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

REMPEC/WG.45/INF.10
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Agenda Item 11

INITIAL DRAFT SUBMISSION TO THE INTERNATIONAL MARITIME ORGANIZATION ENTITLED "PROPOSAL TO DESIGNATE THE MEDITERRANEAN SEA AREA, [OR PARTS THEREOF,] AS AN EMISSION CONTROL AREA FOR SULPHUR OXIDES [AND PARTICULATE MATTER]"

Note by the Secretariat

SUMMARY

Executive Summary:	This document presents the initial draft submission to the International Maritime Organization entitled "Proposal to Designate the Mediterranean Sea area, [or parts thereof,] as an Emission Control Area for Sulphur Oxides [and Particulate Matter]", as prepared pursuant to Specific Objective 15 of the Regional Strategy (2016-2021).
Action to be taken:	Paragraph 3
Related documents:	UNEP(DEPI)/MED IG.22/28, REMPEC/WG.45/11

Background

1. As presented in document REMPEC/WG.45/11, the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC) prepared an initial draft submission to the International Maritime Organization (IMO) entitled "Proposal to Designate the Mediterranean Sea area, [or parts thereof,] as an Emission Control Area for Sulphur Oxides [and Particulate Matter]", hereinafter referred to as "the initial draft submission to the IMO", pursuant to Specific Objective 15 of the Regional Strategy for Prevention of and Response to Marine Pollution from Ships (2016-2021)[1], which was adopted by the Nineteenth Ordinary Meeting of the Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean ("the Barcelona Convention") and its Protocols (COP 19) (Athens, Greece, 9-12 February 2016).

2. The initial draft submission to the IMO is presented in the **Appendix** to the present document.

Action requested by the Meeting

3. **The Meeting is invited to take note** of the information provided in the present document.

[1] UNEP(DEPI)/MED IG.22/28, Decision IG.22/4.

APPENDIX

Initial draft submission to the International Maritime Organization entitled “Proposal to Designate the Mediterranean Sea area, [or parts thereof,] as an Emission Control Area for Sulphur Oxides [and Particulate Matter]”

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INTERNATIONAL
MARITIME
ORGANIZATION

MARINE ENVIRONMENT PROTECTION COMMITTEE
[...] session
Agenda item N

MEPC XX/N/I
Document date
Language: i.e. Original: ENGLISH
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AGENDA ITEM TITLE

Proposal to Designate the Mediterranean Sea area, [or parts thereof,] as an Emission Control Area for Sulphur Oxides [and Particulate Matter]

Submitted by [list of co-sponsors]

SUMMARY

Executive summary:	This document sets forth a proposal to designate the Mediterranean Sea area, [or parts thereof,] as an Emission Control Area for Sulphur Oxides [and Particulate Matter], hereinafter referred to as the proposed Med ECA, in accordance with regulation 14 and Appendix III to MARPOL Annex VI to take effect from [date]. This proposal shows that the designation of the proposed Med ECA is supported by a demonstrated need to prevent, reduce and control emissions of sulphur oxides [and particulate matter] from ships. Moreover, the adoption of the proposed Med ECA will result in significant reductions in ambient levels of air pollution in the Mediterranean Sea area, [or parts thereof,] and in the [Mediterranean coastal States], which will achieve substantial benefits to human health and the environment. The co-sponsors invite the Committee to review this proposal at this session with a view toward the adoption by the Parties to MARPOL Annex VI, at MEPC XX, of amendments to regulation 14.3 of MARPOL Annex VI designating a new Emission Control Area.
Strategic direction, if applicable:	[to be identified]
Output:	[to be identified]
Action to be taken:	Paragraph 24
Related documents:	MEPC XX-INF.NN [others to be identified]

Introduction

1 With this document the [XXX] countries bordering the [Mediterranean Sea] – [list of relevant Mediterranean coastal States] set forth a proposal for the designation of the Mediterranean Sea area, [or parts thereof,] as an Emission Control Area (ECA) to prevent, reduce and control emissions of sulphur oxides (SO_X) [and particulate matter (PM)] from ships pursuant to regulation 14 and Appendix III to Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL), hereinafter referred to as the proposed Med ECA.

2 The designation of the proposed Med ECA is necessary to protect public health and the environment in the [Mediterranean Sea], regional waters and coastlines, and in the communities of the [Mediterranean coastal States] by reducing exposure to harmful levels of air pollution resulting from these emissions. The designation of the proposed Med ECA provides additional needed benefits beyond those afforded by the implementation of the global fuel quality standards pursuant to MARPOL Annex VI, hereinafter referred to as MARPOL VI standards. The burden on international shipping is small compared to the improvements in air quality, the reductions in premature mortality and health incidences associated with this air pollution, and the other benefits to the environment resulting from the designation of the proposed Med ECA.

3 Annex 1 to this proposal provides a complete analysis of how this proposal satisfies each of the eight Criteria for Designation of an ECA established under Appendix III to MARPOL Annex VI. Annex 2 to this proposal sets forth a detailed description of the proposed Med ECA. Annex 3 to this proposal presents a chart of the proposed area of application for the designation of the proposed Med ECA. The co-sponsors have also prepared draft amendments, presented in Annex 4 to this proposal, to include the proposed Med ECA in regulation 14.3 of MARPOL Annex VI. Lastly, a comprehensive bibliography of all the information considered in preparing this proposal has been submitted to the Committee as a separate document, MEPC XX-INF.NN.

Summary of Proposal

4 The designation of the proposed Med ECA will significantly reduce emissions from ships and deliver substantial benefits to large segments of the population, as well as to marine and terrestrial ecosystems. Air pollution from ships occurs not just in the [Mediterranean] ports and coastlines but is also carried hundreds of kilometres inland. When people breathe this polluted air, their health is adversely affected, leading to lost productivity due to increased illnesses, hospitalisations and even premature deaths. In the [Mediterranean] region, 507 million people live in areas with air pollution at levels exceeding respective national ambient air quality standards, and/or levels which are unhealthy according to the World Health Organization (WHO). Moreover, scientists have not identified any ambient threshold for particulate matter below which no damage to health is observed. Thus, air pollution below the WHO levels is still harmful and the health of millions of people in all areas can be enhanced by improving air quality further. In addition, the gains that have been made by extensive domestic regulations to control emissions from land-based sources over the last four decades could be eroded or even reversed by expected growth in human and economic activity, including shipping. To maintain and improve air quality, public health and the environment, decisive action must be taken to realise the benefits that can be gained from additional emissions reductions.

5 The co-sponsors have coordinated this proposal, in line with common interests, shared geography and interrelated economies. The co-sponsors governments have consulted with stakeholders, including representatives from the shipping industry, ports, master mariners, environmental interests and representatives from state and provincial governments. This proposal takes into account the issues raised during consultations and strives to minimise the impact on the shipping community, while achieving needed environmental protection. It is believed that by acting at the international level to reduce the impacts of shipping on air quality, human health and ecosystems, the designation of the proposed Med ECA will remove pressure on regional, national and sub-national jurisdictions to consider regulatory actions to reduce ship emissions.

Populations and Areas at Risk

6 Millions of people and many important ecosystems in the [Mediterranean region] are exposed to harm or damage by emissions from ships, and are at risk of additional harm in the future. The [Mediterranean region] includes a combined population in excess of 500 million, over half of which reside in coastal communities. Further, because ship pollution travels great distances, much of the inland population is also affected by ship emissions and will benefit from the cleaner air made possible by ECA fuel and engine controls. These populations are at risk of increased harm from shipping if an ECA is not designated.

7 Annex 1 to this proposal describes the ways in which air pollution from ships contributes to the impairment of various ecosystems, including: deposition of acidifying sulphate, and changes in visibility. SO_x emissions from ships are carried over land and their derivatives (including PM and sulphur containing compounds) are deposited on surface waters, soils and vegetation. Importantly, air pollution can contribute a significant portion of the sulphur loading that an ecosystem receives. Some areas are more sensitive than others, and many have multiple stressors. [Mediterranean] ecosystems are sensitive especially to acidification due to sulphuric acids formed from SO_x which contributes to aquatic eutrophication that alters biogeochemical cycles and harms animal and plant life. Areas where ships' emissions are deposited are at risk of further damage in the future. The designation of the proposed Med ECA will help reduce the stresses on many sensitive ecosystems, including forests, grasslands, wetlands, rivers, lakes, estuaries, and coastal waters.

8 As established in MARPOL Annex VI, an ECA designation is intended to prevent and reduce the adverse impacts on human health and the environment in areas that can demonstrate a need to prevent, reduce, and control emissions of SO_x and PM. The Parties to MARPOL Annex VI chose this objective because of the known public health and environmental effects associated with SO_x and PM emissions. The designation of the proposed Med ECA directly furthers this objective by reducing the emissions of SO_x [and PM] from ships operating in the proposed area of application for the said designation. The proposed Med ECA is aimed at SO_x [and PM] controls.

Contributions from Ships to Adverse Impacts

9 In developing this proposal, the co-sponsors performed a comprehensive analysis to quantify the degree of human health risk and environmental degradation that is posed by air emissions from ships operating in the [Mediterranean Sea]. For gauging the risk to human populations, state-of-the-art assessment tools were used to apply widely accepted methods with advanced computer modelling techniques, and such methods produced highly reliable and replicable results. Estimating impacts of shipping on human health and the environment required analyses of detailed ship traffic data, fuel use estimates, pollutant emissions estimates, detailed meteorological data, physical dispersion and photochemical reactions, deposition of pollutants to sensitive ecosystems, and epidemiologic modelling of health effects attributable to pollutant exposure levels. According to the analysis conducted for this proposal, the proposed Med ECA achieves similar cost-effective pollution reductions and health benefits as reported for previously designated SECAs. Annual benefits include more than 1,000 avoided premature deaths, avoid more than 2,000 cases of childhood asthma, and benefit many sensitive ecosystems.

10 Emissions from ships contribute to substantially increase ambient concentrations of air pollutants over [Mediterranean] land and sea areas. The WHO reports that the "*highest ambient air pollution levels are in the Eastern Mediterranean Region…, with annual mean levels often exceeding more than 5 times WHO limits.*" Moreover, the WHO Ambient air quality database indicates that 72.7% of cities in the [Mediterranean coastal States] exceed the WHO annual ambient $PM_{2.5}$ pollution guidelines of 10 µg/m^3. Section 3 of Annex 1 to this proposal presents a map that displays the air quality impact of shipping emissions on ambient concentrations of PM. The physical dispersion models used to create these maps account for the varying wind patterns over the course of a representative year and simulate the paths that SO_x or PM travel once emitted from the funnel of a ship operating in the [Mediterranean Sea]. Chemical and physical fate and transport models predict the extent to which SO_x molecules react to form very small particles, known as $PM_{2.5}$. These maps show that the increased ambient concentrations of $PM_{2.5}$ due to ship emissions are largest along major shipping lanes and nearby [Mediterranean] coasts, where many of the most populous cities are located. The increase in particles (aerosols) also degrades visibility as measured by reduction in aerosol optical depth; this pollution may affect the clarity of vistas and views important to persons living near or tourists visiting

[Mediterranean] historical and natural attractions. Emissions are also transported over large distances and have significant impacts well into the interior of European and North African countries.

11 Ship emissions contribute to adverse human health impacts in the [Mediterranean coastal States], especially in densely populated coastal areas. Ships generate emissions that lead to elevated ambient concentrations of $PM_{2.5}$ that contribute to avoidable disease and premature death. Table 1 presents the annual reduction of ship-related adverse health impacts in 2020 that would result from applying the SECA standards. The figures in this table clearly illustrate the health benefits of the designation of the proposed Med ECA. The analysis conducted for this proposal shows that more than 1,000 annual premature deaths will be avoided and more than 2,000 fewer children will suffer asthma annually. Moreover, these estimates apply cardiovascular and lung cancer mortality, and asthma morbidity. Independent studies considering all-cause disease and death indicate that estimates reported here under-estimate the total benefits of the Med ECA.

