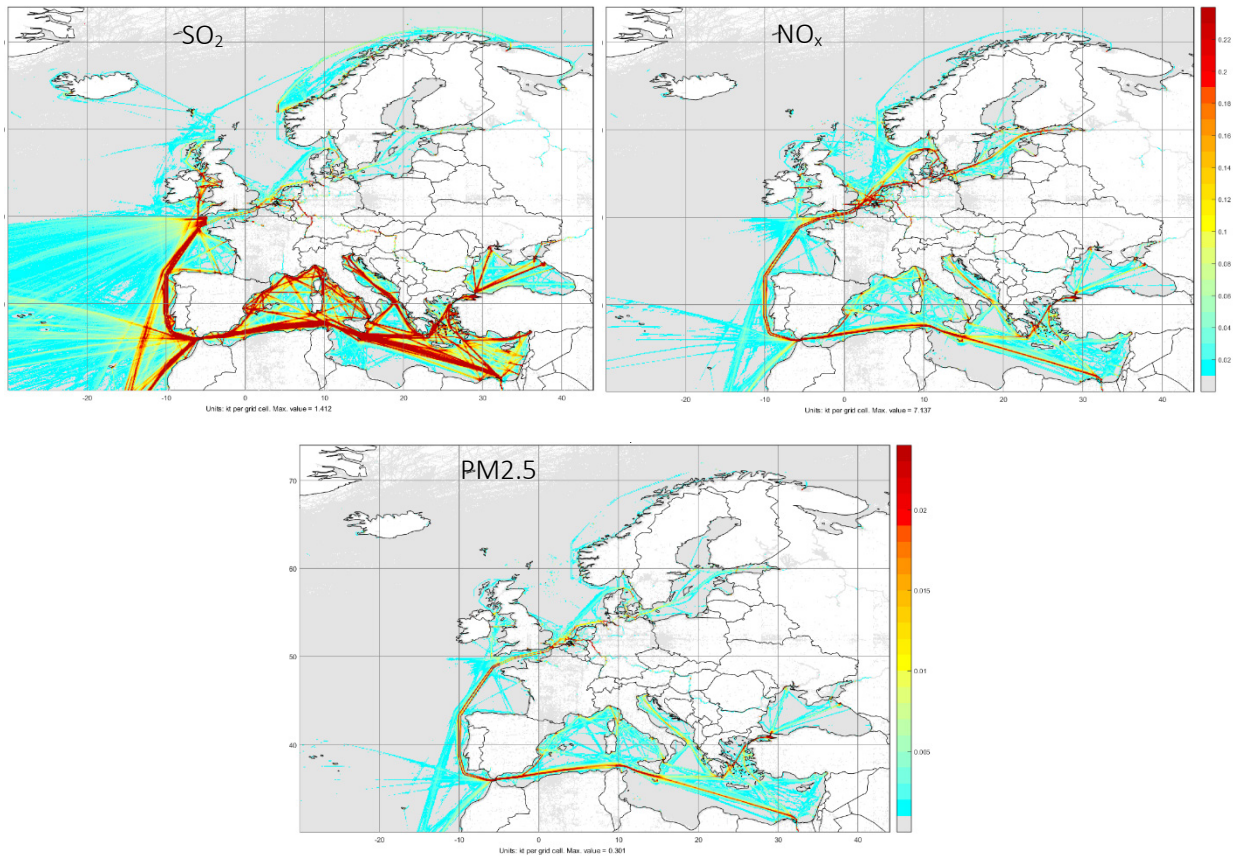


Figure 6: Gridded emissions of SO<sub>2</sub> and NO<sub>x</sub> (upper panel) and PM<sub>2.5</sub> (lower panel) in 2015, kt

### 3.3 Comparison with other inventories

In general, the emission estimates developed for this study compare rather well with the FMI inventory for 2015 (Johansson et al. 2017), which is not surprising given that the gridded FMI inventory for CO<sub>2</sub> was taken as the starting point for this analyses. Differences (less than 7 percent for fuel consumption and lower than 3 percent for SO<sub>2</sub> emissions) are explained by different estimates for national Sea traffic.

Also, for comparable domains, the estimated fuel consumption data are in close agreement ( $\pm 2$  percent) with the statistics developed by the European Maritime Safety Agency (EMSA), which were derived from recorded ship movement data. The EMSA inventory does not include the Atlantic and Arctic Oceans, which prohibits a complete comparison. However, notable differences for some Sea regions need further clarification.

The good agreements of the fuel consumption data are reflected by the NO<sub>x</sub> estimates, and the differences to earlier studies are mainly explained by new information on emission factors. More details are provided in Annex 2.

## 4 Scenarios of future emissions

To explore the costs, health impacts and monetary benefits of additional controls of maritime emissions, this report develops a range of alternative scenarios of future emissions for different assumptions on the evolution of fuel demand, climate policies and emission controls.

### 4.1 Projections of fuel demand

Two alternative projections explore the interplay between the growth in shipping activities, trends in energy efficiency improvements, and climate policies. A baseline projection extrapolates current trends in economic growth, trade relations and fuel efficiencies, while a ‘with climate measures’ scenario illustrates the potential consequences of greenhouse gas reduction policies for maritime activities, and their knock-on effects on air pollutant emissions.

For these scenarios, future fuel consumption trends up to 2030 are derived from the ‘business as usual’ and ‘climate policy’ scenarios developed by COWI, CENIT and VITO (EC 2015), and follow thereafter the corresponding growth rates assumed in the 3<sup>rd</sup> IMO Greenhouse Study (Smith et al. 2015). With these assumptions, total fuel consumption for international shipping on European Seas increases in the baseline case from 1.8 EJ in 2015 to about 4.1 EJ in 2050. In contrast, with climate measures fuel consumption volumes would stabilize at a level below 2.0 EJ after 2030 (Figure 7). Notably, with a 5 percent increase of CO<sub>2</sub> emissions in 2050 relative to 2015, this ‘with climate measures’ scenario falls significantly short of the ambition of the 2018 IMO agreement reached at the MEPC 72 meeting, i.e., to reduce shipping's greenhouse gas emissions by at least 50 percent by 2050 (IMO 2018). Details are provided in Annex 3.

Trends vary across different vessel types, based on the projections developed by (Winnes 2015; Smith et al. 2015; Åström et al. 2018). These suggest a rapid expansion of container and dry cargo traffic, while for oil tankers, passenger vessels and other vessel types much lower increases or even declines are projected. This will lead to a distinct shift in the relative shares of different vessel types. By 2050, container ships would consume 48 percent of all fuel in the baseline case and 38 percent in the ‘with climate policy’ case, compared to 31 percent in 2015. Shares of other vessel types (e.g., tankers) are expected to decrease accordingly (Figure 7).

It is expected that liquefied natural gas (LNG) will play a greater role as a marine fuel, although the exact penetration rate remains open due to uncertainties about fuel supply infrastructure, LNG prices, and investment costs for vessels. This study adopts the global LNG trend of the NPS scenario of the IEA World Energy Outlook 2017 (IEA 2017), assuming that Europe will maintain its share in total global LNG use (11 percent) that has been projected for 2025 by (CE Delft 2016). Thereby, the share of LNG in the total fuel demand at European Seas would increase from less than 2 percent in 2020 to about 5 percent in 2030 and nearly 12 percent in 2050.

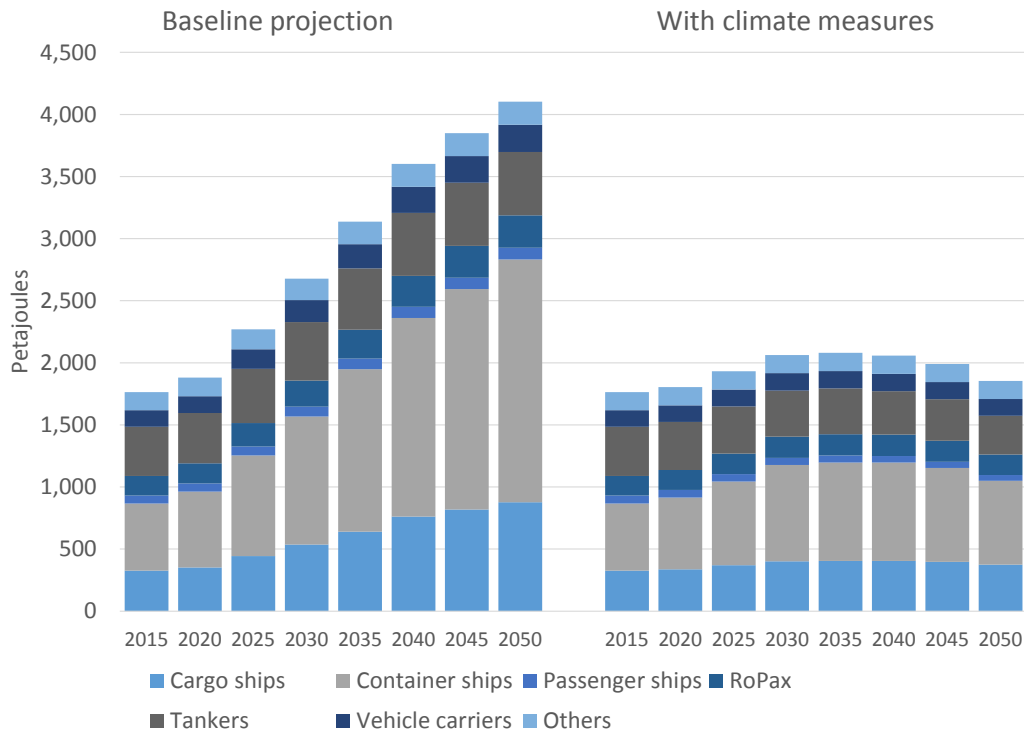


Figure 7: Assumed development of fuel consumption by vessel type

## 4.2 Emission controls

For the two projections listed above, this study develops three families of emission control scenarios:

- The **Current Legislation (CLE)** scenario illustrates the impacts of current policies and regulations for maritime emissions. In particular, it assumes full compliance with the IMO MARPOL Annex VI standards for fuel quality and for NO<sub>x</sub> emissions. As of 2015, these required in the sulphur emission control areas (SECAs) in the Baltic Sea, North Sea and English Channel reductions of the sulphur content down to a limit of 0.1 percent. Fuels with higher sulphur content are allowed, but require flue gas desulfurization. From 2020 onwards, the sulphur content of marine fuels will be limited to 0.5 percent outside the SECAs. For national and international ships berthed and anchored in EU ports the sulphur content is limited to 0.1 percent by the EU Sulphur in Liquid Fuel Directive (2016/802/EU). In addition, vessels built after mid-2011 need to meet Tier II standards for NO<sub>x</sub> emissions and, as of 2021, new vessels operating in NO<sub>x</sub> emission control areas (NECAs) including the North Sea and Baltic Sea have to comply with Tier III NO<sub>x</sub> emission standards. Corresponding emission factors are presented in Annex 4.
- **Extended SO<sub>2</sub> Emission Control Areas (SECA)** as of 2025, imposing a limit of 0.1 percent on the sulphur content of fuel (or equivalent emissions through scrubbers) for all vessels. The temporal introduction of scrubbers follows the assumptions of MECL, 2017 and IHS Markit, 2018 (see Annex 6). Variants

explore different target areas (12 mile zones only/all Sea regions/excluding the Atlantic Ocean outside the 12 nm zone).

- Extended **Tier III NO<sub>x</sub> emission standards** as of 2025, for new vessels only (corresponding to the current requirements for NECAs) or including retrofits of existing vessels. Variants are computed for different Sea regions and earlier introduction (2021).

### 4.3 Emission projections

#### 4.3.1 CO<sub>2</sub> emissions

With the quantitative assumptions described above, CO<sub>2</sub> emissions from international shipping increase in the baseline case by about 50 percent up to 2030 compared to 2015, and by a factor of 2.3 until 2050. In contrast, in the ‘with climate measures’ case they grow by 15 percent up to 2020, and decrease to the 2015 level thereafter (Figure 8). More than 40 percent of total CO<sub>2</sub> is emitted in the Mediterranean Sea.