12 The co-sponsors have also determined that damage to sensitive ecosystems that is attributable to emissions from ships will be reduced by the designation of the proposed Med ECA. Different ecosystems can be sensitive to and harmed by different pollutants, including acidification or eutrophication. The sensitivity of an ecosystem to acidification depends on the ability of the soils and waters to neutralise (or buffer) the deposited acidic pollutants formed from SO_x (see Table 2). Modelling in support of the designation of the proposed Med ECA predicts that improving ship emissions from current performance to SECA standards will significantly reduce the amount of sulphur deposition in sensitive ecosystems. The designation of the proposed Med ECA will help the Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (the Barcelona Convention) meet their goals under the Mediterranean Action Plan (MAP) of the United Nations Environment Programme (UNEP).

Description of the Proposed Area of Application

13 The proposed area of application for the designation of the proposed Med ECA is illustrated in Section 2 of Annex 1 to this proposal. A detailed description of the proposed area of application, including select coordinates, is provided in Annex 2 to this proposal, and a chart is presented in Annex 3 thereto. [The proposed area of application follows the International Hydrographic Organization (IHO) definition of the Mediterranean Sea[1] as being bounded on the southeast by the entrance to the Suez Canal, on the northeast by the entrance to the Dardanelles, delineated as a line joining Mehmetcik and Kumkale lighthouses, and to the west by the meridian passing through Cap Spartel lighthouse, also defining the western boundary of the Straits of Gibraltar. The proposed area of application is identical to the geographic area described in Article 1.1 of the Barcelona Convention, which is hereinafter referred to as the Mediterranean Sea area.] The waters of the proposed Med ECA involve the [twenty-two (22)] Contracting Parties to the Barcelona Convention, namely [Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syrian Arab Republic, Tunisia, Turkey and the European Union].

Table 1. Summary of health benefits evaluated for the proposed Med ECA (model year 2020)

<table>
<tr><th>Scenario Results
(Linear C-R Model)</th><th colspan="2">Reduced Mortality
(annual premature adult deaths)</th><th colspan="2">Avoided Childhood Asthma
(annual avoided incidents)</th></tr>
<tr><td rowspan="4">Health benefits of the proposed Med ECA</td><td colspan="2">Reduced Mortality</td><td colspan="2">Reduced Asthma Morbidity</td></tr>
<tr><td>CV Mortality Avoided</td><td>969
(CI 95% 551; 1,412)</td><td rowspan="3">Avoided Childhood Asthma</td><td rowspan="3">2,314
(CI 95% 1,211; 3,406)</td></tr>
<tr><td>LC Mortality Avoided</td><td>149
(CI 95% 32; 270)</td></tr>
<tr><td>Combined Avoided Mortality</td><td>1,118
(CI 95% 583; 1,682)</td></tr>
</table>

[1] https://www.iho.int/iho_pubs/standard/S-23/S-23_Ed3_1953_EN.pdf.

Table 2. Summary of proxies for other benefits associated with the proposed Med ECA

Environmental Benefit Proxy	Relative Range of Change (%)	Areas of greater benefit shown:
Wet sulphate deposition	1 to 15% reduction	Percent decrease in annual wet sulphate deposition between MARPOL VI and Med ECA
Dry sulphate deposition	1 to 50% reduction	Percent decrease in annual dry sulphate deposition between MARPOL VI and Med ECA
Wet PM_{Total} deposition	0.5 to 5% reduction	Percent decrease in annual wet PM_{Total} deposition between MARPOL VI and Med ECA
Dry PM_{Total} deposition	0 to 10% reduction	Percent change in annual dry PM_{Total} deposition between MARPOL VI and Med ECA
Aerosol optical depth (PM-related)	1 to 6% increase	Percent Change in aerosol optical depth (PM species) between MARPOL VI and Med ECA

Ship Traffic and Meteorological Conditions

14 Ship traffic in the [Mediterranean Sea area] is substantial as it is navigated by more than thirty thousand vessels annually, with the majority of vessels calling on [Mediterranean] ports and engaging in regional commerce among the [Mediterranean coastal States]. In addition, many vessels transit the [Mediterranean Sea area] in close proximity to heavily populated areas collectively containing hundreds of millions of inhabitants.

15 Meteorological conditions in the [Mediterranean Sea area] transport to land a significant portion of emissions from ships at-sea and the resulting pollutants formed in the atmosphere. The emissions from ships of SO_x and their derivatives (including PM) can remain airborne for around five to ten days before they are removed from the atmosphere (e.g., by deposition or chemical transformation). During the time from being emitted into and removed from the air, pollutants can be transported hundreds of nautical miles over water and hundreds of kilometres inland by the winds commonly observed in the [Mediterranean Sea area]. The analysis conducted for this proposal indicates that winds frequently blow onshore in all areas of the [Mediterranean Sea]. Some wind patterns are more common than others, thus the impact of air pollution from ships at-sea is larger on some areas than on others. Further, airborne transport of SO_x and PM from ships crosses national boundaries, adversely affecting large portions of the [Mediterranean coastal States].

Land-Based Emissions Controls

16 Nearly all [Mediterranean coastal States] have already imposed stringent restrictions on emissions of SO_x, PM and other air pollutants from a wide range of industrial, commercial and transportation activities. Examples of industrial and commercial sources subject to emissions restrictions include large and small manufacturing plants, smelting and refining facilities, chemical and pharmaceutical companies; and combustion sources at factories and power plants. Examples of transportation sources subject to emissions restrictions and fuel quality standards include automobiles, trucks, buses, locomotives and domestic commercial and recreational watercraft. Figure 1 illustrates the trend in land-side SO_x emissions for European Union (EU) Mediterranean coastal States and Turkey. [The submission can present additional data if made available from relevant Mediterranean coastal States.]

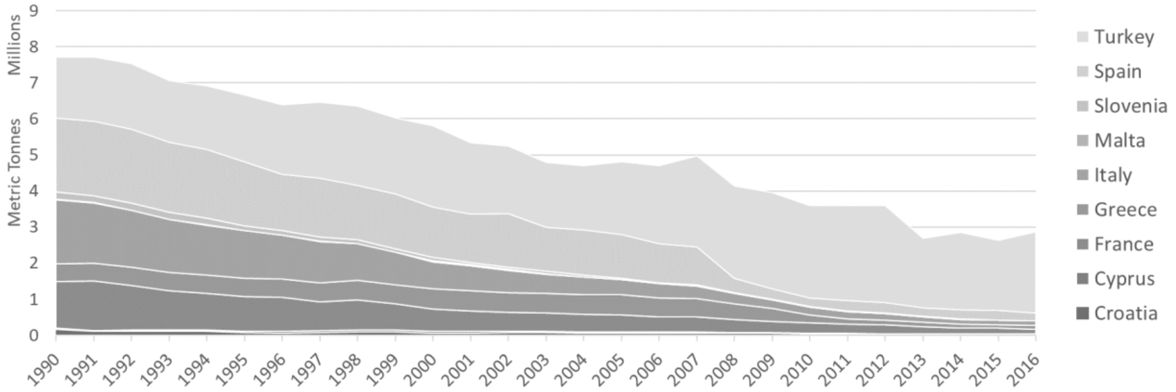

Figure 1. Trend in Land-side SO_x Emissions for EU Mediterranean coastal States and Turkey

17 The European and North African national air pollution control programmes for sources of air pollution other than ships have been highly successful. European countries reduced their SO_x emissions by nearly two-thirds since 1990, by more than half since 2000, and an additional 20% since 2010, without direct economic impact on net growth and cyclic recession recovery. According to the United Nations National Baseline Pollution Budgets (NBB), countries like Israel "*will be reducing indirect atmospheric emissions to the marine environment of NO_x and SO_x by 90% [by 2022 relative to 2017] due to the planned installation of scrubbers in 6 coal powered units of the main coastal power stations as well as the closure of 4 coal power units.*" The Egypt State of the Environment Reports for 2012 and 2016 indicate that SO_x emissions have reduced more than 75% since 1999. Even so, the WHO indicates the Egyptian Delta Region exceeds its $PM_{2.5}$ guidelines and Annex indicates that SO_x emissions from ships contribute to $PM_{2.5}$ in that region. [Aside from the European Union and some United Nations reporting, national level detail was not identified; the submission can present additional data if made available from relevant Mediterranean coastal States] The [Mediterranean coastal States] continue to find cost-effective reductions that can be achieved from additional controls on the remaining sources. Most importantly, as land-side sectors control emissions, the relative contribution of ship emissions to national air quality problems increases the need for SECA controls. The designation of the proposed Med ECA will greatly reduce emissions from the increasingly significant ocean transportation sector.

Estimated Costs, Benefits, and Cost-effectiveness

18 As marginal costs for next-step measures typically increases for land-side emissions sources, cost-effective control of ship emissions appears both technically feasible and cost-effective. The costs of implementing and complying with the proposed Med ECA are expected to be small both absolutely and compared to the costs of achieving similar emissions reductions through additional controls on land-based sources. The co-sponsors estimate the total costs of improving ship emissions from current performance to SECA standards will be approximately US$ 1.7 billion in 2020; along with global MARPOL VI standards, this achieves a 95% net reduction in SO_x and a 62% net reduction in $PM_{2.5}$ from ships operating in the proposed Med ECA. If equivalent or greater reductions can be achieved using abatement technologies and/or advanced fuels – and if these technologies can save money for some vessels – then total compliance costs may be less. Consistent with prior experience in other SECA regions and following the insights and findings of the IMO Fuel Availability Study (MEPC 70/INF.6), appropriate fuels and technologies will be available in sufficient quantities to meet the agreed-to SECA emission limit implementation dates.

19 The monetary value of small changes in mortality risks using SECA compliant fuels can be considered in terms of an economic term called the "value of a statistical life" or VSL. Formally, VSL is the monetary value of small changes in mortality risks, scaled up to reflect the value associated with one expected fatality in a large population. The value of avoided impacts may be considered to include the monetised sum of:

$$\begin{aligned} &Value\ of\ avoided\ impacts \\ &\quad = Avoided\ Mortality\ (\$V_{Mortality}) + Avoided\ Morbidity\ (\$V_{Illness+\ Care}) \\ &\quad + Avoided\ Deposition\ Damages\ (\$V_{Acidification}) + Improved\ Visibility\ (\$V_{Haze}) + etc. \end{aligned}$$

20 While the value of all of these benefits has been estimated in other studies using European monetary values (as presented in a model called Alpha RiskPol), this proposal presents a more conservative estimate limited only to the monetised benefits of avoided mortality associated with cardiovascular disease and lung cancer. Moreover, this proposal calibrates the VSL to the economies of the [Mediterranean coastal States]. Therefore, these under-estimated benefits are presented in terms of their potential sufficiency for the designation of the proposed Med ECA, acknowledging that additional benefits described above remain non-monetised. Table 3 presents results of that analysis, indicating that the monetised benefits of avoided mortality singly exceed the total costs of implementing the proposed Med ECA.

Table 3. Mortality-weighted VSL for [Mediterranean coastal States]

Policy Regime	Mortality-weighted VSL for [Mediterranean coastal States] ($ Millions)
No Action	2.157
MARPOL VI	1.094
Med ECA	1.818

21 Cost-effectiveness also indicates support for the designation of the proposed Med ECA, as illustrated in Table 4. The costs for each tonne of SO_x and PM avoided are estimated at US$ 13,400 and US$ 155,000, respectively. These costs per tonne are a measure of cost-effectiveness, and are comparable or favourable to the cost-effectiveness of the controls imposed on many land-based sources. When compared with prior SECA proposals, such as the North American ECA, the net cost-effectiveness to achieve 0.1% Sulphur (S) fuel limits from pre-2020 IMO standards is very similar. Improving current ship emission levels to SECA standards is one of the most cost-effective measures available to obtain necessary improvements to the air quality in the proposed Med ECA and for the [Mediterranean coastal States] individually.

Table 4. Cost-effectiveness comparison with North American ECA[2]

Benefit Type	U.S. estimates for North American ECA	North American ECA results with adjusted fuel prices[3]	Med ECA combining MARPOL VI and SECA results
Control Target			
Abated SO_x emissions	$4,500 /MT SO_x	$14,000 /MT SO_x	$8,900 /MT SO_x
Abated $PM_{2.5}$ emissions	$43,000 /MT $PM_{2.5}$	$128,000 /MT $PM_{2.5}$	$94,000 /MT $PM_{2.5}$
Health Outcome			
Avoided mortality[4]	$0.410 M/Δ Mortality	$1.229 M/Δ Mortality	$0.353 M/Δ Mortality
Avoided asthma illnesses[5]	$16 k/Δ Morbidity	$49 k/Δ Morbidity	$21 k/Δ Morbidity

22 The economic impacts of complying with the program on ships engaged in international trade are expected to be modest. As in other SECA regions, ship operators are expected to be able to pass additional costs associated with complying with the SECA fuel sulphur control measures to the purchasers of marine transportation services. Transportation costs ultimately are embedded in prices for the goods being shipped. Potential price impacts are expected to be small because transportation is only a small share of total production costs for finished goods.

[2] Combined MARPOL VI and the proposed Med ECA costs for the analysis conducted for this proposal compared with United States (U.S.) NOx and PM data to reduce ship fuel from pre-MARPOL VI conditions to 0.1% S SECA conditions.

[3] Given that the 2009 North American proposal to designate an ECA used a fuel price difference of $145/MT to shift from HFO to SECA compliant fuel, and the analysis conducted for this proposal uses a fuel price difference of ~$434/MT, the U.S. cost-effectiveness estimates (column 2, above) was multiplied by the ratio of these price differences to match with fuel price changes used for the analysis conducted for this proposal.

[4] North American mortality methods are similar to those used here, although they may use a health risk equation similar to the log-linear equation discussed and compared in Sofiev et al, Nature Communications 2018 (*1*).

[5] For comparison purposes with the childhood asthma illness results of the analysis conducted for this proposal, the set of childhood asthma related diseases reported separately by the U.S. was summed.

Conclusion

23 Ship emissions contribute significantly to air pollution, adverse human health outcomes and ecosystem damage in the [Mediterranean Sea area]. The designation of the proposed Med ECA will reduce these effects and improve public health and the environment within the [Mediterranean coastal States]. The [Mediterranean coastal States] have already implemented emission controls on land-based sources of air pollution. Applying SECA standards to vessels engaged in international shipping in the [Mediterranean Sea area] will achieve substantial benefits at comparable, and reasonable, costs.

Action requested of the Committee

24 The Committee is invited to consider the information presented in this document and to approve the proposed Med ECA, with a view toward the adoption by the Parties to MARPOL Annex VI, at MEPC XX, of amendments to regulation 14.3 of MARPOL Annex VI, as shown in Annex 4, to formally designate the Mediterranean Sea area, [or parts thereof,] as an ECA for Sulphur Oxides [and Particulate Matter] taking effect on [date].

ANNEX 1

Information responding to the criteria in Appendix III to MARPOL Annex VI

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List of Acronyms and Abbreviations

CO_2	Carbon Dioxide
ECA	Emission Control Area
EERA	Energy and Environmental Research Associates, LLC
EGCS	Exhaust Gas Cleaning System (mainly termed in this document as “scrubber”)
FMI	Finnish Meteorological Institute
GHG3	Third IMO Greenhouse Gas Study 2014
GHO	Global Health Observatory
HFO	Heavy Fuel Oil (residual fuel by-product and or blends including IFO 380, IFO 180, etc.)
IER	Integrated Exposure Response
IHO	International Hydrographic Organization
IMO	International Maritime Organization
k	Thousands (as in Thousands of Dollars)
kW	Kilowatt
kWh	Kilowatt-hour
LNG	Liquefied Natural Gas
M	Millions (as in Millions of Dollars)
MARPOL	International Convention for the Prevention of Pollution from Ships
MARPOL VI	MARPOL Annex VI (global fuel-sulphur limit of 0.5% S)
MDO	Marine Distillate Oil (including blended or refined products meeting MARPOL VI 0.5% S)
Med ECA	Mediterranean Emission Control Area for Sulphur Oxides [and Particulate Matter] (regional fuel-sulphur limit of 0.1% S)
MGO	Marine Gas Oil (including refined products meeting SECA fuel limits of 0.1% S)
MMT	Million Metric Tonnes
MT	Metric Tonnes
NO_x	Nitrogen Oxides
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter 2.5µ or smaller
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
S	Sulphur
SECA	SO_x Emission Control Area
SILAM	System for Integrated modeLling of Atmospheric coMposition
SO_x	Sulphur Oxides
STEAM	Ship Traffic Emission Assessment Model
U.S.	United States
UNFCCC	United Nations Framework Convention on Climate Change
VSL	Value of a statistical life (or monetary value to reduce risk of a statistical premature death)
WHO	World Health Organization

1 Introduction

The information in this annex supports the proposal by [list of co-sponsors] for the designation of the Mediterranean Sea area, [or parts thereof,] as an Emission Control Area (ECA) to prevent, reduce and control emissions of sulphur oxides (SOx) [and particulate matter (PM)] from ships pursuant to regulation 14 and Appendix III to Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL), hereinafter referred to as the proposed Med ECA.

1.1 Countries Submitting this Proposal

The [XXX] countries bordering the [Mediterranean Sea] – [list of relevant Mediterranean coastal States] share a common interest in the [Mediterranean Sea] and in addressing emissions from ships along their coastlines. These countries ask the Committee to consider this proposal at MEPC XX and refer it for adoption by the Parties to MARPOL Annex VI, meeting under the auspices of MEPC XX.

As of [date], among the [Mediterranean coastal States], Croatia, Cyprus, France, Greece, Italy, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syrian Arab Republic, Tunisia, and Turkey, have ratified MARPOL Annex VI. Albania, Algeria, Bosnia and Herzegovina, Egypt, Israel, Lebanon, and Libya have not yet ratified MARPOL Annex VI (Table 1.1-1).

[PLACEHOLDER FOR DESCRIPTION OF FURTHER ACTIONS TOWARDS RATIFICATION]

Table 1.1-1. Status of ratification of MARPOL Annex VI by [Mediterranean coastal States] (as of [date])

Country	MARPOL Annex VI
Albania	
Algeria	
Bosnia and Herzegovina	
Croatia	x
Cyprus	x
Egypt	
France	x
Greece	x
Israel	
Italy	x
Lebanon	
Libya	
Malta	x
Monaco	x
Montenegro	x
Morocco	x
Slovenia	x
Spain	x
Syrian Arab Republic	x
Tunisia	x
Turkey	x

1.2 Criteria for Designation of an Emission Control Area

Under MARPOL Annex VI, an ECA may be considered by the International Maritime Organization (IMO) if supported by a demonstrated need to prevent, reduce and control air pollution from ships. The following eight criteria are laid out under section 3 of Appendix III to MARPOL Annex VI, as quoted:

3.1.1. a clear delineation of the proposed area of application, along with a reference chart on which the area is marked;

3.1.2. the type or types of emission(s) that is or are being proposed for control (i.e. NO_x or SO_x and particulate matter or all three types of emissions);

3.1.3. a description of the human populations and environmental areas at risk from the impacts of ship emissions;

3.1.4. an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified;

3.1.5. relevant information pertaining to the meteorological conditions in the proposed area of application, to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts;

3.1.6. the nature of the ship traffic in the proposed emission control area, including the patterns and density of such traffic;

3.1.7. a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NO_x, SO_x and particulate matter emissions affecting the human populations and environmental areas at risk that are in place and operating concurrent with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI; and

3.1.8. the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade.

2 Description of the Proposed Area of Application

This section presents information that addresses criteria 3.1.1, 3.1.2 and 3.1.3 of Appendix III to MARPOL Annex VI, as quoted:

Criterion 3.1.1	The proposal shall include a clear delineation of the proposed area of application, along with a reference chart on which the area is marked.
Criterion 3.1.2	The proposal shall include the type or types of emission(s) that is or are being proposed for control (i.e. NO_x or SO_x and particulate matter or all three types of emissions).
Criterion 3.1.3	The proposal shall include a description of the human populations and environmental areas at risk from the impacts of ship emissions.

2.1 Proposed Area of Application

The [Mediterranean] is an important region for international shipping and commercial navigation. The [Mediterranean Sea] represents approximately 0.7% of navigable seas and oceans, and [Mediterranean] ship traffic accounts for about 7% of global shipping activity, energy use, and emissions. Based on AIS observations, more than 30,000 vessels are observed to operate annually in the [Mediterranean Sea]. Based on the analysis conducted for this proposal, shipping CO_2 emissions represent about 10% of the [Mediterranean coastal States]' CO_2 inventories, as reported to the United Nations Framework Convention on Climate Change (UNFCCC).

The proposed area of application for the designation of the proposed Med ECA, as modelled in this document, is illustrated in Figure 2.1-1. [The proposed area of application follows the International Hydrographic Organization (IHO) definition of the Mediterranean Sea[6] as being bounded on the southeast by the entrance to the Suez Canal, on the northeast by the entrance to the Dardanelles, delineated as a line joining Mehmetcik and Kumkale lighthouses, and to the west by the meridian passing through Cap Spartel lighthouse, also defining the western boundary of the Straits of Gibraltar. The proposed area of application is identical to the geographic area described in Article 1.1 of the Barcelona Convention, which is hereinafter referred to as the Mediterranean Sea area.] The waters of the proposed Med ECA involve the [twenty-two (22)] Contracting Parties to the Barcelona Convention, namely [Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syrian Arab Republic, Tunisia, Turkey and the European Union]. Additional detail on the proposed area of application is included in Annex 2 to this proposal.

Figure 2.1-1. Contracting Parties to the Barcelona Convention and proposed Med ECA

2.2 Types of Emissions Proposed for Control

This proposal supports designation of an ECA to control SO_x [and PM] emissions from ships. SO_x is a precursor to fine PM formation. Section 4 provides details on the health impacts associated with PM, and Section 5 provides details on the impacts to ecosystems from deposition of PM and compounds containing wet and dry sulphate.

2.2.1 SO_x and PM Pollution

SO_x pollution is formed during marine engine combustion, from available sulphur in marine fuel. SO_x emissions from ship exhausts contribute to the formation of sulphate (SO_4) aerosols, which are small particles. Small sulphate aerosol particles, along with other PM species, are able to penetrate deep into the lungs of living organisms, including humans, contributing to increased lung cancer and cardiovascular disease mortality and asthma morbidity. In addition, deposition of SO_4 particles contribute to increased acidification of surface waters and terrestrial systems, which is deleterious to the environment.

[6] https://www.iho.int/iho_pubs/standard/S-23/S-23_Ed3_1953_EN.pdf.

2.3 Populations and Areas at Risk from Exposure to Ship Emissions

The [Mediterranean Sea area] is enclosed on all sides by land masses with significant coastal populations. The [Mediterranean coastal States] are home to 507.5 million people, many of whom live in coastal towns and cities (Figure 2.3-1). The [Mediterranean Sea] is an essential shipping route for goods travelling from East Asia to European, West Asian, and North African markets, meaning that a large number of people live in close proximity to one of the world's major shipping gateways.

The [Mediterranean Sea area] is home to many sites of significant cultural heritage, including sensitive ecosystems and ancient ruins. Because ship pollution can travel great distances, transported by atmospheric processes, large inland populations and ecosystems will benefit from the proposed Med ECA, in addition to populations, sites, and ecosystems in coastal locations.