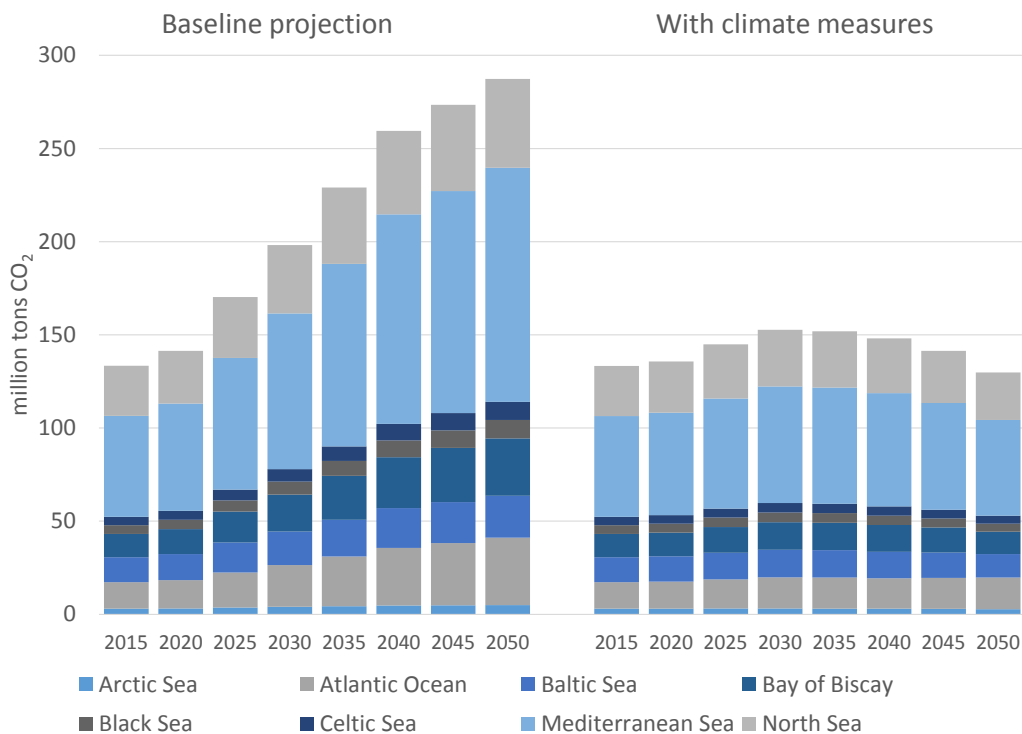


Figure 8: Emissions of CO<sub>2</sub> by Sea region, million tons

#### 4.3.2 SO<sub>2</sub> emissions

Current legislation will lead to a clear decoupling of shipping volumes and SO<sub>2</sub> emissions, although future emission levels will be critically linked to the evolution of fuel consumption, which is likely to be strongly determined by greenhouse gas policies. In the baseline, fuel consumption is expected to grow by 50 percent in 2030 and 130 percent in 2050 relative to 2015. Current emission regulations will reduce SO<sub>2</sub> emissions in the European Seas by 65 percent in 2030 and by almost 50 percent in 2050 (Figure 9). Climate measures would effectively reduce fuel consumption and lead, as a side-effect, to a further decline of SO<sub>2</sub> emissions,

by 73 percent in 2030 and by 78 percent in 2050. Declaration of all Sea regions as SECAs would cut SO<sub>2</sub> emissions in 2030 and beyond by 90-94 percent, depending on the ambition of climate measures.

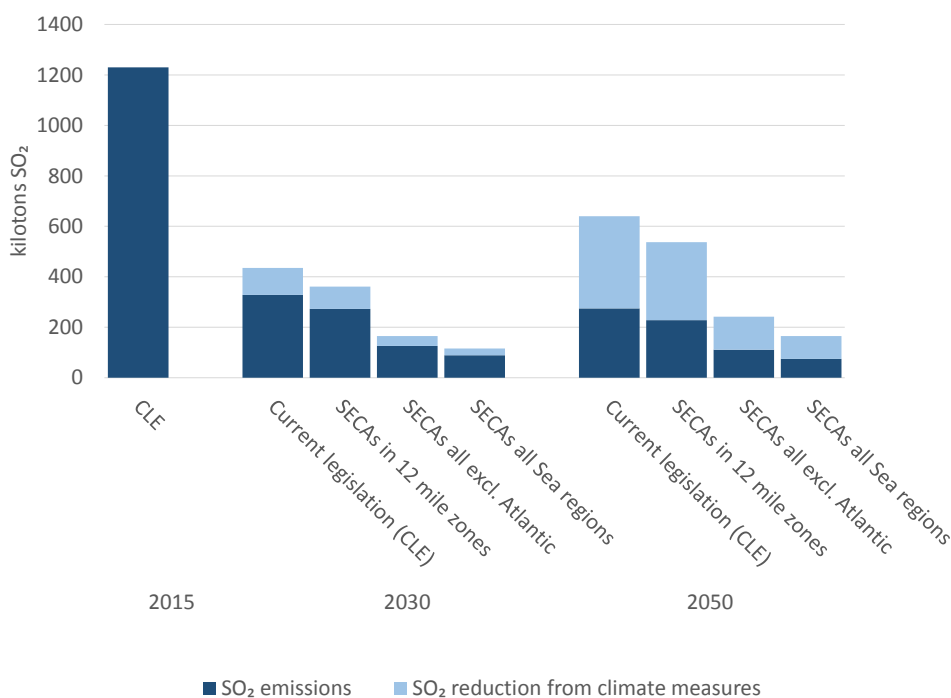


Figure 9: SO<sub>2</sub> emissions from international shipping in the European Seas, measures applied in all Sea regions. The total bars refer to the baseline case, while the light blue areas indicate the reduction from climate measures.

### 4.3.3 PM<sub>2.5</sub> and BC emissions

The current emission standards will also affect trends of PM<sub>2.5</sub> emissions, leading to 30 percent lower emissions in 2030, after which emissions rebound to current levels in the baseline in 2050. Greenhouse gas measures would decrease PM<sub>2.5</sub> by about 50 percent as a side-effect (Figure 10).

An introduction of SECAs in all Sea regions would cut PM<sub>2.5</sub> emissions further. They fall in the baseline case by about 45 percent until 2030. Thereafter, the continuing increase in traffic volumes lets PM<sub>2.5</sub> grow again, but emissions will remain 25 percent below the 2015 level up to 2050. In contrast, SECAs combined with climate measures could cut PM<sub>2.5</sub> emissions in 2050 by two thirds below today's level.

Installation of particle filters (PF) for ships could reduce PM<sub>2.5</sub> emissions by up to 80 percent in 2030 and 97 percent in 2050.

As a side effect, emission controls for SO<sub>2</sub> will also influence trends of black carbon (BC) emissions, although to a lesser extent than those of PM<sub>2.5</sub>. In the baseline case, BC emissions grow after 2030 by up to 40 percent in 2050 (while fuel consumption is projected to increase by 130 percent). The climate measures would cut them by 37 percent in 2050 (Figure 11). SECAs and dedicated PM controls could deliver additional cuts, and reduce black carbon emissions by up to 87 percent in 2050.

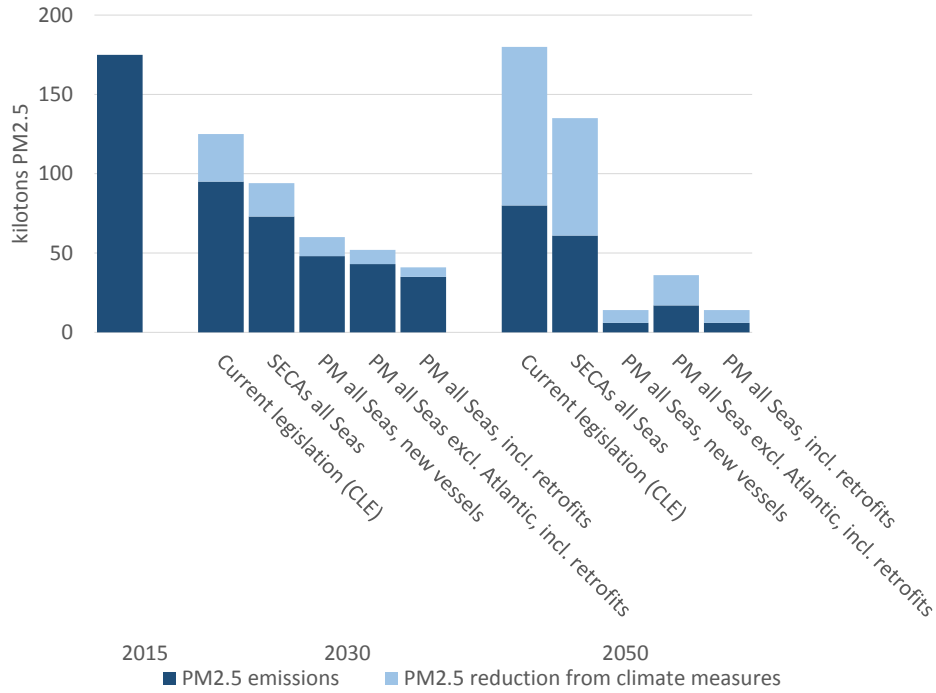


Figure 10: PM2.5 emissions from international shipping in the European Seas, measures applied in all Sea regions. The total bars refer to the baseline case, while the light blue areas indicate the reduction from climate measures.

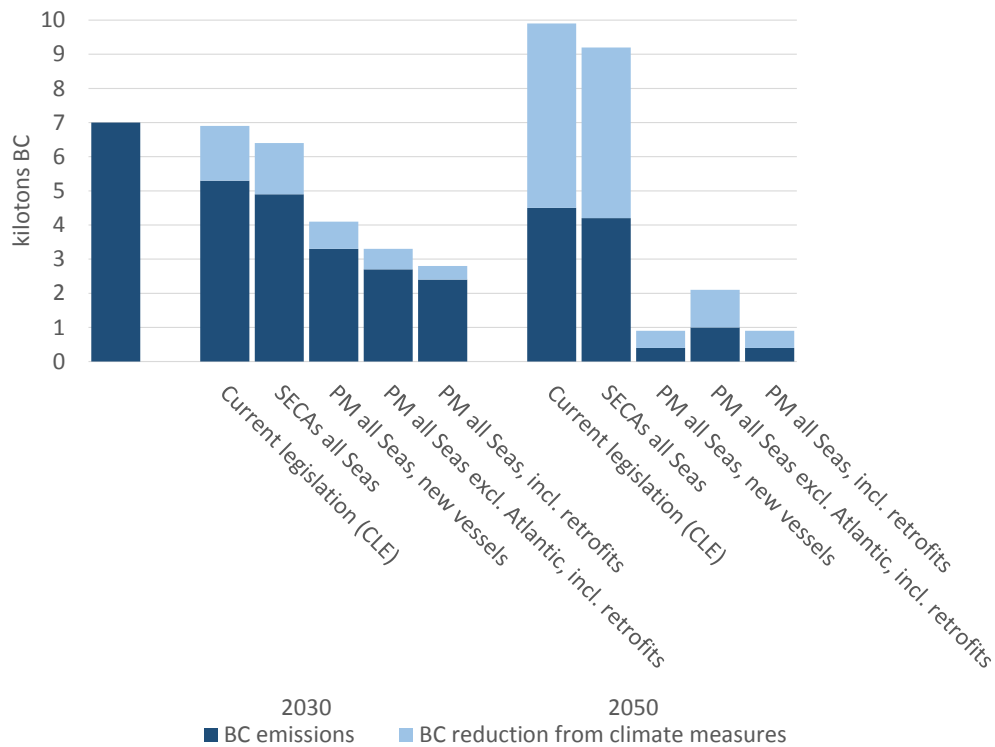


Figure 11: BC emissions from international shipping in the European Seas, measures applied in all Sea regions. The total bars refer to the baseline case, while the light blue areas indicate the reduction from climate measures.



#### 4.3.4 NO<sub>x</sub> emissions

For NO<sub>x</sub>, current legislation will affect emissions at a slower pace, due to the fact that the IMO NO<sub>x</sub> standards apply to new vessels only. Thus, the benefits of Tier III standards in the NECAs in the Baltic and the North Sea and of the Tier II standards in other Sea regions will be partly offset by expected increased fuel consumption in the baseline scenario. Thus, baseline NO<sub>x</sub> emissions in the European Seas increase by 26 percent until 2030, and up to 60 percent by 2050. In contrast, the climate measures scenario stabilizes NO<sub>x</sub> emissions in the European Seas in the coming decades, and reduces them by one third until 2050.

Larger emission reductions could be achieved through enhanced application of Tier III standards. If applied to all new vessels from 2025 onwards, NO<sub>x</sub> emissions would not grow by more than five percent in 2030 in the baseline, and could decline by 16 percent if combined with greenhouse gas measures. Retrofitting vessels to Tier III standards would cut NO<sub>x</sub> already in 2030 by 16-31 percent, depending on climate measures. Imposing these regulations from 2021 onwards would reduce NO<sub>x</sub> emission by 22-36 percent in 2030.

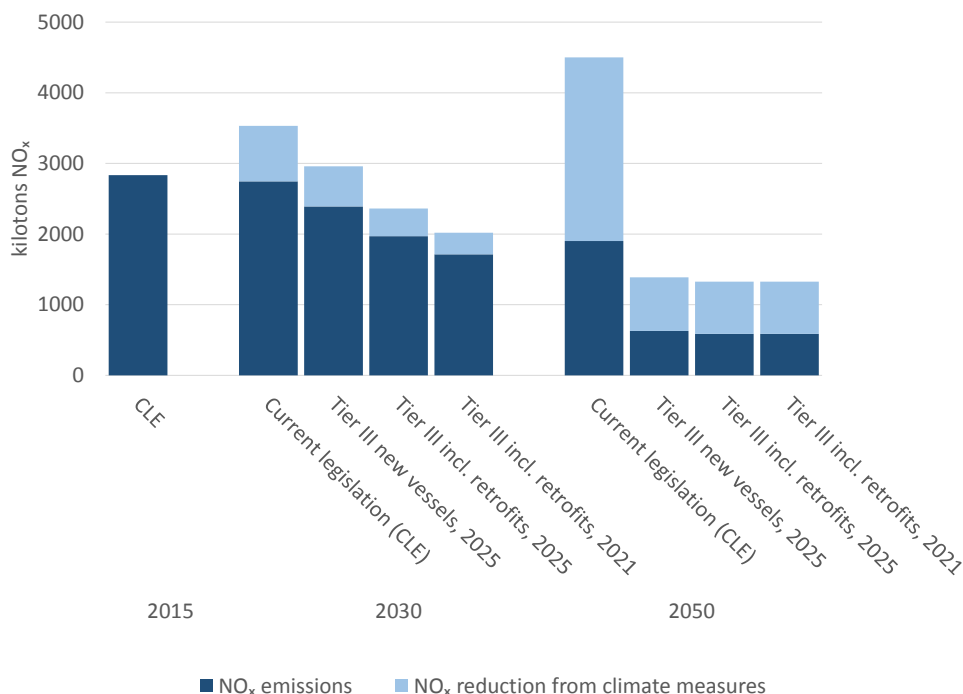


Figure 12: NO<sub>x</sub> emissions from international shipping in the European Seas, measures applied in all Sea regions

#### 4.4 Emissions in the Mediterranean Sea

While this assessment has been carried out for all European Sea regions (detailed results are presented in Annex 5), there is special interest in the potential impacts of emission controls in the Mediterranean Sea. For this purpose, the emission control variants introduced in Section 4.2 have been explored in details for four potential ECAs in the Mediterranean:

- Territorial waters (12 nm from coast) of EU countries
- Exclusive economic zones (12 - 200 nm from coast) of EU countries
- Territorial waters of all countries
- Exclusive economic zones of all countries (i.e., the whole Mediterranean).