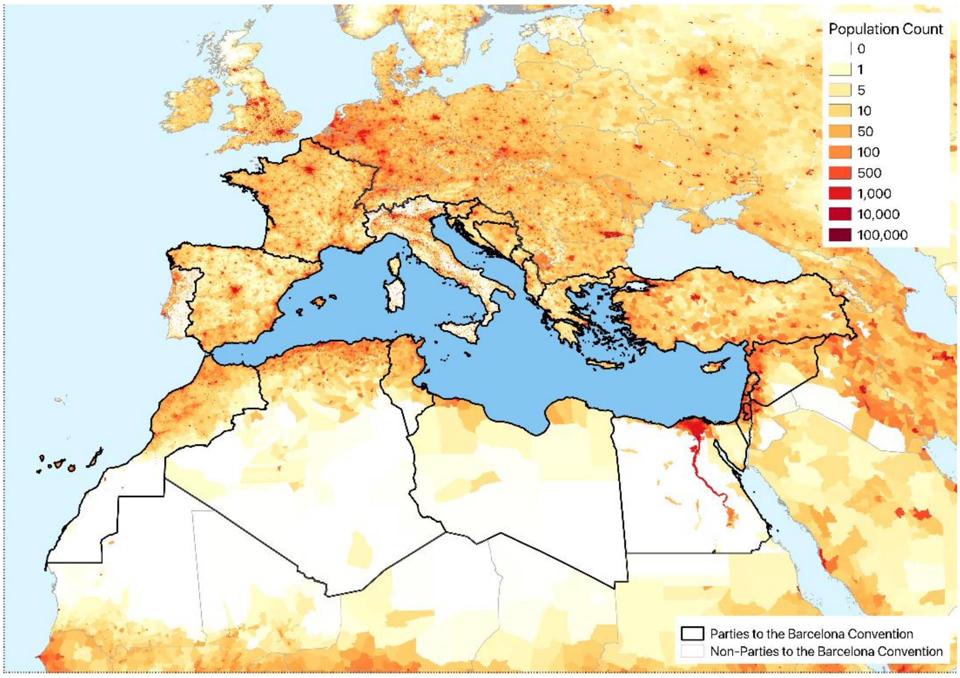

Figure 2.3-1. Gridded population in the [Mediterranean coastal States]

2.4 Summary of Description of the Proposed Area of Application

Based on the information presented in the previous sections 0, 2.2, and 2.3, this proposal fulfils criteria 3.1.1, 3.1.2, and 3.1.3 of Appendix III to MARPOL Annex VI.

3 Contribution of Ships to Air Pollution and Other Environmental Problems

This section presents information that addresses criterion 3.1.4 of Appendix III to MARPOL Annex VI, as quoted:

Criterion 3.1.4 The proposal shall include an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified.

3.1 Synopsis of the Assessment

[PLACEHOLDER FOR SYNOPSIS TO BE PROVIDED THROUGH ROAD MAP]

3.2 The [Mediterranean Sea area] Emissions Inventory Summary

Lower-sulphur fuels that would be required under the proposed Med ECA would result in lower emissions than current practices, and lower emissions compared with global MARPOL VI 2020 limits. SO_x reductions are directly proportion to the shift from 0.5% to 0.1% fuel. PM reductions depend primarily on the fraction of ship-emitted PM that results from fuel-sulphur content.

MARPOL VI standards will reduce SO_x emissions by approximately 75% from typical operations using residual fuels. Implementing SECA standards would achieve about a 95% reduction in SO_x emissions form ships compared with current operations. PM reductions of about 51% are associated with MARPOL VI, and SECA standards would increase that to about 62% reduction in emissions.

Baseline SO_x and $PM_{2.5}$ emissions are estimated to be 681,000 and 97,500 MT in 2016. Under the MARPOL VI scenario emissions of these species fall by 75.3% and 50.7% respectively. Emission inventory results under the proposed Med ECA 2020 scenario for SO_x and $PM_{2.5}$ species are reduced by a further 78.7% and 23.7% compared to MARPOL VI 2020 (Table 3.2-1).

3.2.1 Emissions Inventory Modelling and Inputs for 2020 Scenario and Future Years

International ship power systems currently consume mainly petroleum-based fuel products and by-products, with limited use of liquefied natural gas. Most of the fleet consumes residual fuel, also known as heavy fuel oil (HFO), which includes several grades of blended petroleum by-products of refining (*2*). Current limits prescribed under MARPOL VI will require marine vessels to adopt fuels meeting a global limit of 0.5% Sulphur (0.5% S) in 2020. This proposal models default compliance with MARPOL VI to result from a switch from non-compliant fuel (average 2.4% S) to MARPOL VI compliant (0.5% S) fuel. All future year scenarios consider technical and economic feasibility of the proposed Med ECA to be compared with conditions defined using MARPOL VI compliant fuel.

Table 3.2-1. Baseline and 2020 scenario criteria and GHG pollution emissions

MT	MED 2016 Baseline	MARPOL VI 2020	Proposed Med ECA 2020
Total SO_x	681,000	168,000	35,800
Total $PM_{2.5}$	97,500	48,100	36,700
Total NO_x	1,330,000	1,160,000	1,170,000
Total CO_2	58,070,000	51,700,000	51,880,000

In considering the proposed Med ECA, compliance alternatives modelled in this document begin by assuming a switch from MARPOL VI compliant fuel to SECA compliant fuel. In other words, the proposed Med ECA would result in a shift from 0.5% S to 0.1% S marine fuel. Recognising that SECA compliance can be achieved through alternative compliance mechanisms, this document considers these mainly as part of the economic feasibility (Sections 9.3.1 and 9.3.2); fleet operators would be expected to adopt compliance alternatives to fuel switching where the long-run costs of SECA compliance were reduced. Alternative approaches to SECA compliance consider adoption of exhaust abatement technology or advanced fuel alternatives. This document models onboard sulphur scrubbers, also termed exhaust gas cleaning systems (EGCS), as the primary exhaust abatement technology to meet lower-sulphur limits of the proposed Med ECA. This document models liquefied natural gas (LNG) as the advance fuel alternative to meet lower-sulphur limits of the proposed Med ECA. Acknowledging that other technologies and fuels may be specified, this document utilises an analytical framework that can be applied to more specifically investigate other compliance strategies (e.g., various scrubber designs, methanol, hydrogen or other marine fuel-power combinations).

This document uses the Ship Traffic Emission Assessment Model (STEAM) to model the activity-based fuel consumption and emissions of over 30,000 vessels operating annually in the [Mediterranean Sea area]. Informed by Ship Automated Identification System (AIS) for the year 2016, the STEAM model integrates vessel activity, technology and design characteristics, and fuel type inputs to estimate vessel-specific energy requirements, fuel consumption, and emissions. These estimates are aggregated by vessel type and within the [Mediterranean Sea area] to produce annual fuel and emissions estimates for a base year 2016. The STEAM Model also produces a set of future-year estimates for 2020, 2030, 2040, and 2050, employing assumptions about future fleet demand, vessel economies of scale, improvements in fuel economy, and fleet replacement rates.

3.3 Shipping Contribution to Ambient Air Quality

3.3.1 Shipping Contribution to Ambient $PM_{2.5}$ Air Pollution in the [Mediterranean Sea area]

Air quality modelling shows that emissions of SO_x and PM from ships have a significant impact on air quality in the [Mediterranean Sea area]. Furthermore, modelling shows that the proposed Med ECA would lead to widespread benefits throughout the [Mediterranean Sea area] and far inland due to the long range nature of pollution from ships.

3.3.1.1 Improvement of Ambient Air Quality with the proposed Med ECA ($PM_{2.5}$)

Figure 3.3-1 shows the geospatially-modelled annual average difference in $PM_{2.5}$ concentration due to implementation of the proposed Med ECA compared to the MARPOL VI 2020 baseline. Areas in blue show places where $PM_{2.5}$ under MARPOL VI is greater than for the proposed Med ECA scenario, i.e. where the proposed Med ECA leads to a reduction in $PM_{2.5}$. As shown, all water areas of the [Mediterranean Sea] experience reductions in $PM_{2.5}$ concentration of between 0.05 and 0.6$\mu g.m^{-3}$, with coastal land benefits being realised primarily along the North African coastline, Spain, France, Italy, Malta, and Greece. Areas with the greatest expected reductions in $PM_{2.5}$ concentrations attributable to ships are at the western [Mediterranean Sea], along the coastlines of Spain and Morocco, in the central [Mediterranean Sea] to the south of Sicily and over Malta, to the south and east of Greece, and along the north coast of Egypt approaching the entrance to the Suez Canal.

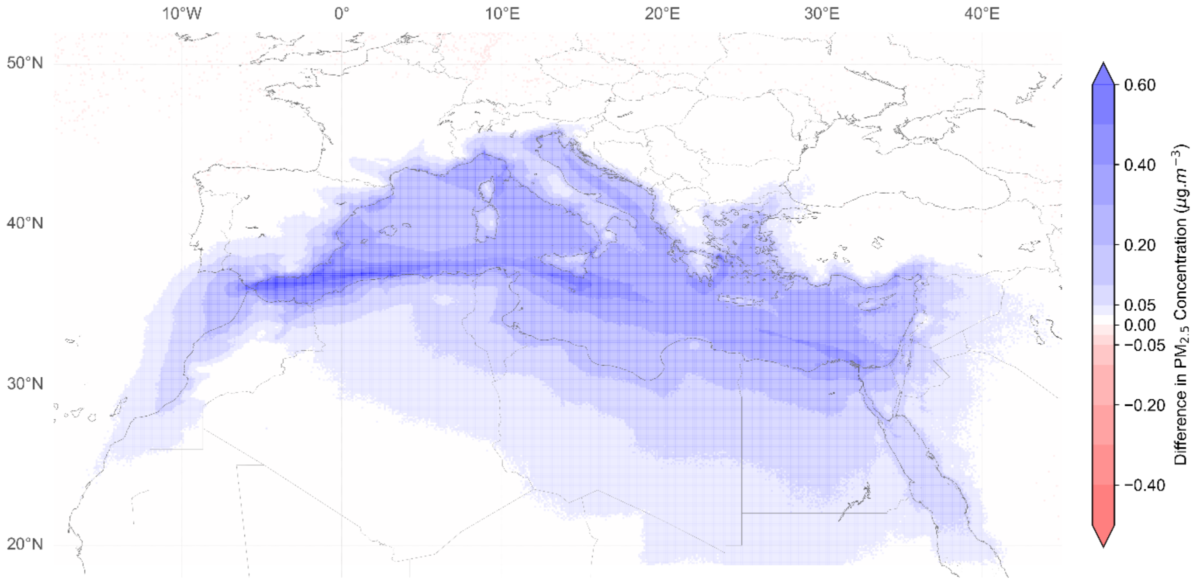

Figure 3.3-1. Difference in $PM_{2.5}$ concentration between MARPOL VI and the proposed Med ECA scenarios

3.4 Summary of Shipping Contribution to Ambient Air Quality

As the data in Figure 3.3-1 shows, a SECA established under regulation 14 would yield benefits for all coastal communities surrounding the proposed Med ECA, and also benefit communities far inland. The air quality benefits of the proposed Med ECA have been clearly demonstrated and fulfil the contributions of ships to air quality portion of criterion 3.1.4 of Appendix III to MARPOL Annex VI.

4 Impact of Emissions from Ships on Human Health

This section presents further information building on Section 3, which addresses criterion 3.1.4 of Appendix III to MARPOL Annex VI, as quoted:

Criterion 3.1.4	The proposal shall include an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic

ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified.

4.1 Health Effects Related to Exposure to Air Pollutants

The expected avoided lung cancer and cardiovascular disease mortality, and childhood asthma morbidity, associated with the proposed Med ECA were estimated using the state-of-the-art health model, recently published in *Nature Communications (1),* and referenced in MEPC 70/INF.34. This model produces high resolution (10km x 10km) mortality and morbidity estimates, corresponding to the resolution of underlying concentration grids provided by the System for Integrated modeLling of Atmospheric coMposition (SILAM) model. The high-resolution modelling approach reduces under and over estimation of mortality and morbidity inherent with coarser (50km x 50km) models of emissions and population. The model outputs include high resolution gridded estimates of mortality and morbidity, and country-specific burdens of disease for the countries shown in Figure 2.1-1. Country-specific population growth estimates, disease incidence rates, and age structures, as well as global gridded population and socioeconomic data from the Socioeconomic Data and Applications Center (SEDAC) (*3*) were used.