A SECA in the 12 nm zones of EU Member States would reduce SO<sub>2</sub> emissions by about 15 percent compared to the baseline situation, and by 50 percent if extended to the 200nm zones of EU Member States. Applied to all coastal States in the Mediterranean, a 12 nm SECA would lead to about 25 percent lower emissions, and the 200 nm zone to 80 percent lower SO<sub>2</sub> (Figure 13).

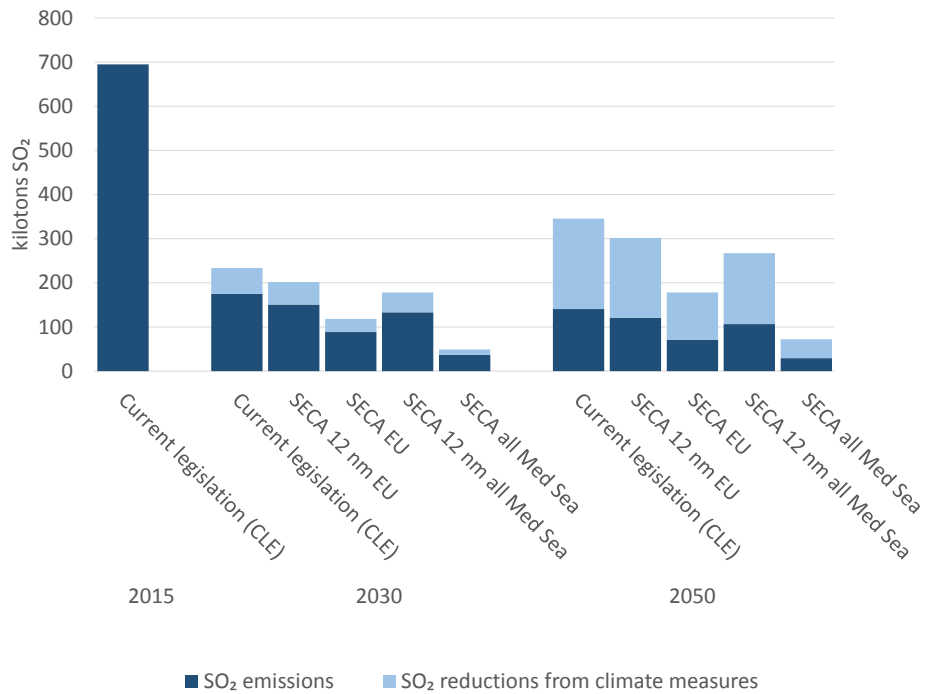


Figure 13: SO<sub>2</sub> emissions from international shipping in the European Seas, measures applied in the Mediterranean Sea

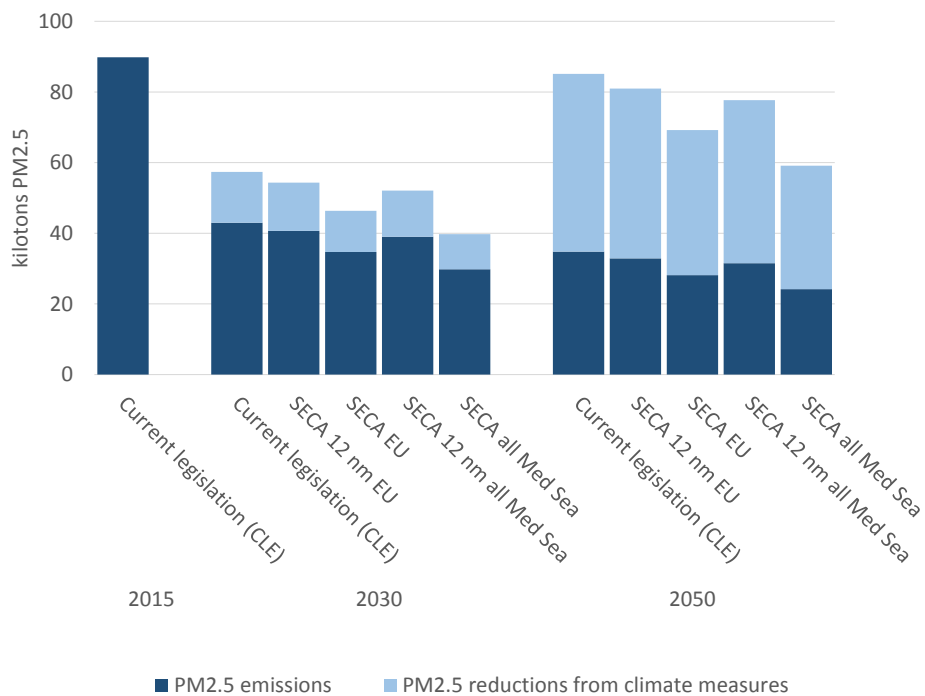


Figure 14: PM<sub>2.5</sub> emissions from international shipping in the European Seas, measures applied in the Mediterranean Sea

The lower sulphur content will also reduce PM2.5 emissions, by 5 percent and 20 percent for the 12 nm and 200 nm zones of EU countries, respectively, and by 10 percent and 30 percent if applied in all coastal countries (Figure 14).

Declaration of the whole Mediterranean Sea as a NECA in 2025 would reduce NO<sub>x</sub> emissions by 17 percent in 2030, of which 10 percentage points are achieved in EU waters. A NECA declaration in 2021 would increase the emission reduction to 28 percent in 2030 (17 percentage points in EU waters). By 2050, NO<sub>x</sub> reductions increase to about 46 percent for a NECA in EU waters, and to 73 percent for the whole Mediterranean Sea (Figure 15).

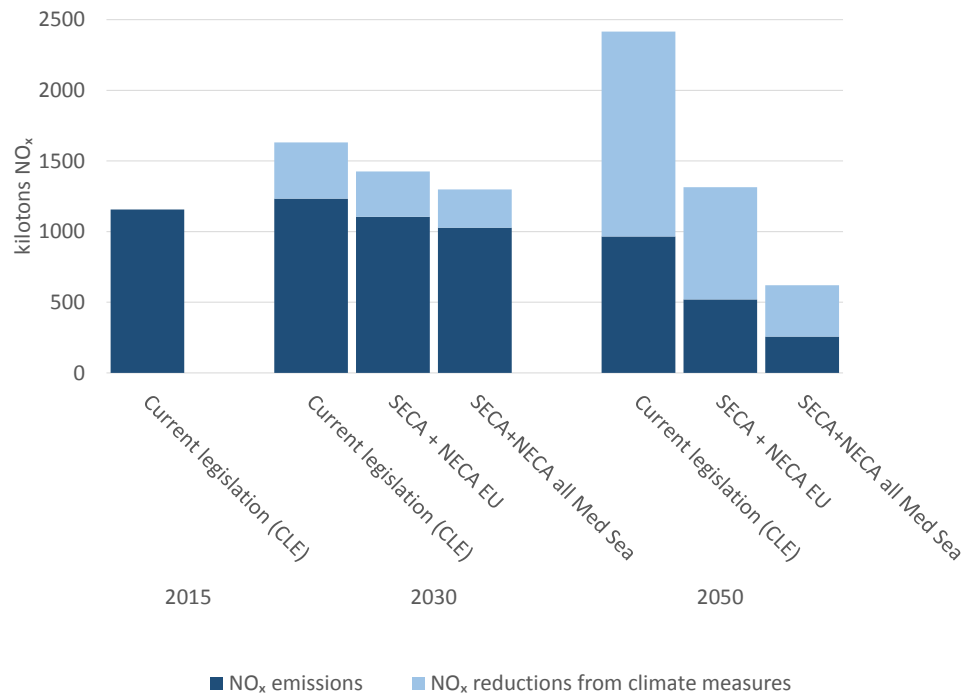


Figure 15: NO<sub>x</sub> emissions from international shipping in the European Seas, measures applied in the Mediterranean Sea

## 5 Emission control costs

As an input for the assessment of costs and benefits of additional emission controls for international shipping, this study assesses, for each of the scenarios presented above, the costs for implementing the emission reduction measures. These estimates have been derived with IIASA's GAINS model (Amann et al. 2011) based on data about technologies and costs from literature sources. Methodology and data used for the cost calculation are presented in Annex 6.

The evaluation of emission control costs in the future will critically depend on a number of factors that are hard to predict. These include the stringency of future climate policy measures, which will determine the future volumes of fuel consumption and thus the need for emission controls. In addition, SO<sub>2</sub> control costs depend heavily on the future price premium for low sulphur marine fuels on the world market, as well as on the penetration rates of sulphur scrubbing. The developments of both factors are uncertain, and there are likely strong connections between the price premiums and the penetration of scrubbing. With the fuel price premiums that have been presented in (MECL 2017; IHS Markit 2018), sulphur scrubbing appears as a competitive option for meeting the SO<sub>2</sub> emission standards (see Annex 6).

### 5.1 Measures in all European Seas

Assuming the penetration schedule as listed in Annex 6, costs for implementing the current legislation for SO<sub>2</sub> are estimated between 4.0 and 3.1 billion €/yr in 2030, for the baseline and 'with climate measures' cases, respectively. By 2050, they would decline to 3.7 billion €/yr in the baseline, and to 1.8 billion €/yr with climate measures. Without scrubbers, baseline costs would increase to 4.7 billion €/yr in 2030 and to 7.0 billion €/yr in 2050. Lower fuel consumption from climate measures reduces emission control costs to 3.7 billion €/yr in 2030 and to 3.2 billion €/yr in 2050. Details are presented in Annex 6.

In a sensitivity analysis with the assumptions on the fuel price premiums taken from the recent REMPEC study (by EERA/FMI 2018), costs would increase to 7.0 billion €/yr ('with climate measures') and to 9.1 billion €/yr (baseline) in 2030, and to 2.8 – 6.0 billion €/yr in 2050. About 40 percent of these costs are linked to the SECAs in the Baltic and the North Sea.

An extension of the SECA regulations to all European Seas would entail additional costs of 1.2 billion €/year (baseline) and 0.9 billion €/year ('with climate measures').

For NO<sub>x</sub>, emission control costs for current legislation range between 0.18 and 0.24 billion €/year in 2030 and 0.35-0.69 billion €/year in 2050, for the baseline and the 'with climate measures' cases, respectively. Additional costs for Tier III for all new vessels from 2025 onwards amount to 0.1-0.17 billion €/year in 2030, and 0.44-1.06 billion €/year in 2050. With retrofits of existing vessels to Tier III, additional costs (on top of current legislation) increase to 0.46-0.69 billion €/year in 2030, and to 0.47-1.11 billion €/year in 2050 (Annex 6).

Introduction of particle filters (including retrofits) would require 0.21-0.39 billion €/year in 2030 and 0.21-0.50 billion €/year.

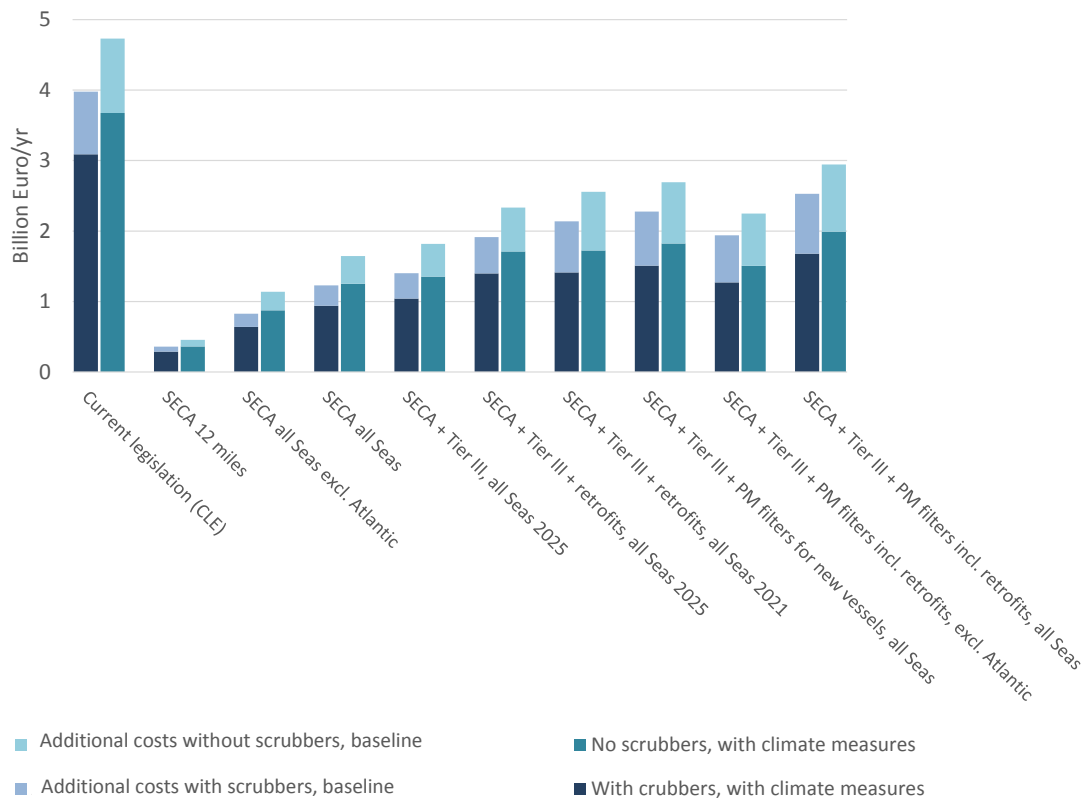


Figure 16: Current legislation emission control costs in 2030 and incremental costs for additional ECA scenarios.

## 5.2 Measures in the Mediterranean Sea

For 2030, costs for SECAs in the 12 mile zones of the EU Member States are estimated between 146 and 176 million €/yr, depending on the climate policy measures and assuming penetration of scrubbing. Without scrubbers, estimates increase to 179-219 million €/yr. SECAs in all 12 mile zones in the Mediterranean would increase costs by about 50 percent, while a SECA covering the entire Mediterranean would triple costs.

For 2050, the costs for SECAs for the 12 mile zones of the EU Member States decrease to 76-110 million €/yr (with scrubbing), depending on the climate policy measures. Without scrubbers, estimates range between 150 and 271 million €/yr.

Costs of applying Tier III NO<sub>x</sub> standards in the EU economic zones range between 60 and 90 million €/year in 2030, and between 90 and 140 million €/year if applied to the entire Mediterranean (see Annex 5). For 2050, costs are estimated at 210-464 million €/yr for the EU economic zones, and at 316-738 million €/yr for the entire Mediterranean.

## 6 Ambient air quality

The policy measures to reduce emissions from international shipping on European Seas will have impacts on air quality and subsequently on human health. To this end, IIASA's GAINS model, complemented by more detailed calculations with the latest version of the EMEP atmospheric chemistry and transport model by the Norwegian Meteorological Institute (Simpson et al. 2012) has been used to estimate the decrease in ambient concentrations of PM<sub>2.5</sub> across Europe and along the Mediterranean coast, as well as the impacts on population exposure in the various countries. Human exposure to PM<sub>2.5</sub> has been chosen as the most relevant health impact indicator, due to the strong epidemiological evidence on its association with premature mortality. Note that lower primary emissions of PM<sub>2.5</sub> will have direct impact on ambient PM<sub>2.5</sub> levels. In contrast, the impacts of lower SO<sub>2</sub> and NO<sub>x</sub> emissions on ambient PM<sub>2.5</sub> occur through chemical reactions with NH<sub>3</sub> that form secondary PM<sub>2.5</sub> aerosols, i.e., ammonium sulphate and ammonium nitrate. The EMEP atmospheric chemistry and transport model simulates these reactions, which depend *inter alia* on the availability of NH<sub>3</sub> (ammonia) in the atmosphere.

### 6.1 Ambient concentrations of PM<sub>2.5</sub>

In general, the emission reduction scenarios show largest effects along the coast of Mediterranean countries, and in particular along the North African coast. Here the concentrations of PM<sub>2.5</sub> decrease by up to 1.2 µg/m<sup>3</sup> in 2030 (Figure 17) and up to 1.5 µg/m<sup>3</sup> in 2050 (Figure 18). Biggest improvements emerge for extended SECAs; NECAs deliver lower reductions, especially in the short run and when the introduction of Tier III standards is limited to new vessels only.

In the Mediterranean, tighter sulphur standards deliver the largest air quality improvements along the coast line (upper panel in Figure 19 and Figure 19). Also here, the benefits of Tier III standards are limited, especially in 2030 when only a small share of the fleet will be affected (lower panels in Figure 19 and Figure 19).

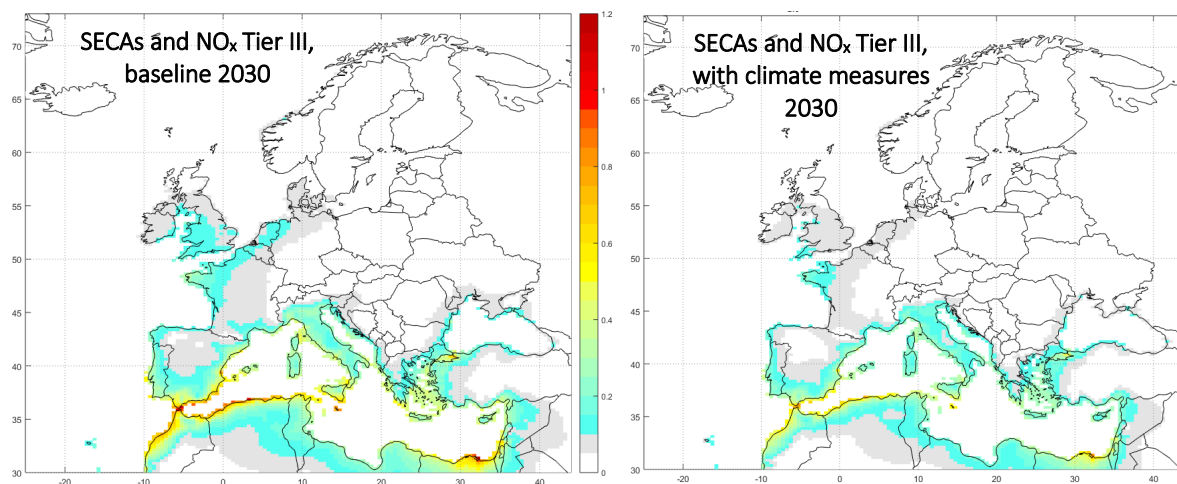


Figure 17: Decrease of ambient PM<sub>2.5</sub> concentrations (µg/m<sup>3</sup>) in 2030 from implementation of SECAs and Tier III standards for NO<sub>x</sub> (including retrofits) in all European Sea regions, for the baseline case (left panel) and the scenario with climate measures (right panel)

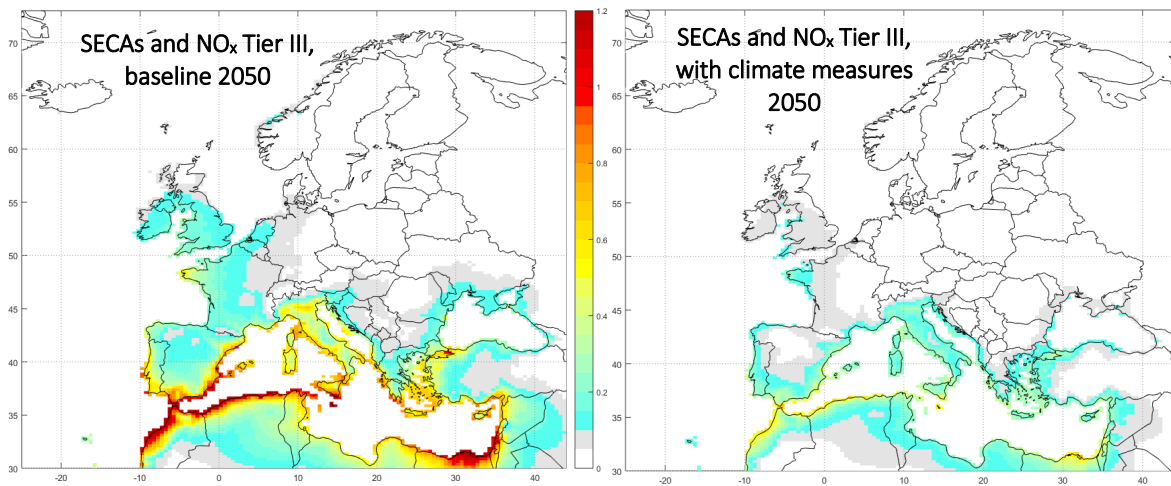


Figure 18: Decrease of ambient PM<sub>2.5</sub> concentrations ( $\mu\text{g}/\text{m}^3$ ) in 2050 from implementation of SECAs and Tier III standards for NO<sub>x</sub> (including retrofits) in all European Sea regions, for the baseline case (left panel) and the scenario with climate measures (right panel)

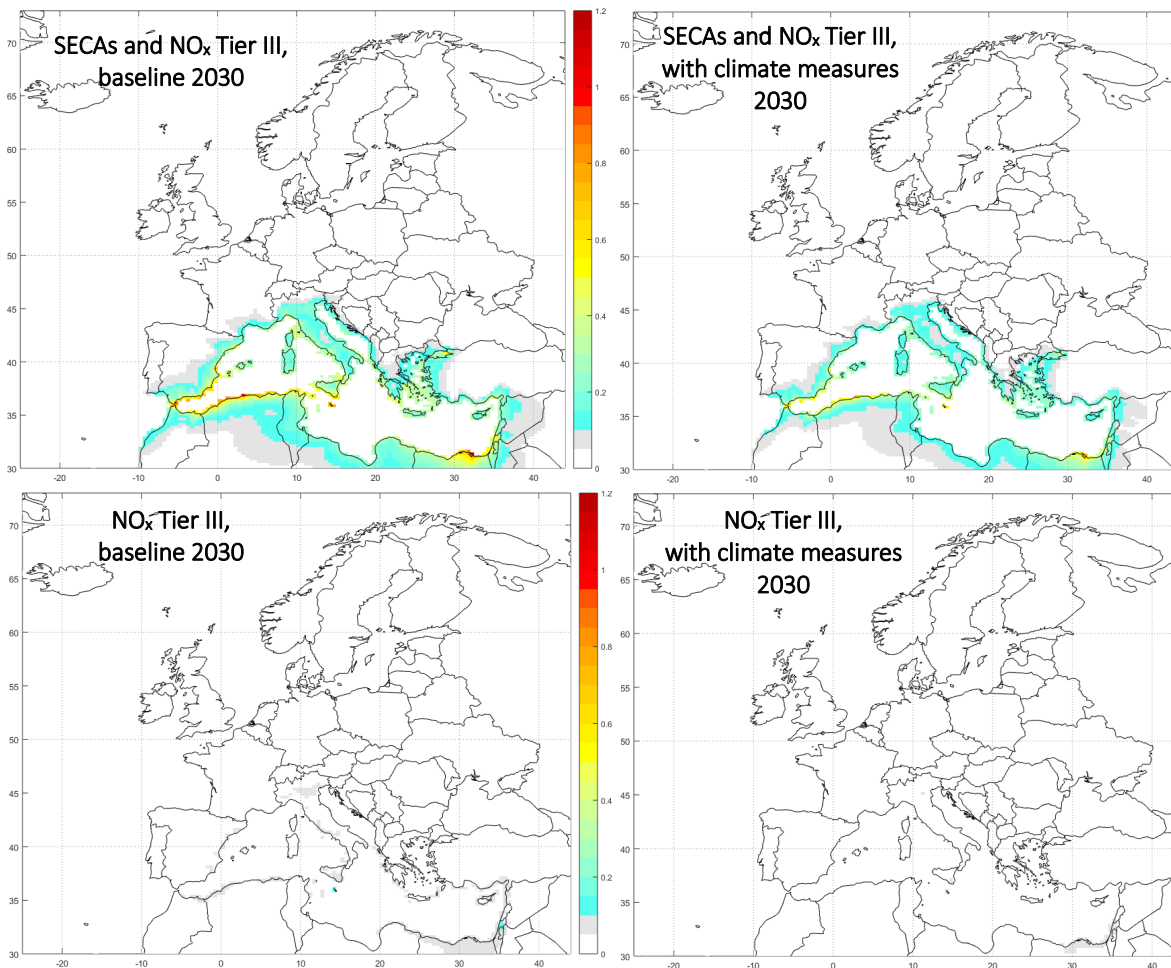


Figure 19: Decrease of ambient PM<sub>2.5</sub> concentrations ( $\mu\text{g}/\text{m}^3$ ) in 2030 from implementation of SECAs (upper panels) and Tier III standards for NO<sub>x</sub> including retrofits (lower panels) in the Mediterranean Sea, for the baseline case (left panel) and the scenario with climate measures (right panel)