4.2 Nature of PM Health Effects

PM particles less than 10 microns in diameter (PM_{10}) can be breathed deep into the lungs and contribute to disease. Specifically, PM particles less than 2.5 microns in diameter ($PM_{2.5}$) can pass through the lung barrier and enter the blood stream which increases the risk of cardiovascular and respiratory disease, including lung cancer. Chronic exposure to high concentrations of PM is associated with greater risk of cardiovascular and lung cancer disease than exposure to low concentrations, however, no lower threshold has been identified, with increased risk of disease at all levels of exposure to PM.

4.3 Methodology for Estimating Health Effects

The methodology for modelling health impacts follows the approach discussed in previous work (*4, 5*). Earlier work applied mortality risk functions identified in Ostro (2004) (*6*), which in turn builds on work developed out of the U.S. Harvard Six Cities study conducted earlier by Pope, et al. (*7-9*).

$PM_{2.5}$ exposure concentrations in the [Mediterranean Sea area] are similar to those in the Harvard Six Cities study, indicating that premature mortality risk functions derived from the Harvard Six Cities study can be applied to the said area.

This health impacts assessment follows work published in *Nature Communications* in 2018 that employs a concentration-response (C-R) function from Lepeule, et al. (2012), which updates epidemiology from the Harvard Six Cities study (*10*). Health outcomes are estimated using a linear C-R function, which reflects updated understanding of the relationship between health and exposure to air pollution and provides improved estimates of health outcomes where ambient concentrations of $PM_{2.5}$ exceed WHO guidelines (>20µg m^{-3}). Health outcome estimates focus on cardiovascular and lung cancer mortality responses in populations aged over 30 years old, aligned with Lepeule, et al. (2012). As in earlier work (Sofiev et al., 2018), an assessment of childhood (<14 years) asthma morbidity, which uses similar concentration-response equations based on reported asthma incident rates by country (*11*), was included.

Gridded population data for 2020 are from NASA's Socioeconomic Data and Applications Center (SEDAC) Population of the World, Version 4.10 (*3*). These data provide gridded population counts, which were resampled to 0.1° x 0.1° resolution (~10km x 10km) to reflect regional differences in population counts. These population data are built upon UN statistics and apply sub-national rates of population change (growth/decline) to estimate population counts in the future. Country-level age cohort fractions directly to the population counts for each country from the United Nations were applied to determine the age cohort populations by country (*12*). A uniform population age structure was assumed across each country, multiplying the population grid by the country-specific fraction of population under the age of 14 and between the ages of 30 and 99. This approach likely does not account for regional differences in age cohorts, but represents the best available practice given the paucity of country-specific age-cohort data.

Country-specific incidence rates for cardiovascular disease and lung cancer are derived from data from the World Health Organization's Global Health Observatory (GHO) (Table 4.3-1) (*13, 14*) . To determine overall health outcomes associated with ship emissions and the proposed Med ECA, we calculate avoided mortality based on the change in $PM_{2.5}$ concentration between the 2020 MARPOL VI (0.5% S) scenario and the proposed Med ECA (0.1% S) scenario.

Table 4.3-1. WHO cardiovascular and lung cancer disease mortality, and childhood asthma morbidity rates

COUNTRY	CARDIOVASCULAR (DISEASE PER 100,000)	LUNG CANCER (DISEASE PER 100,000)	ASTHMA (DISEASE PERCENT, AGE <14)
ALBANIA	330.0	26.0	3.6
ALGERIA	220.3	8.7	7.1
BOSNIA AND HERZEGOVINA	277.8	29.1	9.9
CROATIA	208.0	22.9	5.2
CYPRUS	142.3	20.7	9.9
EGYPT	412.3	7.6	5.2
FRANCE	70.6	27.8	12.6
GREECE	135.1	31.8	9.8
ISRAEL	77.1	20.3	10.3
ITALY	103.2	22.9	11.4
LEBANON	295.0	17.0	11.6
LIBYA	324.0	19.0	9.9
MALTA	138.5	20.9	14.1
MONACO	70.6	27.8	9.9
MONTENEGRO	329.2	36.6	9.9
MOROCCO	260.3	12.8	13.3
SLOVENIA	138.5	28.7	9.9
SPAIN	82.1	23.8	13.9
SYRIAN ARAB REPUBLIC	377.5	17.0	5.1
TUNISIA	278.5	15.7	9.3
TURKEY	202.6	29.8	9.9

Country-specific incidence rates for childhood asthma are provided in the 2014 Global Asthma Report (*15*). For Asthma disease, the "Asthma Ever" data in the 13-14 year old age group reported in the 2014 Global Asthma Report (Table 4.3-1) was used, and this percentage was applied to the population fraction under the age of 14. Zheng et al (*11*) provide relative risk (RR) factors for childhood asthma from exposure to $PM_{2.5}$ pollution (Table 2 of Zheng), which were converted to β coefficients.

Avoided mortality and morbidity due to changes in total particulate matter concentrations were calculated using approaches mentioned above, consistent with other recent work in this area (*5, 16*). The total effect (E) of changes for each grid cell is given as:

$$E = AF \cdot B \cdot P$$

where *B* represents the incidence rate of the given health effect (Table 4.3-1); *P* is the relevant population, weighted by the age cohort; and *AF* is the attributable fraction of disease due to the shipping-related PM pollution, and is given by:

$$AF = \frac{RR-1}{RR}$$

For a "linear" C-R model, the response RR is given by the function (*17*):

$$RR = e^{\beta \cdot (C_1 - C_0)}$$

And therefore,

$$AF = 1 - e^{\beta \cdot (C_0 - C_1)}$$

which leads to

$$E = \left[1 - e^{\beta\cdot(C_0 - C_1)}\right] \cdot B \cdot P$$

where β = 0.023111 (95% CI = 0.013103, 0.033647) for cardiovascular mortality; β = 0.031481 (95% CI = 0.006766, 0.055962) for lung cancer related mortality (*8, 10, 18*); and where β = 0.002469 (95% CI = 0.001291, 0.003633) for childhood asthma morbidity (*11*).

This approach follows WHO guidelines in the 2016 Global Burden of Disease (*19*) by combining WHO-derived health incidence data with gridded population and ambient air quality data. The functional form of the integrated exposure response (IER) follows a modified, but functionally similar, form of the IER recommended by the WHO.

4.4 Quantified Human Health Impacts from Exposure to Ship Emissions

4.4.1 Avoided Cardiovascular and Lung Cancer Mortality

Health outcomes are improved in all coastal areas of all [Mediterranean coastal States]. Figure 4.4-1 shows the combined avoided lung cancer and cardiovascular mortality associated with implementing the proposed Med ECA. In many cases, health outcomes are improved hundreds of miles inland. Modelling results show a reduction in cardiovascular disease mortality of ~970 deaths/year and a reduction in lung cancer mortality of ~150 deaths/year. Due to the interaction between air quality improvements, population centres, and country-specific incidence rates, hotspots where avoided mortality from reduced ship emissions is greater are seen. Clusters of these hotspots can be seen in North Africa as well as areas of the eastern [Mediterranean].

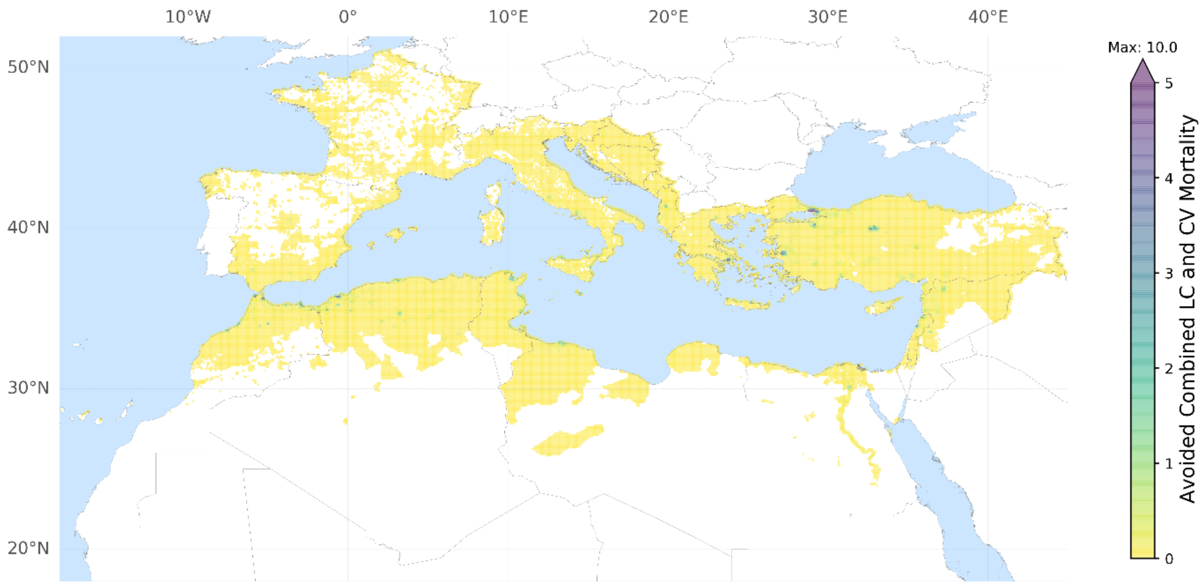

Figure 4.4-1. Combined avoided lung cancer and cardiovascular mortality with the proposed Med ECA

4.4.2 Childhood Asthma Morbidity

Childhood asthma health outcomes are improved in all [Mediterranean coastal States]. Figure 4.4-1 shows the avoided childhood asthma morbidity associated with implementing the proposed Med ECA. Avoided morbidity in this case refers to the number of children experiencing one or more ship-pollution induced asthma events each year. In many instances, improved health outcomes are observed hundreds of miles inland, and in many [Mediterranean coastal States] experience the benefits of the proposed Med ECA over the entirety of their land area. Modelling results show a reduction in childhood asthma morbidity of ~2,300 children experiencing one or more ship-pollution induced asthma events per year. As for morbidity, health outcomes are improved across large areas of the [Mediterranean coastal States], with a hotspot of avoided asthma morbidity seen in North Africa and the eastern [Mediterranean].