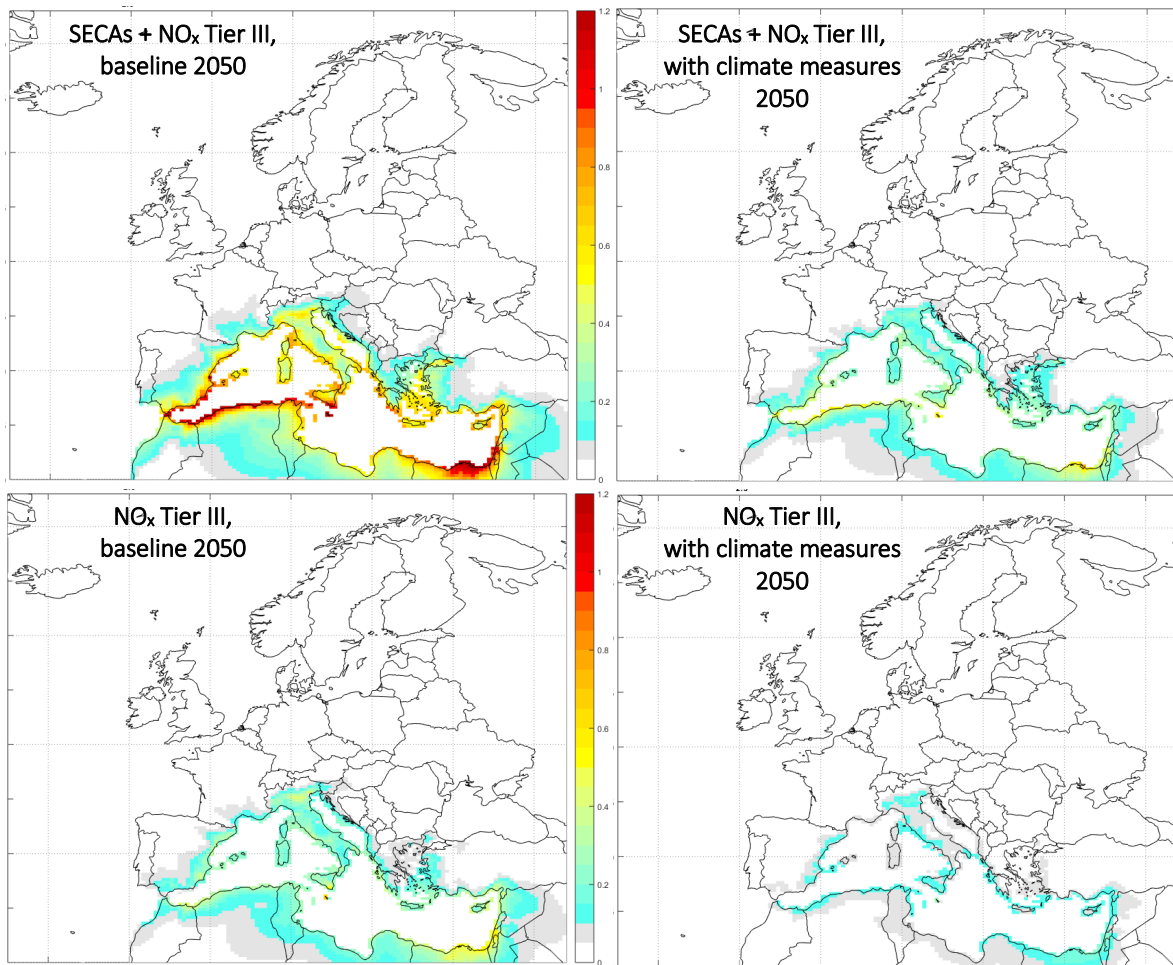


Figure 20: Decrease of ambient PM<sub>2.5</sub> concentrations ( $\mu\text{g}/\text{m}^3$ ) in 2050 from implementation of SECAs (upper panels) and Tier III standards for NO<sub>x</sub> including retrofits (lower panels) in the Mediterranean Sea, for the baseline case (left panel) and the scenario with climate measures (right panel)

Air quality impacts from emission controls for international shipping are largest along the coast. Almost half of the EU's population lives less than 50 km from the Sea, and within the model domain approximately 23 percent within a 30 km distance to the coast (27 percent in the EU-28, 16 percent in other European countries, and 24 percent in Africa and Middle East). Especially large impacts of shipping emissions, and subsequently of emission controls, occur in port cities, for which the contributions from shipping to ambient PM<sub>2.5</sub> levels estimated in this study (typically between 5 and 15 percent in 2015; Figure 21) align well with other assessments (Viana et al. 2014).



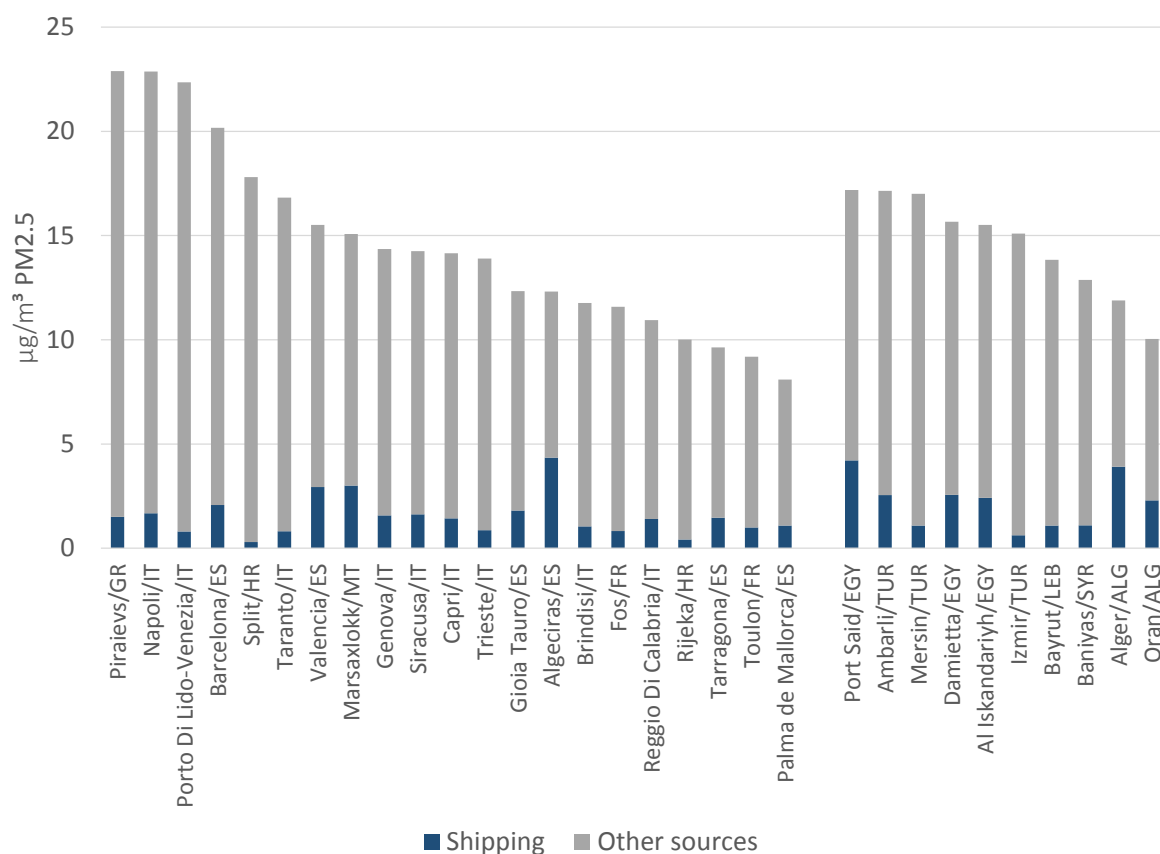


Figure 21: Contribution of shipping emissions to ambient PM2.5 concentrations in the 28\*28 km grid cells with Mediterranean port cities in 2015 (Source: GAINS calculations)

A SECA in EU waters of the Mediterranean Sea could reduce PM2.5 concentrations on average by 0.5 µg/m³ compared to the baseline levels in 2050, and by up to 1 µg/m³ in Algeiras/ES, Valencia/ES and Marsaxlokk/MT. Tier III standards for NO<sub>x</sub> could deliver an additional 0.2 to 0.3 µg/m³ in port cities by 2050. SECAs and NECAs covering the whole Mediterranean Sea could reduce ambient PM2.5 concentrations in non-EU ports typically by 1 µg/m³ in 2050 (Figure 23).

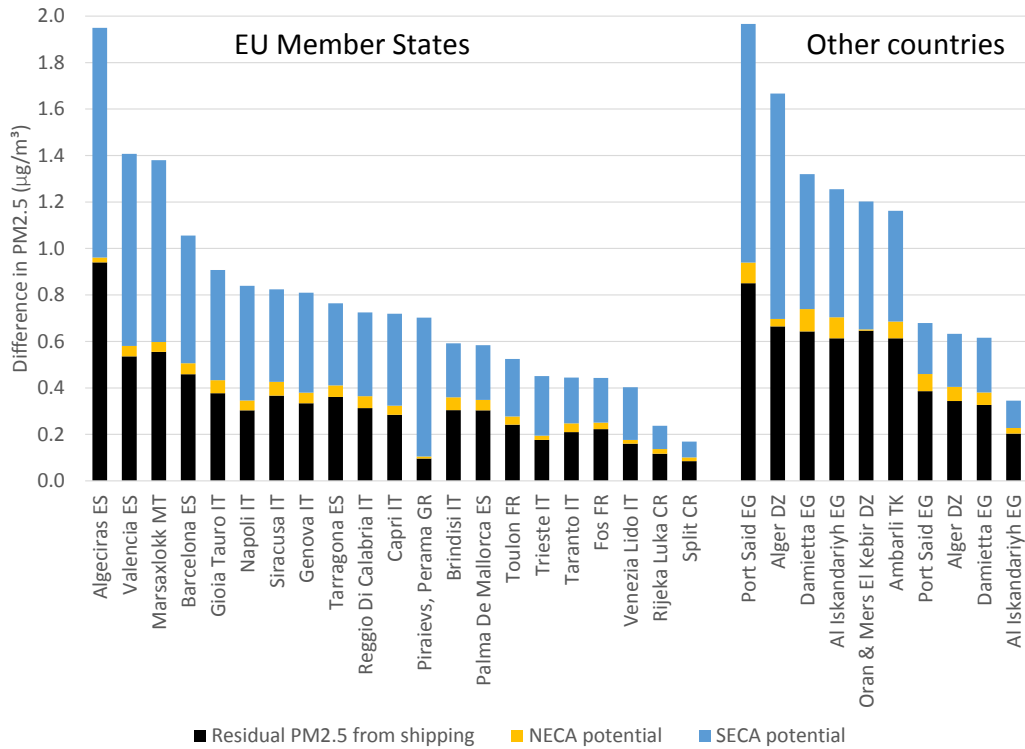


Figure 22: Estimated reductions of ambient PM2.5 concentrations in port cities from SECAs and NECAs (averaged across the 28\*28km grid cell of the city), baseline 2030

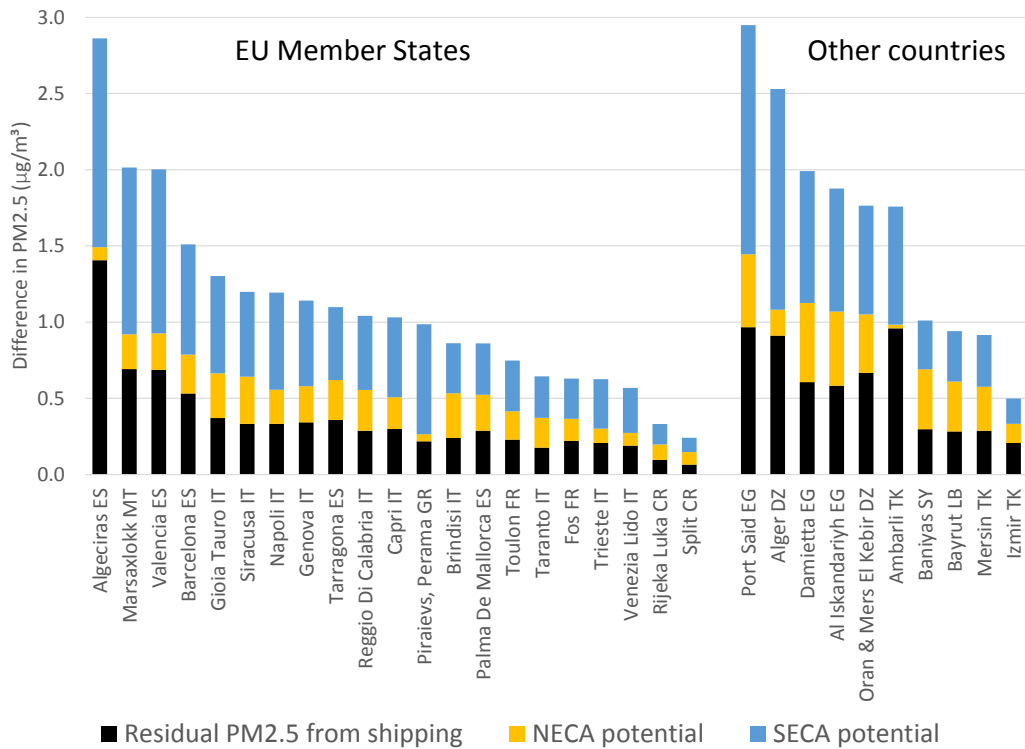


Figure 23: Estimated reductions of ambient PM2.5 concentrations in port cities from SECAs and NECAs (averaged across the 28\*28km grid cell that contains the port city), baseline 2050

## 7 Benefits of the emission controls

### 7.1 Premature mortality

The reduced population exposure to PM<sub>2.5</sub> that would occur as a consequence of lower shipping emissions will alleviate health impacts from air pollution and avoid, inter alia, thousands of cases of premature deaths annually.

In 2030, the most ambitious emission controls, i.e., SECAs, NECAs and PM filters together, could avoid up to 8000 cases of premature deaths, about 40 percent of them in North Africa and the Middle East (Figure 24). Enhanced penetration of emission controls combined with population growth will double this number in 2050 (Figure 25).