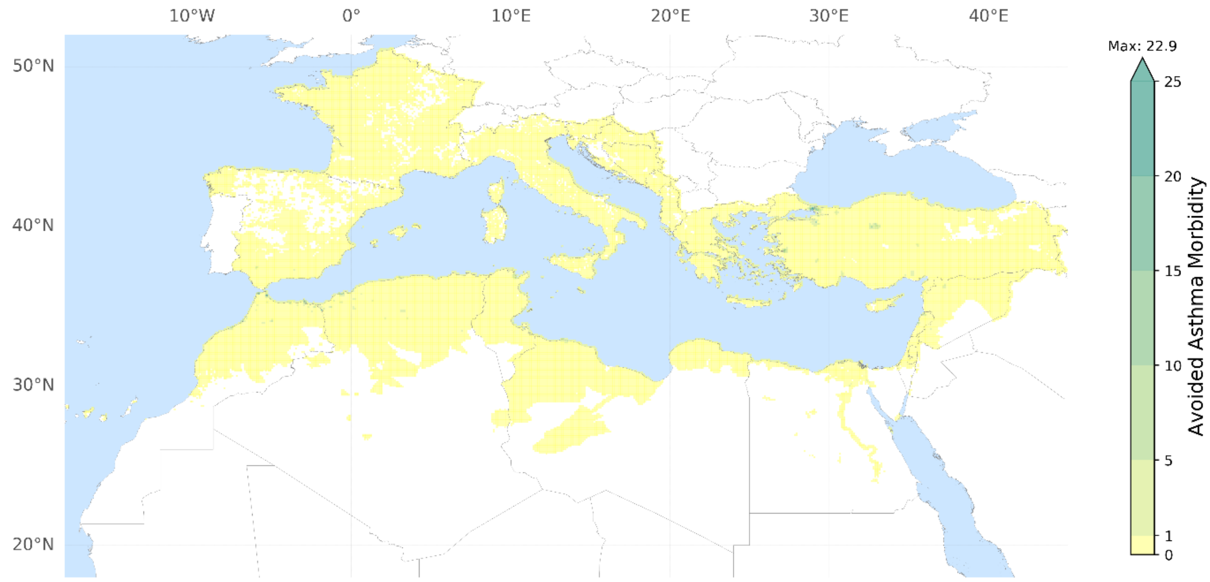

Figure 4.4-2. Avoided childhood asthma morbidity with the proposed Med ECA

4.4.3 Summary of Evaluated Health Benefits

The health effects estimated in this document are shown in Table 4.4-1, along with 95% confidence intervals. It is estimated that improving to SECA standards from MARPOL VI would result in 969 avoided cases of cardiovascular mortality, and 149 cases of lung cancer mortality. Furthermore, childhood asthma morbidity would be reduced in 2,314 children under the age of 14 each year.

Table 4.4-1. Summary of health benefits evaluated for the proposed Med ECA (model year 2020)

Scenario Results (Linear C-R Model)	**Reduced Mortality (annual premature adult deaths)**		**Avoided Childhood Asthma (annual avoided incidents)**	
	Reduced Mortality		**Reduced Asthma Morbidity**	
Health benefit of the proposed Med ECA	CV Mortality Avoided	969 (CI 95% 551; 1412)	**Avoided Childhood Asthma**	**2314 (CI 95% 1211; 3406)**
	LC Mortality Avoided	149 (CI 95% 32; 270)		
	Combined Avoided Mortality	**1,118 (CI 95% 583; 1682)**		

4.5 Summary of Impact of Emissions from Ships on Human Health

As described above, emissions from ships contribute to a large number of adverse human health impacts. The designation of the proposed Med ECA would reduce the risk of premature mortality and contribute to the avoidance of many morbidity-related health impacts. Thus, this proposal fulfils the human health portion of criterion 3.1.4 of Appendix III to MARPOL Annex VI.

5 Impact of Emissions from Ships on Ecosystems

This section presents further information building on Sections 3 and 4, which addresses criterion 3.1.4 of Appendix III to MARPOL Annex VI, as quoted:

Criterion 3.1.4 — The proposal shall include an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified.

5.1 Overview of Deposition Resulting from Ship SO_x and PM Emissions

Air quality modelling shows widespread reductions in wet and dry SO_x and $PM_{2.5}$ deposition resulting from fuel sulphur reductions due to the proposed Med ECA. This indicates that sensitive ecosystems and areas of cultural heritage around the [Mediterranean Sea area] would benefit from improvements to environmental health resulting from the proposed Med ECA.

5.2 Environmental and Ecosystem Impacts and Areas at Risk

SO_x pollution is formed during marine engine combustion, from available sulphur in marine fuel. SO_x emissions from ship exhausts contribute to the formation of sulphate (SO_4) aerosols, which are small particles. Sulphate aerosols are acidic. They can be transported while airborne over land or water, where they may be deposited through wet (e.g. rain) or dry (e.g. gravitational settling) processes. Increased acid deposition associated with SO_x emissions leads to deleterious effects on aquatic and terrestrial ecosystems. Sulphate deposition to water leads to lower pH levels in aquatic environments. Lower pH levels alter sensitive ecosystems as acid-intolerant flora and fauna species are adversely affected, which can lead to wider trophic changes and ecosystem shifts. Sulphate deposition to terrestrial environments is damaging to plants, as increased acid deposition can lead to reductions in minerals and nutrients necessary for plant growth, as well as damaging foliage, which reduces photosynthetic capacity. Furthermore, atmospheric sulphate has a light scattering effect, which can lead to increased haze and reduced visibility. In addition to environmental impacts, acid deposition can damage the material of built structures and statues.

5.2.1 Sulphate deposition (SO_4)

Decreases in wet (Figure 5.2-1) and dry (Figure 5.2-3) sulphate (SO_4) deposition associated with the proposed Med ECA show similar orders of magnitude, but follow different patterns. Decreases in wet sulphate deposition are largest in the western and northern [Mediterranean], and show reductions in SO_4 deposition occurring far inland. Reductions in dry sulphate deposition are more closely correlated to the high traffic shipping lanes. Taking the [Mediterranean Sea area] as a whole, the average reduction in wet sulphate deposition is 43.3 $g.ha^{-1}.yr^{-1}$, and the maximum observed reduction is 3,127.8 $g.ha^{-1}.yr^{-1}$. The maximum percent decrease in wet sulphate deposition observed is 14.23% (Figure 5.2-2), which occurred over the Straits of Gibraltar. The average percent decrease in wet sulphate deposition estimated for the [Mediterranean Sea area] is 1.16%.

The maximum percent decrease in dry sulphate deposition observed is 48.13% (Figure 5.2-4), which occurred over the Straits of Gibraltar and extending eastwards towards Algiers. The average percent decrease in dry sulphate deposition estimated for the [Mediterranean Sea area] is 1.95%.

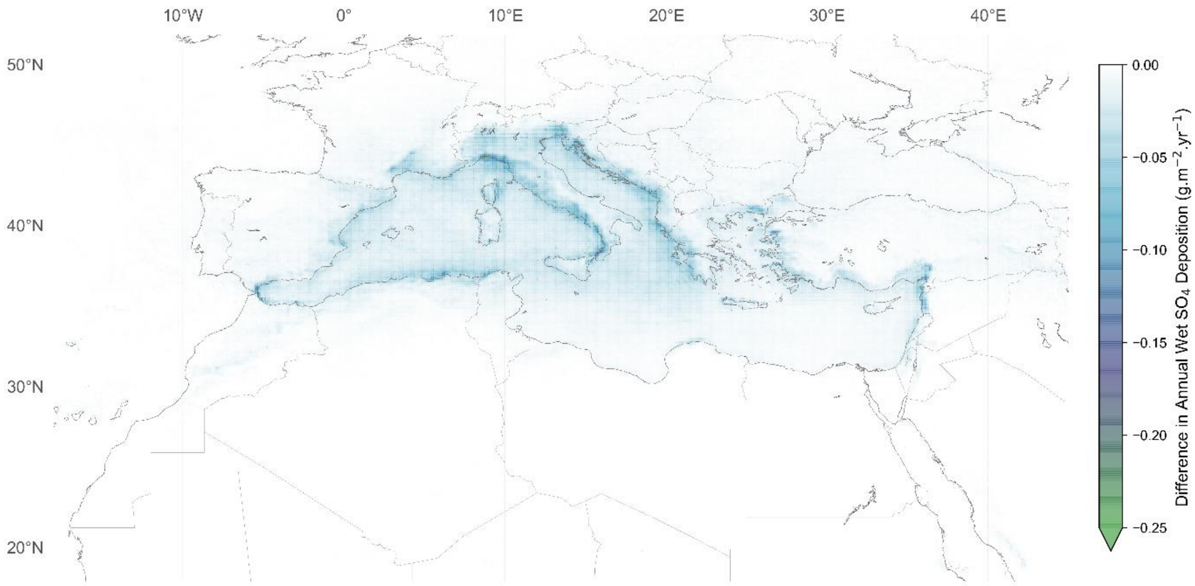

Figure 5.2-1. Decrease in annual wet sulphate deposition between MARPOL VI and the proposed Med ECA

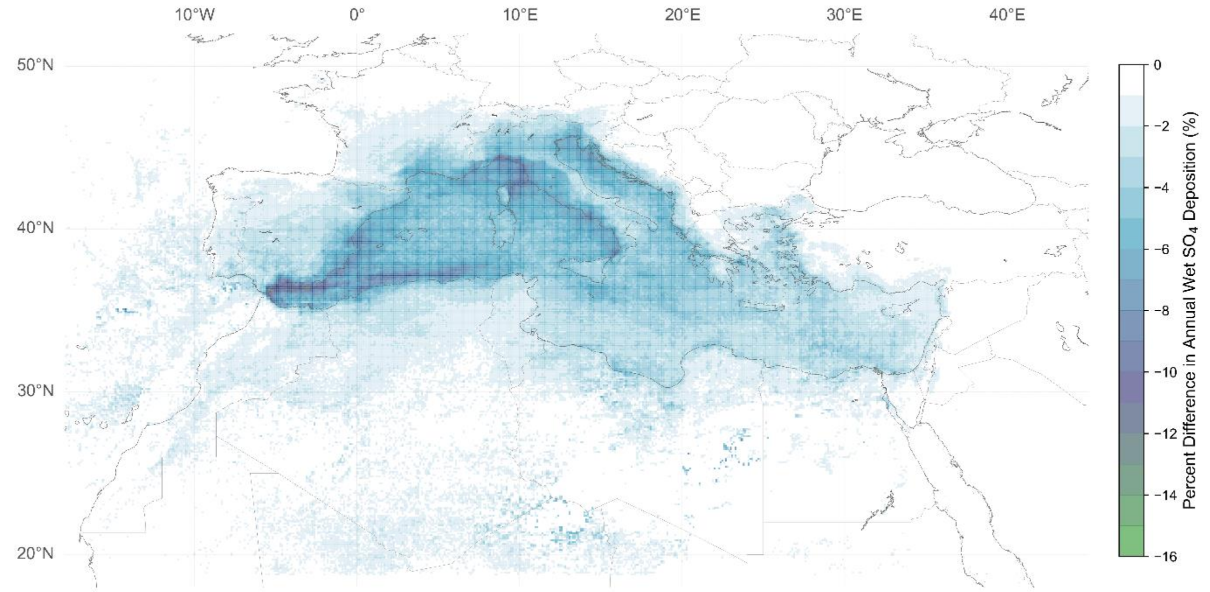

Figure 5.2-2. Percent decrease in annual wet sulphate deposition between MARPOL VI and the proposed Med ECA

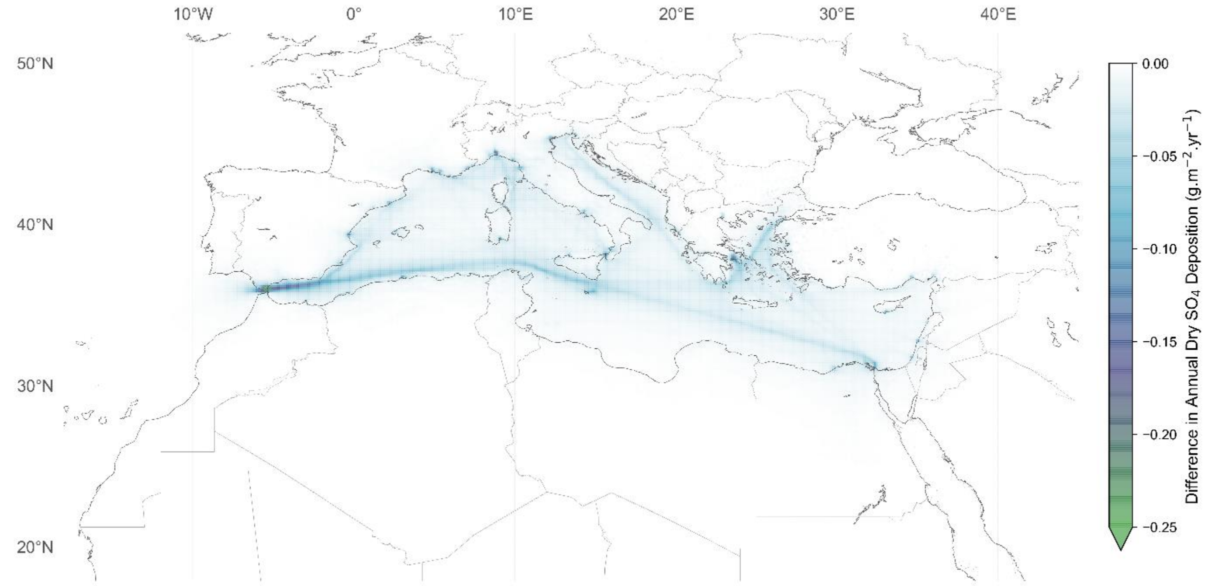

Figure 5.2-3. Decrease in annual dry sulphate deposition between MARPOL VI and the proposed Med ECA

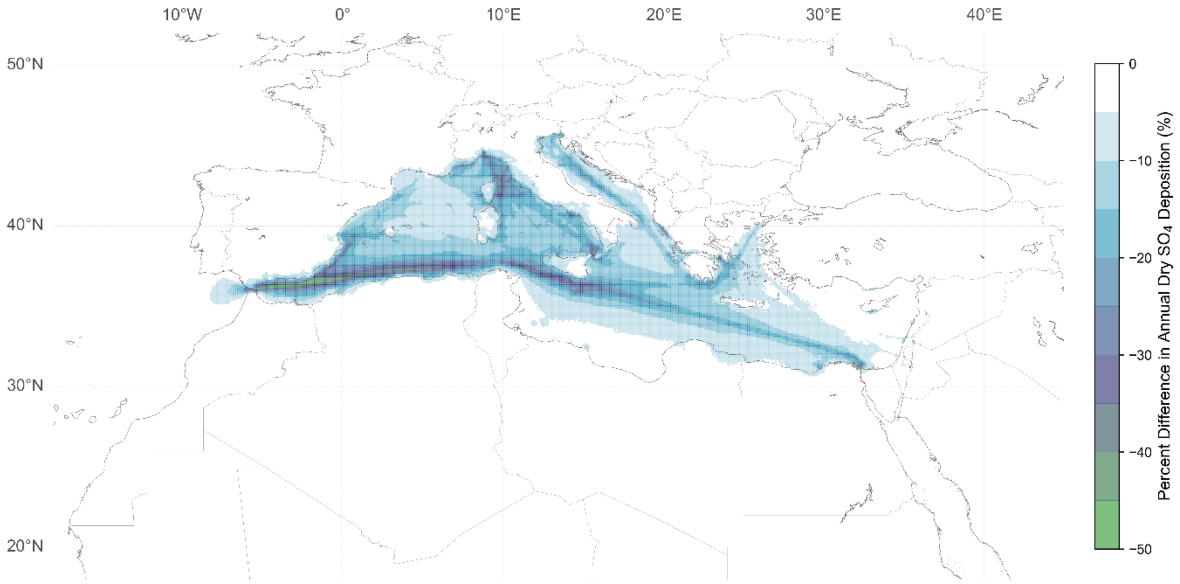

Figure 5.2-4. Percent decrease in annual dry sulphate deposition between MARPOL VI and the proposed Med ECA

5.2.2 PM_{Total} Deposition

Changes in wet (Figure 5.2-5) PM_{Total} deposition associated with the proposed Med ECA are two orders of magnitude greater than decreases in dry deposition, and follow different geographic distributions. Decreases in wet PM_{Total} deposition are largest in the western and northern [Mediterranean], and show reductions in PM_{Total} deposition far inland. Reductions in dry PM_{Total} deposition (Figure 5.2-7) are more geographically limited to western Spain, northern Algeria, the Alps, and isolated areas in Greece, and dry PM_{Total} deposition actually increases over water along the main shipping lane through the Straits of Gibraltar, past Malta and over towards the Suez.

The maximum percent decrease in wet PM_{Total} deposition observed is 4.58% (Figure 5.2-6), which occurred over the Straits of Gibraltar. The average percent decrease in wet PM_{Total} deposition estimated for the [Mediterranean Sea area] is 0.25%.

The maximum percent increase in dry PM_{Total} deposition observed is 8.45% (Figure 5.2-8), which occurred over the Straits of Gibraltar and extending eastwards towards Algiers. The average percent change in dry sulphate deposition estimated for the [Mediterranean Sea area] is 0.66%, indicating that dry PM_{Total} deposition increases overall when going from MARPOL VI to the proposed Med ECA, but shows significant geographic variation.

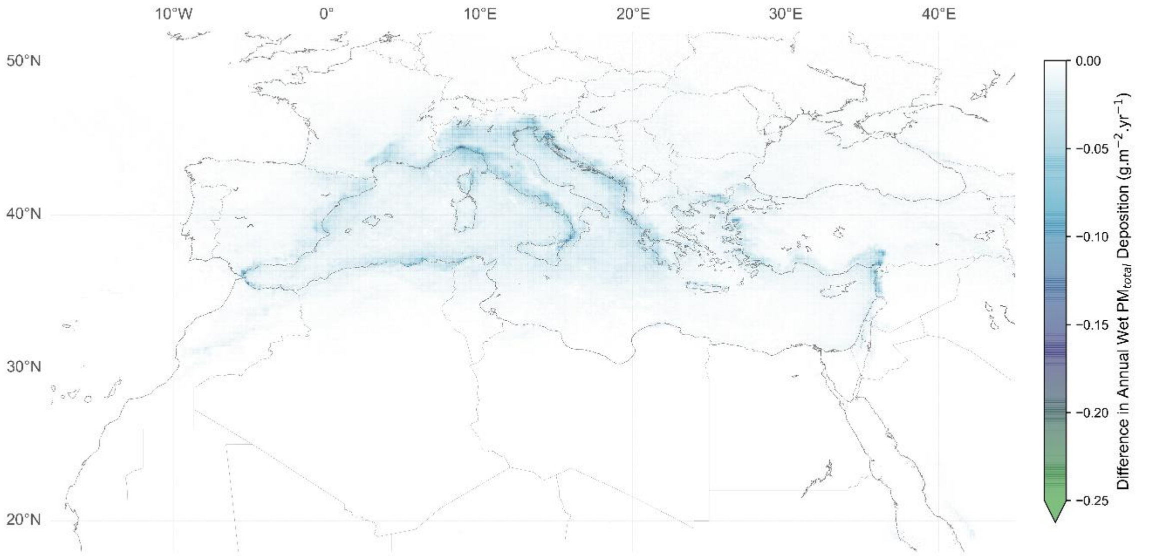

Figure 5.2-5. Decrease in annual wet PM_{Total} deposition between MARPOL VI and the proposed Med ECA

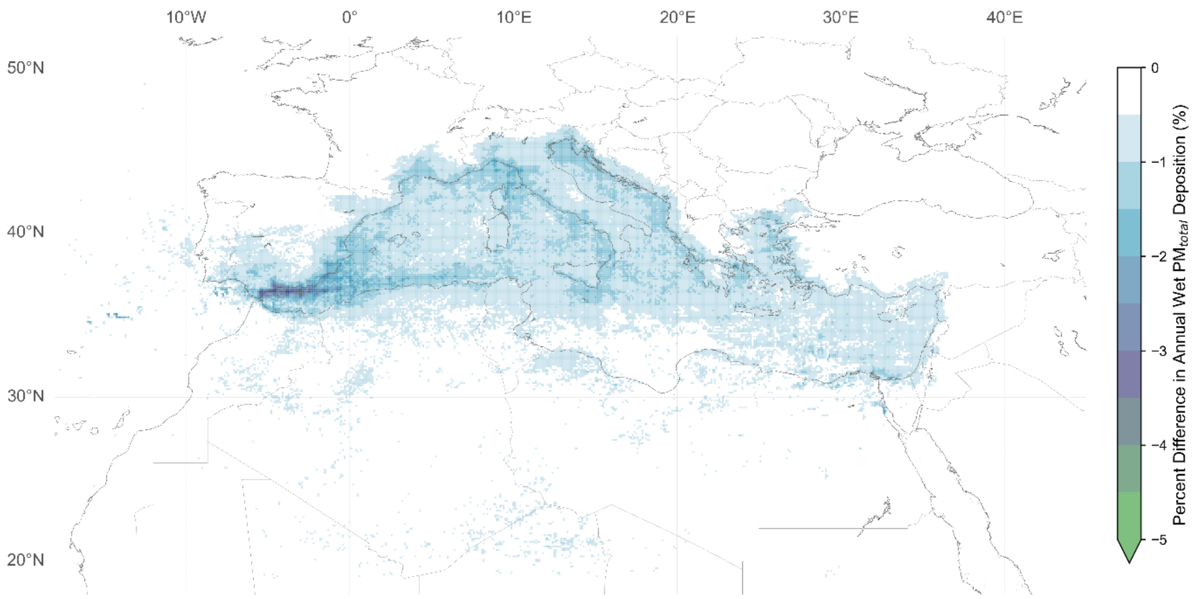

Figure 5.2-6. Percent decrease in annual wet PM_{Total} deposition between MARPOL VI and the proposed Med ECA

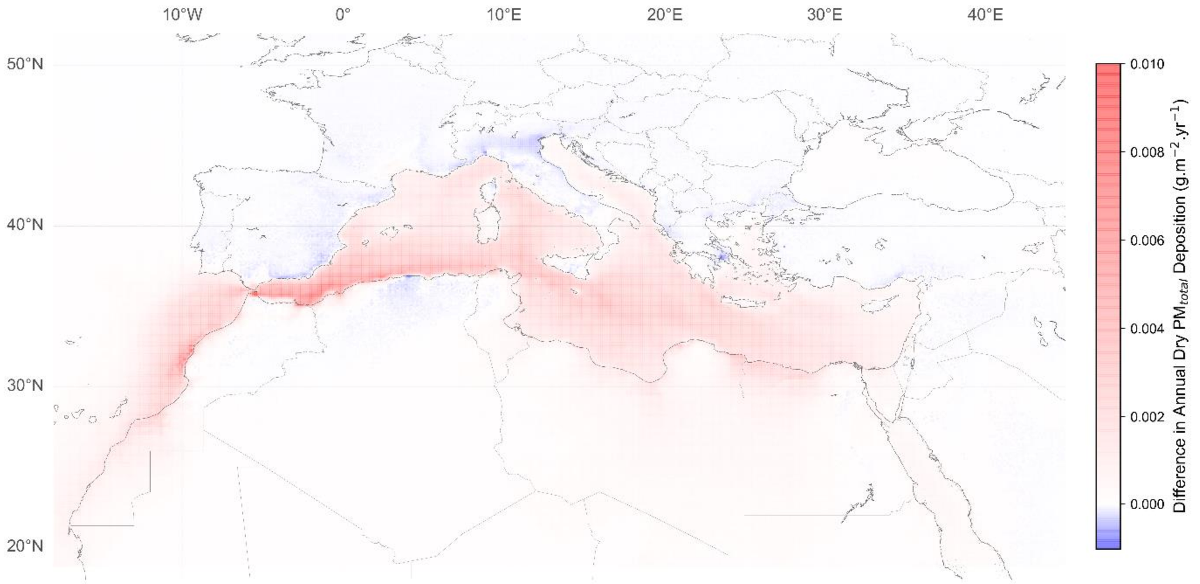

Figure 5.2-7. Change in annual dry PM_{Total} deposition between MARPOL VI and the proposed Med ECA