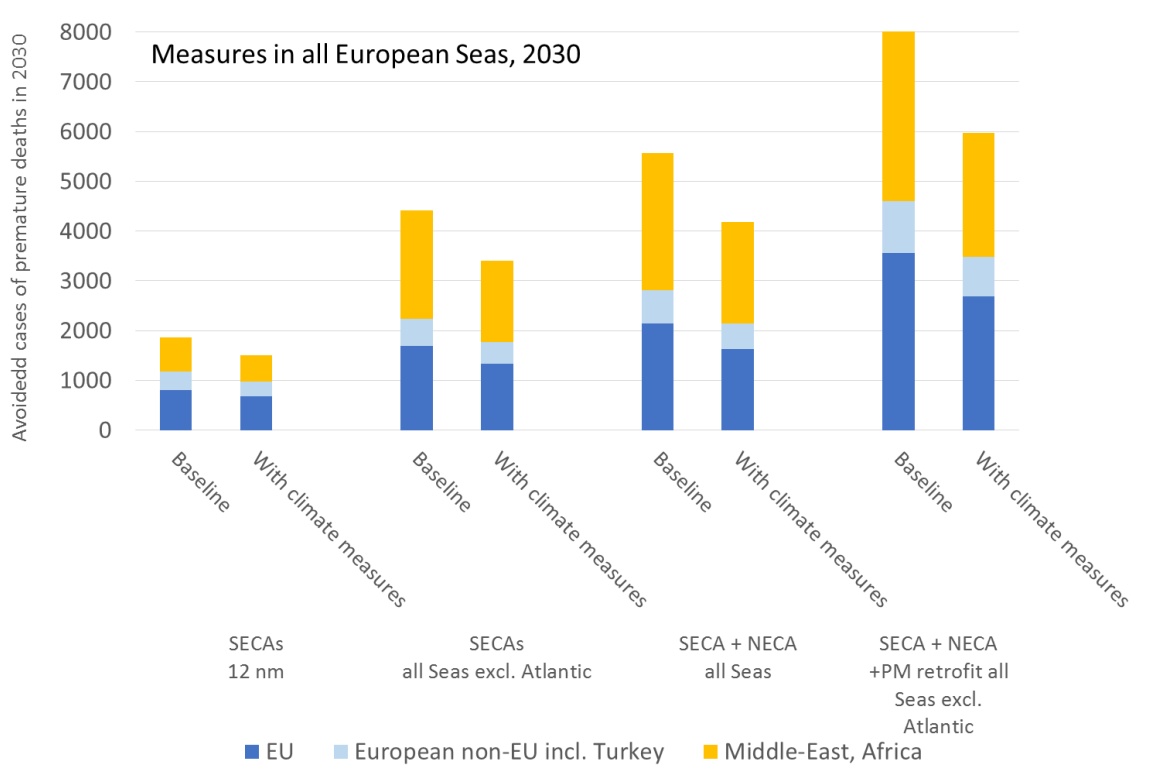


Figure 24: Avoided cases of premature deaths from the control of shipping emissions in all European Seas in 2030

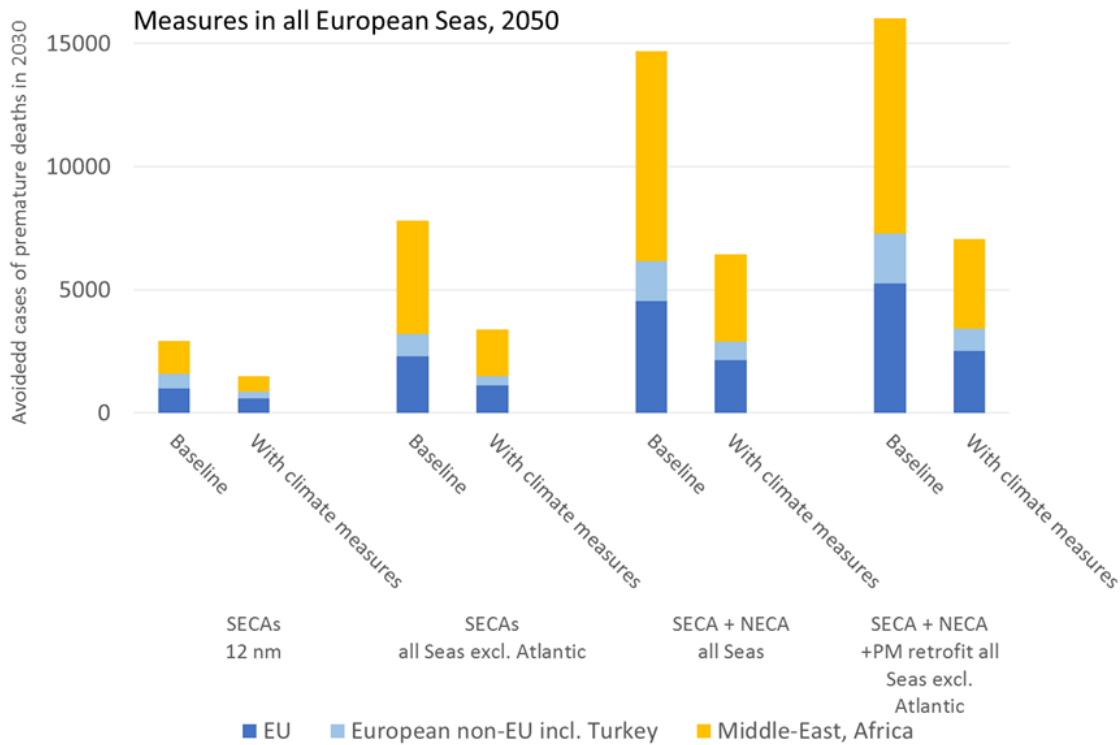


Figure 25: Avoided cases of premature deaths from the control of shipping emissions in all European Seas in 2050

SECAs and NECAs in the Mediterranean Sea could avoid between 3,100 and 4,100 cases of premature deaths in 2030, of which about one third occur in the EU Member States and more than half in North Africa and the Middle East (Figure 26). By 2050, these measures could save more than 10,000 lives in the region annually, especially in North Africa where significant population growth is expected (Figure 27).

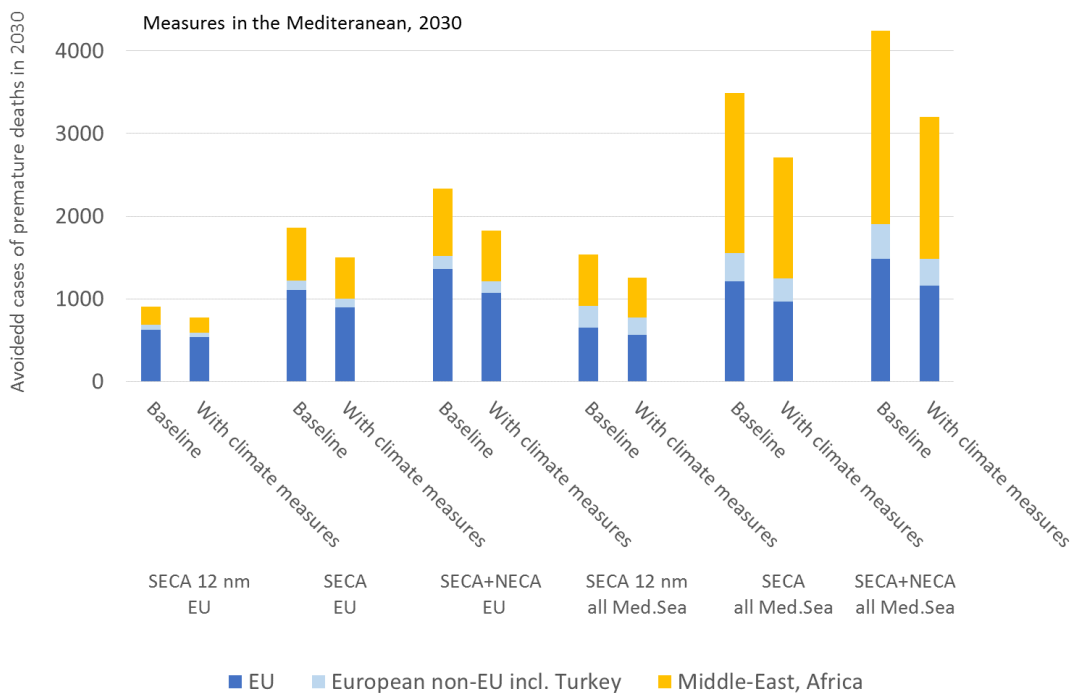


Figure 26: Avoided cases of premature deaths from the control of shipping emissions in the Mediterranean Sea in 2030

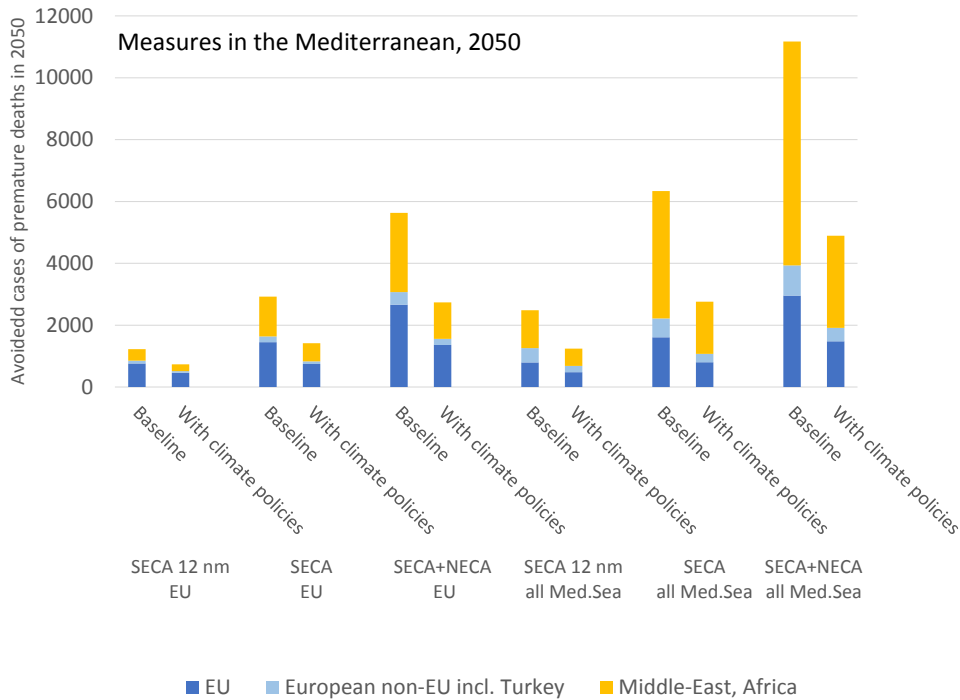


Figure 27: Avoided cases of premature deaths from the control of shipping emissions in the Mediterranean Sea in 2050

## 7.2 Monetized health benefits

Monetized health benefits have been estimated along the impact pathway approach as used previously for analysis of proposals made in the context of the EU's Thematic Strategy on Air Pollution and Clean Air Programme ((Holland 2014a, b) using the ALPHA-Riskpoll (ARP) model (Holland et al. 2013). For the present analysis the model has been extended to include countries in North Africa and the Middle East. A detailed description of the methodology is provided in Annex 7. Key inputs to the analysis, in addition to information on population-weighted pollution exposure data PM2.5 from the GAINS model were:

- Population data: UN Medium Projections (UN 2017);
- Health response functions: WHO-Europe's HRAPIE (Health Risks of Air Pollution in Europe) study (WHO Regional Office for Europe 2013; Holland 2014b);
- Valuation data: Estimates adopted for the EU's Clean Air Package of 2013 (Holland 2014a). Valuation data are given in Euro, at 2005 prices to match the cost data used in GAINS.

Analysis performed with the ALPHA-Riskpoll model reveals that the most important monetary benefit from controlling emissions of air pollutants is reduction of premature mortality.

### 7.2.1 Measures in all European Seas

For emission controls in all European Seas, largest benefits occur for simultaneous controls of SO<sub>2</sub>, NO<sub>x</sub> and PM2.5 emissions. Benefits estimate vary for different methodological approaches, e.g., depending whether the value of a life year (VOLY) or the value of statistical life (VSL) is applied for the monetization of premature

mortality, as well as for the different assumptions on climate measures, which have large impact on emissions, exposure and mortality. In 2030, benefits estimate reach up to 20 billion €/year, and double until 2050 (Figure 28).

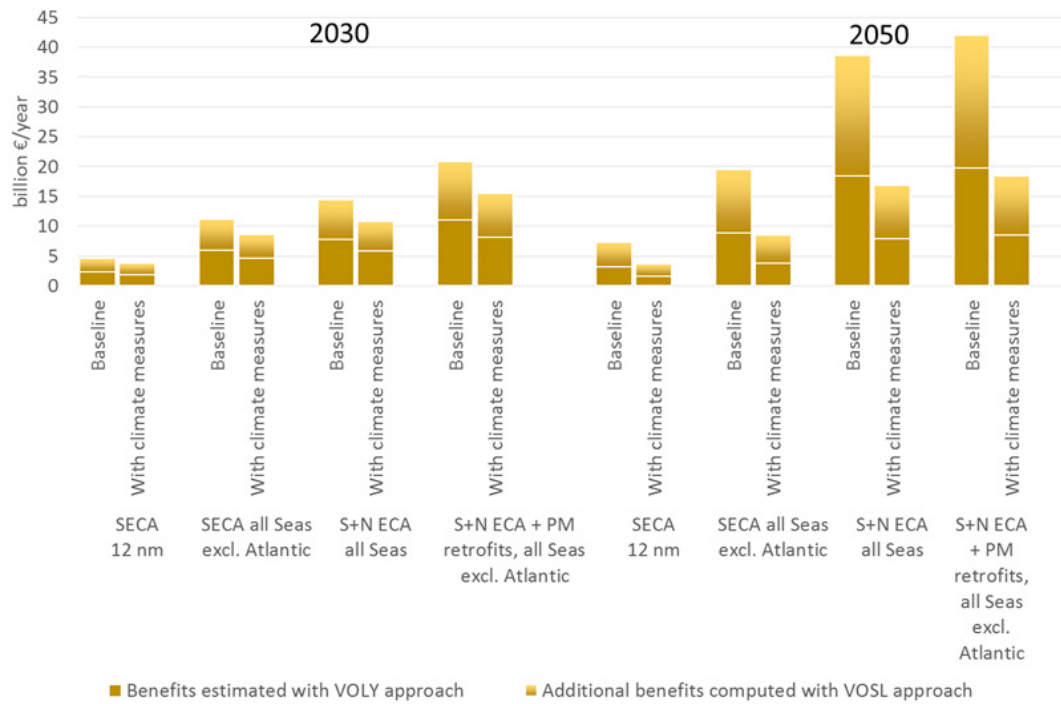


Figure 28: Benefits estimated for the emission control scenarios for all European Seas

## 7.2.2 Measures in the Mediterranean Sea

For the emission controls in the Mediterranean, the estimates of monetized benefits reach up to 10 billion €/year in 2030 and increase to almost 30 billion €/year in 2050 (Figure 29). Details are provided in Annex 7.

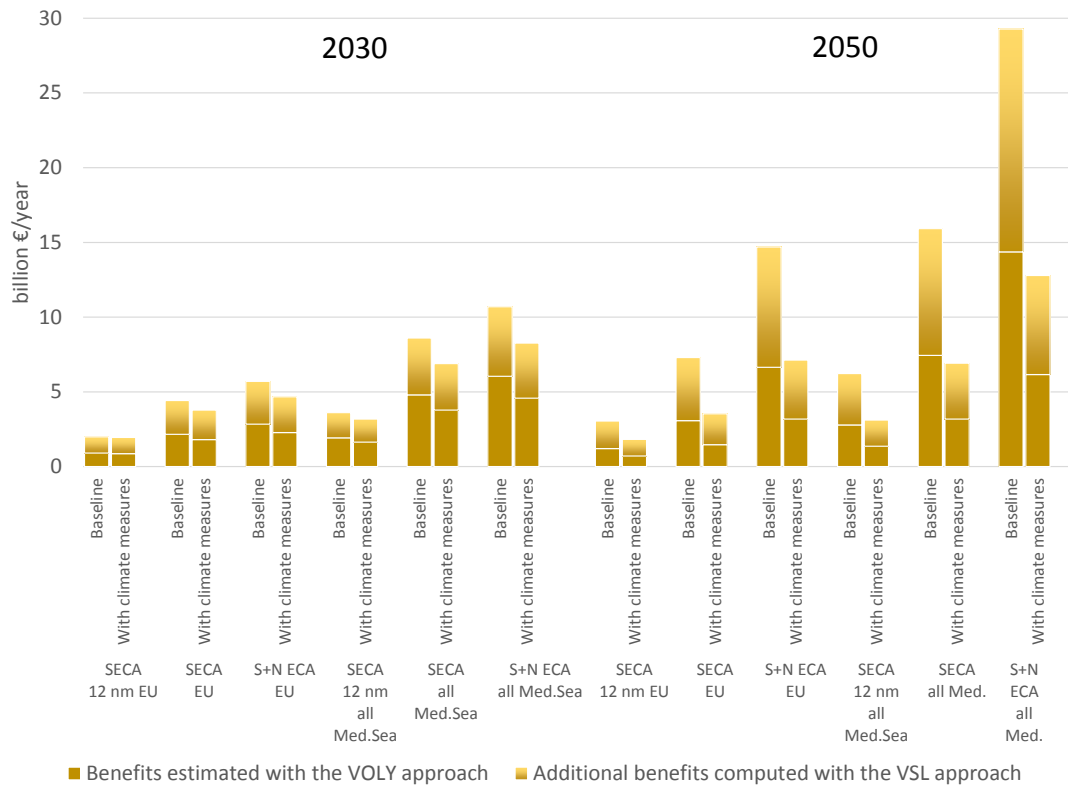


Figure 29: Benefits estimated for the emission control scenarios in the Mediterranean Sea

## 8 Comparison of costs and benefits

A comparison of costs (see Section 5) and monetized benefits (Section 7) clearly reveals that for all examined emission control scenarios the benefits outweigh the emission control costs by a wide margin (Figure 30). For measures across all European Seas, on average the monetized benefits exceed costs by a factor of 6 in 2030 (Figure 31) and a factor of 12 in 2050 (Figure 32).

### 8.1.1 Measures in all European Seas

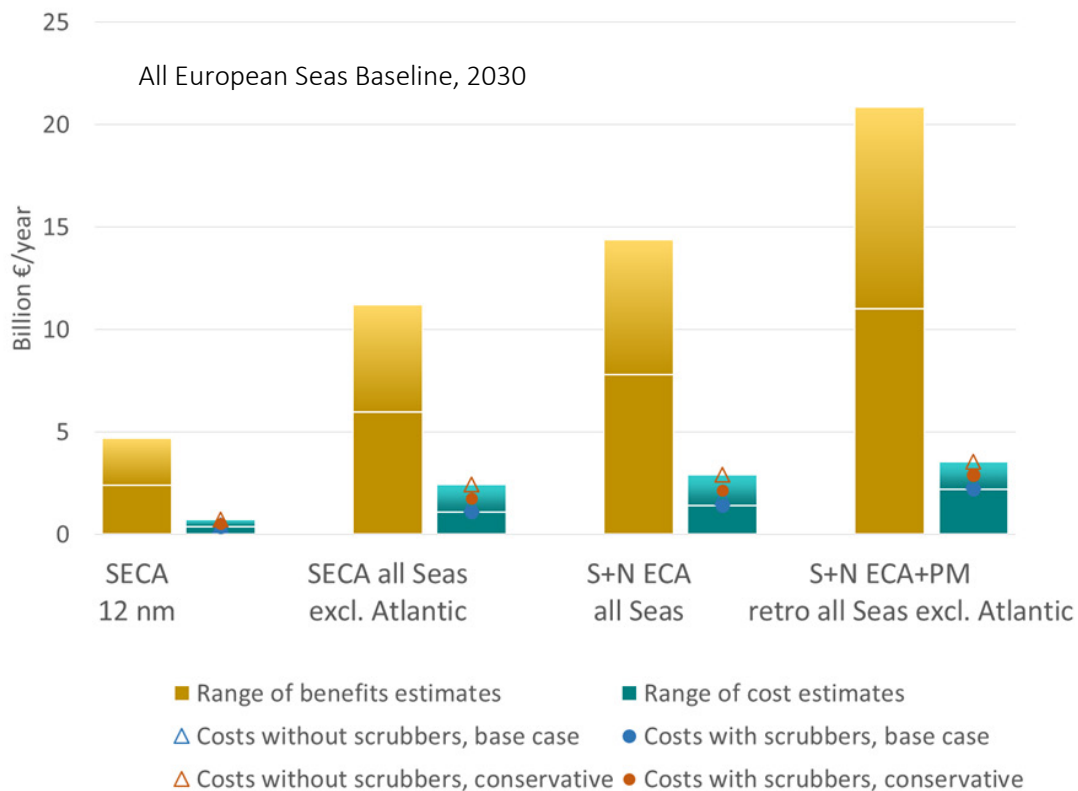


Figure 30: Monetized benefits and costs for the emission control scenarios for all European Seas in 2030. Base case – base estimate of low sulphur fuel price premium; conservative – conservatively high cost premium for low sulphur fuel



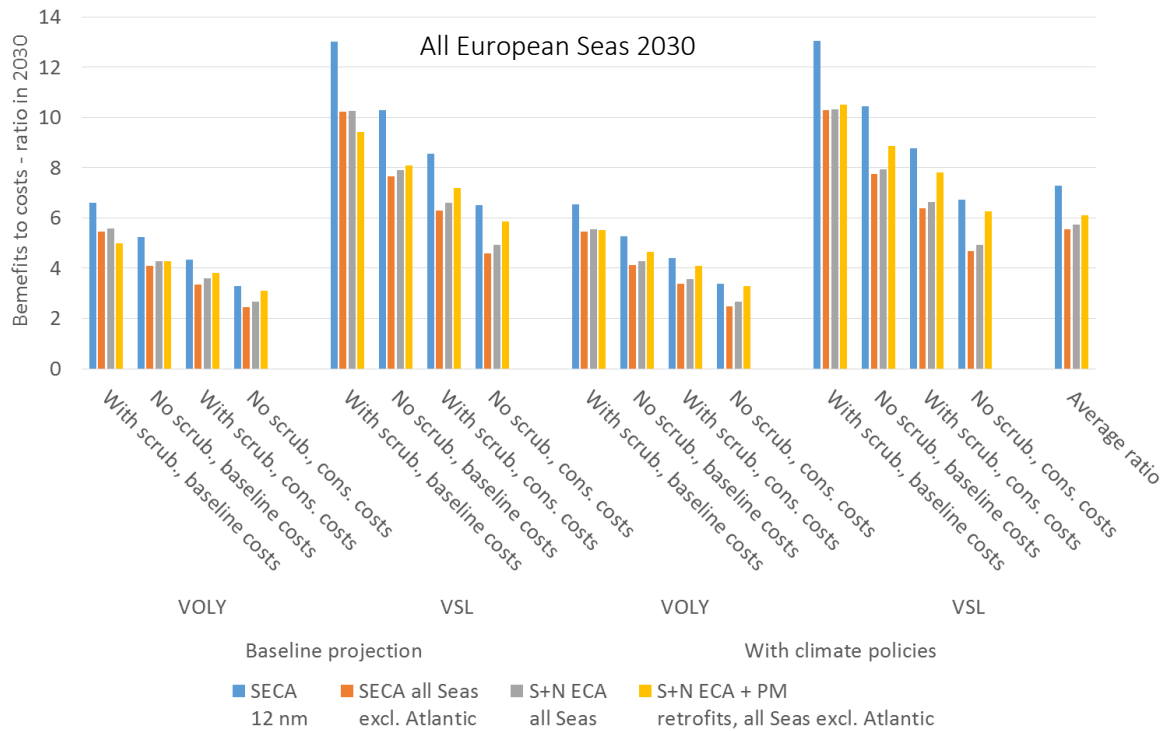


Figure 31: Benefits-to-costs ratios for the emission control scenarios for all European Seas, 2030 (VSL –Value of Statistical Life; VOLY –Value of Life Year. Baseline costs - base estimate of low sulphur fuel price premium; cons. costs – conservatively high cost premium for low sulphur fuel

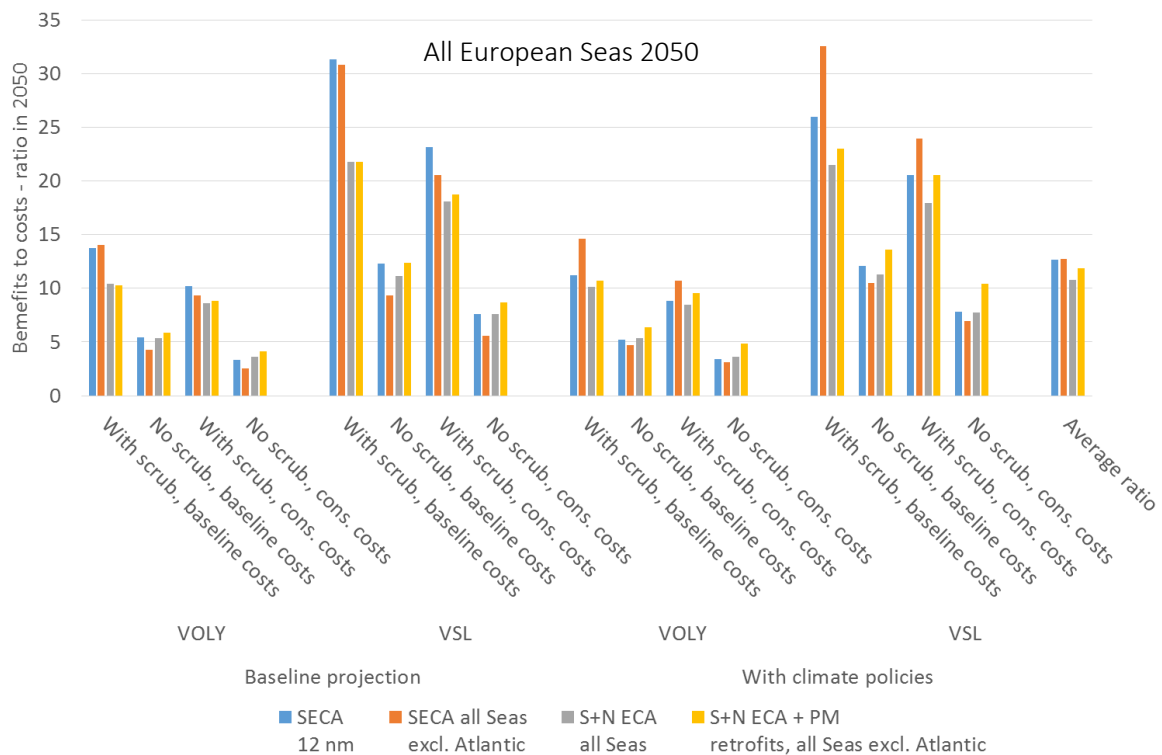


Figure 32: Benefits-to-costs ratios for the emission control scenarios for all European Seas, 2050 (VSL – Value of Statistical Life; VOLY –Value of Life Year. Baseline costs - base estimate of low sulphur fuel price premium; cons. costs – conservatively high cost premium for low sulphur fuel Measures in the Mediterranean Sea

For the emission controls for the Mediterranean Seas, monetized benefits exceed costs on average by a factor of 6.5 in 2030 (Figure 33, Figure 34) and a factor of 12 in 2050 (Figure 35, Figure 36).

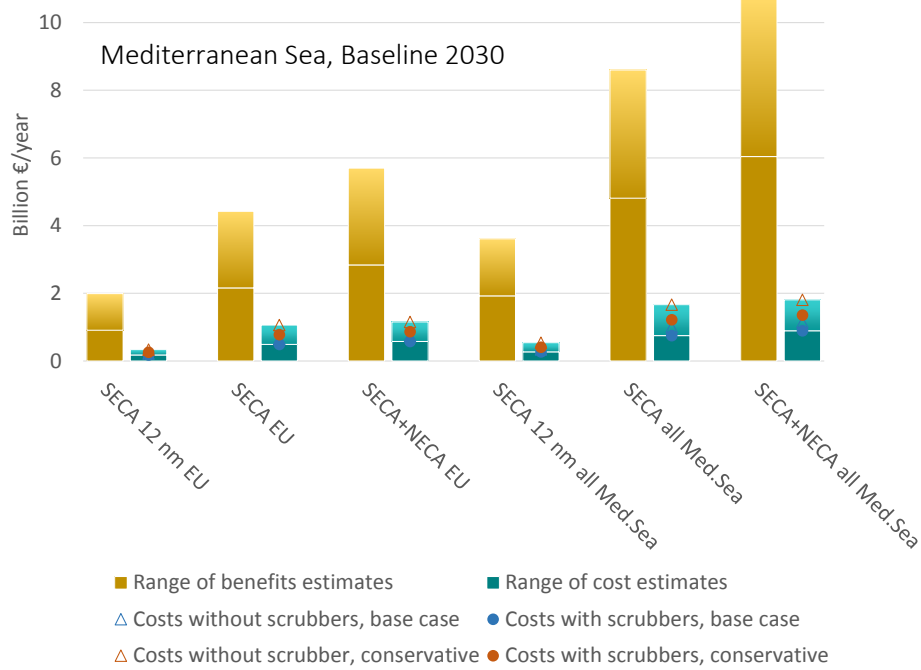


Figure 33: Monetized benefits and costs for the emission control scenarios for the Mediterranean Sea, 2030. Base case – base estimate of low sulphur fuel price premium; conservative – conservatively high cost premium for low sulphur fuel

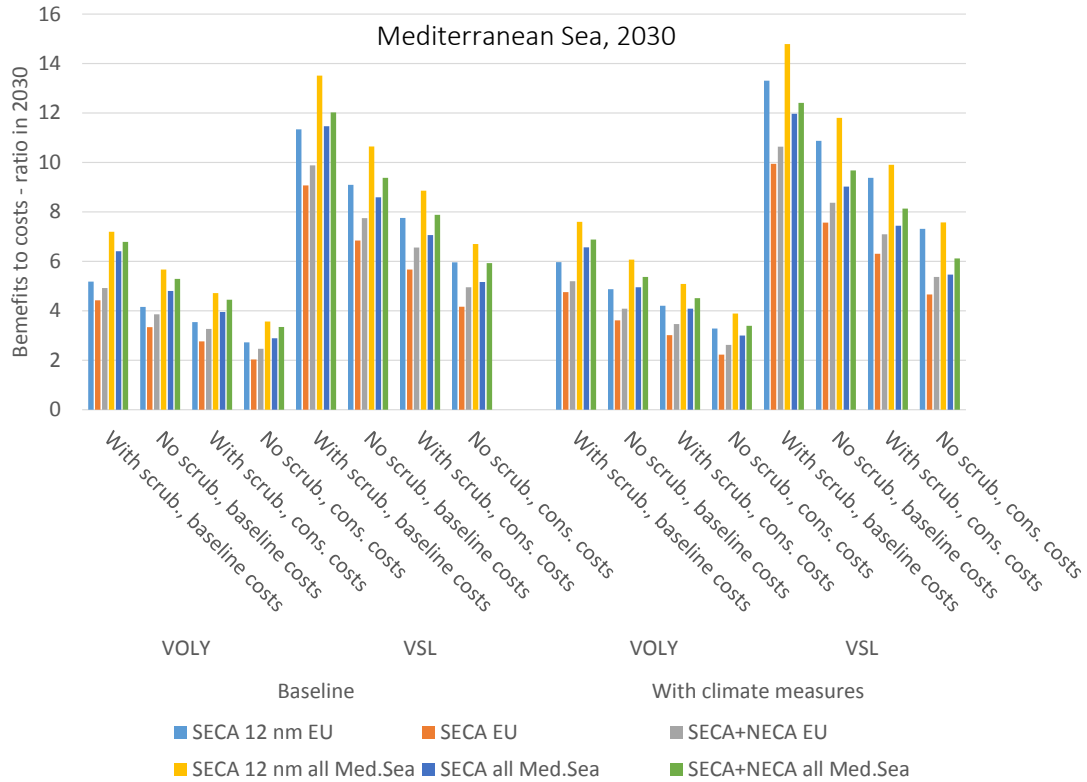


Figure 34: Benefits to costs ratios for the emission control scenarios in the Mediterranean Sea, 2030 (VSL – Value of Statistical Life; VOLY – Value of Life Year; cons. costs – conservatively high cost premium for low sulphur fuel)

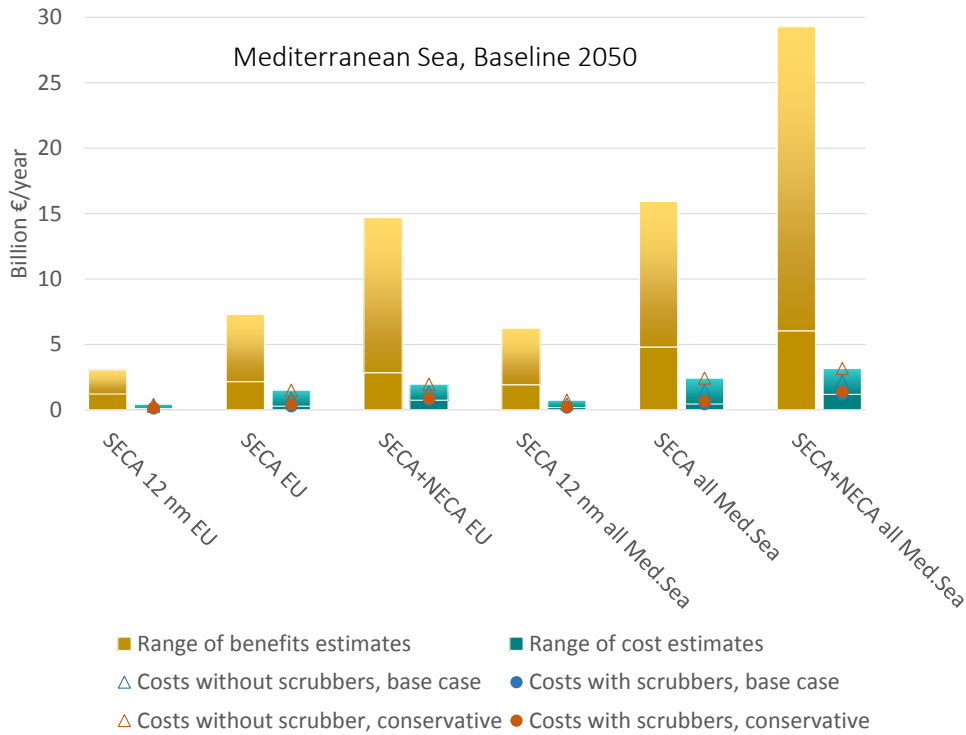


Figure 35: Monetized benefits and costs for the emission control scenarios for the Mediterranean Sea, 2050. Base case – base estimate of low sulphur fuel price premium; conservative – conservatively high cost premium for low sulphur fuel

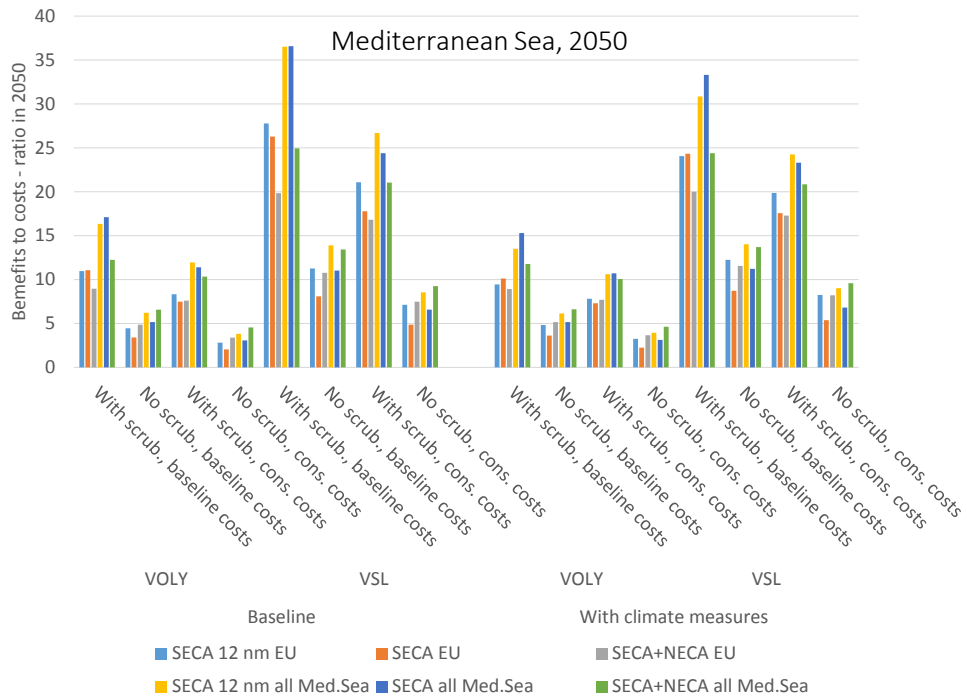


Figure 36: Benefits to costs ratios for the emission control scenarios in the Mediterranean Sea, 2050 (VSL – Value of Statistical Life; VOLY – Value of Life Year; cons. costs – conservatively high cost premium for low sulphur fuel)

## 9 Conclusions

This report revisits the potentials for further emission reductions from international shipping in the European Seas and compares associated costs with resulting benefits. Maintaining consistency with other recent studies, this report:

- updates the projections of the likely development of maritime transport activities,
- provides new assessments of costs of compliance with current legislation,
- improves the understanding of the role of emissions from vessels in ports, and the options for reducing these emissions,
- develops new scenarios of future emissions that would result from different policy interventions, including additional ECAs in the Mediterranean Sea and other European Sea regions,
- assesses their impacts on ambient air quality and resulting population exposure, and
- estimates the associated benefits to human health, and quantifies these benefits in monetary terms.

As a central tool, this report employs the GAINS (Greenhouse gas – Air Pollution Interactions and Synergies) model (Amann et al. 2011), complemented by more detailed computations with MET Norway's EMEP atmospheric chemistry-transport model (Simpson et al. 2012). Subsequently, EMRC's ALPHA-RiskPoll model (Holland et al. 2013) provided full benefit analyses.

Maritime shipping is found as an important contributor to poor air quality in Europe, and has particularly large impacts in port cities and coastal areas. While current IMO and EU regulations will cut sulphur emissions up to 2030, current fuel consumption trends imply that emissions from international shipping will grow further after 2030 in the absence of additional regulations. Overall, current legislation is expected to cut SO<sub>2</sub> emissions by 50-80 percent in the coming decades. In contrast, NO<sub>x</sub> emissions are expected to further increase and shortly after 2030 they will reach levels that exceed total land-based emissions in the EU-28.

Enhanced emission controls could cut emissions from international shipping in the European Seas by 80-90 percent compared to 2015. An extension of the sulphur emission controls to all Sea regions could reduce SO<sub>2</sub> emissions by more than 90 percent, accompanied by a 20 – 70 percent reduction of PM<sub>2.5</sub> emissions. Tier III standards could lower NO<sub>x</sub> emissions in the European Seas by 50 – 80 percent in 2050.

Climate policy measures, through their reduction of fuel consumption, have significant co-benefits on air pollutant emissions from shipping. Compared to a 130% increase in CO<sub>2</sub> emissions from international shipping in the European Seas that would emerge in 2050 from current fuel consumption trends, a scenario that assumes climate measures that lead to the stabilization of CO<sub>2</sub> emissions from shipping by 2050 (but does not achieve the 50 percent emission cut established by the IMO) would allow an additional 50 percent reduction in SO<sub>2</sub>, NO<sub>x</sub> and PM<sub>2.5</sub> emissions compared to what could be achieved with the full set of emission controls in the baseline scenario.

Further emission controls for international shipping could deliver important improvements for air quality throughout Europe, particularly in coastal areas. Such measures could improve air quality for a large share of European population, given that about half of the EU population lives within 50 km distance from the Sea. Largest improvements would occur along the coast of Mediterranean countries, and in particular along

the North African coast. Here the ambient concentrations of PM<sub>2.5</sub> could decrease by up to 1.2 µg/m<sup>3</sup> in 2030 and up to 1.5 µg/m<sup>3</sup> in 2050.

The air quality improvements of further emission controls could save up to 15,000 cases of premature deaths annually, about one third of them in the EU Member States, and 50 percent in North Africa and the Middle East. Until 2030, sulphur in fuel controls that can be quickly introduced offer the largest potentials for fast improvements, and 40 percent of the full potential of the SECAs could be obtained with measures in the 12 nm zones. Application of Tier III standards for NO<sub>x</sub> will need longer time until their full benefits are unfolded, but by 2050 the NO<sub>x</sub> reductions will double the benefits of SECAs.

It is found that the benefits of further emission controls for international shipping outweigh the costs by a wide margin. For measures across all European Seas, on average the monetized benefits exceed costs by a factor of 6 in 2030 and by a factor of 12 in 2050.

Specifically for the Mediterranean Sea, designating this Sea as an Emission Control Area could by 2030 cut emissions of SO<sub>2</sub> and NO<sub>x</sub> from international shipping by 80 and 20 percent, respectively, compared to current legislation. These additional emission reductions could avoid 4,100 cases of premature deaths in 2030 and more than 10,000 annual premature deaths in 2050.

For measures on the Mediterranean Sea, on average the monetized benefits exceed costs by a factor of 6.5 in 2030 and by a factor of 12 in 2050. Even with the most conservative assumptions for health valuation, monetized benefits are on average 4.4 times higher than the costs in 2030 and 7.5 times higher in 2050.

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