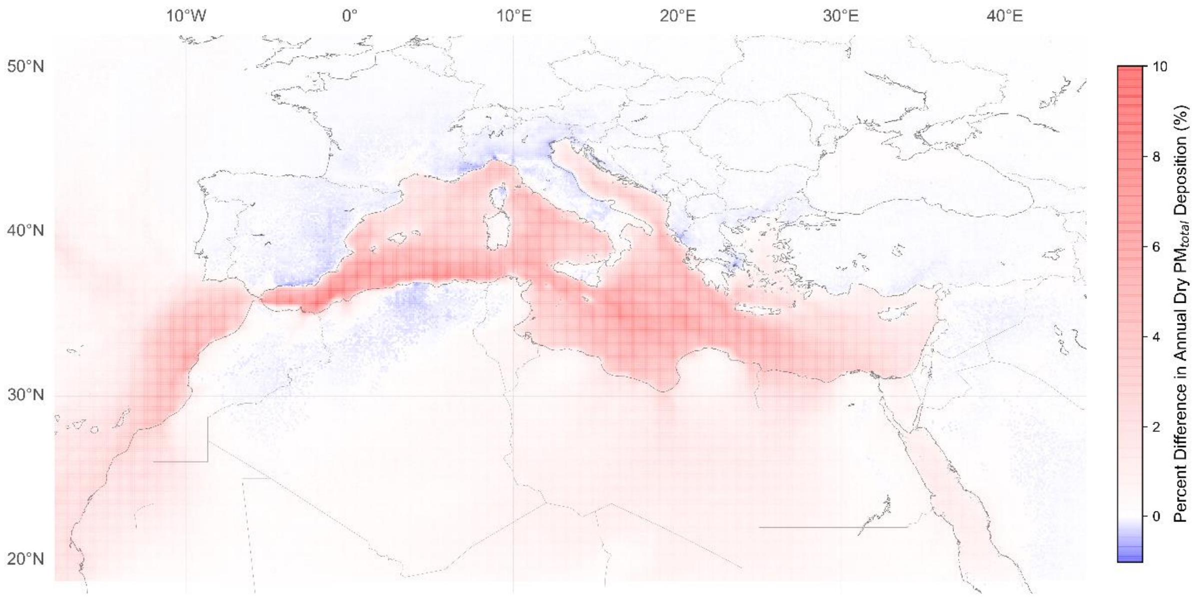

Figure 5.2-8. Percent change in annual dry PM_{Total} deposition between MARPOL VI and the proposed Med ECA

5.2.3 Change in Visibility

The estimated percent increase in PM aerosol optical depth is shown in Figure 5.2-9. Increases in aerosol optical depth are associated with reduced haze and increased visibility. This figure shows a widespread increase in aerosol optical depth over water areas of the [Mediterranean Sea], and extending far inland over North Africa. That greatest increases in PM aerosol optical depth occur over the Straits of Gibraltar and northern Morocco and Algeria, and along the main shipping lane connecting the Straits of Gibraltar, Malta, and towards the Suez.

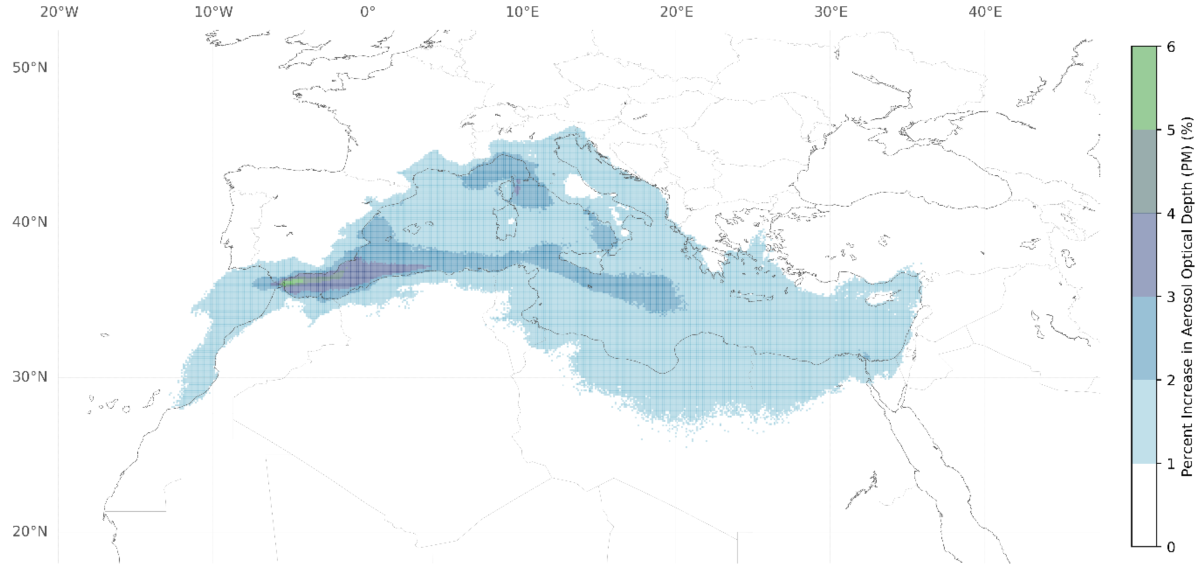

Figure 5.2-9. Percent Change in aerosol optical depth (PM species) between MARPOL VI and the proposed Med ECA

5.3 Impacts Associated with Deposition of $PM_{2.5}$ and Air Toxics

[PLACEHOLDER FOR QUANTIFICATION TO BE PROVIDED THROUGH ROAD MAP]

5.4 Summary of Environmental Benefits

Sulphate deposition reductions are a proxy indicator for potential change in pH acidification to aquatic and terrestrial ecosystems. PM_{Total} deposition reductions are a proxy indicator for potential change in other particle and nutrient effects. Note that Dry PM_{Total} deposition indicated some regions with small increases in deposition, due to non-linear PM formation responses with the reduction of sulphates, consistent with findings reported in science literature. Aerosol optical depth is a proxy for increased suspended particles affecting regional haze and visibility impairment, an increase in aerosol optical depth indicates an improvement in visibility.

It is also noted that while this analysis focuses on benefits to the [Mediterranean coastal States], human health and environmental benefits may extend to countries outside the [Mediterranean Sea area].

Table 5.4-1. Summary of proxies for other benefits associated with the proposed Med ECA

Environmental Benefit Proxy	Relative Range of Change (%)
Wet sulphate deposition	1-15 % reduction
Dry sulphate deposition	1-50 % reduction
wet PM_{Total} deposition	0.5 to 5 % reduction
Dry PM_{Total} deposition	0 to 10 % reduction
Aerosol optical depth (PM-related)	1% to 6 % increase

5.5 Summary of Impact of Emissions from Ships on Environment

As described above, emissions from ships contribute to an increased deposition of acidifying species and PM. The designation of the proposed Med ECA would reduce deposition of acidifying and particulate species across the [Mediterranean Sea area] and lead to improvements in visibility. Thus, this proposal fulfils the environmental health portion of criterion 3.1.4 of Appendix III to MARPOL Annex VI.

6 Role of Meteorological Conditions in Influencing Air Pollution

3.1.5. relevant information pertaining to the meteorological conditions in the proposed area of application to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological, or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts

Meteorological conditions in the [Mediterranean Sea area] transport to land a significant portion of emissions from ships at-sea and the resulting pollutants formed in the atmosphere. The emissions from ships of SO_x and their derivatives (including PM) can remain airborne for around five to ten days before they are removed from the atmosphere (e.g., by deposition or chemical transformation). During the time from being emitted into and removed from the air, pollutants can be transported hundreds of nautical miles over water and hundreds of kilometres inland by the winds commonly observed in the [Mediterranean Sea area]. The analysis conducted for this proposal indicates that winds frequently blow onshore in all areas of the [Mediterranean Sea]. Some wind patterns are more common than others, thus the impact of air pollution from ships at-sea is larger on some areas than on others. Further, airborne transport of SO_x and PM from ships crosses national boundaries, adversely affecting large portions of the [Mediterranean coastal States].

7 Shipping Traffic in the Proposed Area of Application

This section presents information that addresses criterion 3.1.6 of Appendix III to MARPOL Annex VI, as quoted:

Criterion 3.1.6 The proposal shall include the nature of the ship traffic in the proposed emission control area, including the patterns and density of such traffic.

7.1 Shipping Traffic Patterns

Geographically, fuel consumption is driven by regional shipping patterns. The highest fuel consumption is observed at the western end of the [Mediterranean Sea] at the entrance to the Straits of Gibraltar, in the central [Mediterranean Sea] off of the north coast of Tunisia, and at the eastern end of the [Mediterranean Sea] at the entrance to the Suez Canal (Figure 7.1-1). Relative fuel consumption patterns are unchanged in the various scenario years.

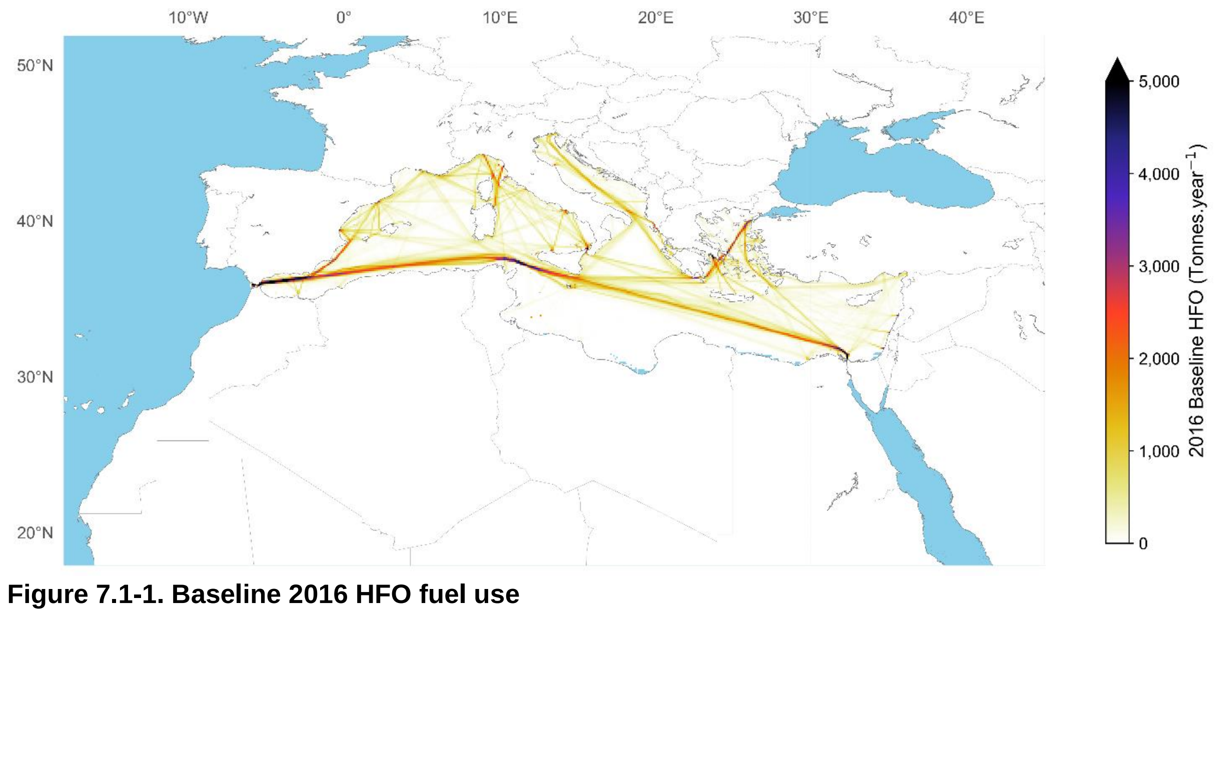

Figure 7.1-1. Baseline 2016 HFO fuel use

Baseline (2016) fuel use inventories show total fuel use of 19.16 million tonnes in the [Mediterranean Sea area] (Table 7.1-1). AIS data show 33,163 unique vessels operating in the [Mediterranean] in the baseline 2016 year.

The dominant fuel used in 2016 was HFO (78.8%). MDO was the next most commonly used fuel (17.2%), and MGO and LNG comprised a small fraction of overall fuel usage (2.8% and 1.3%, respectively). The STEAM model predicts that under MARPOL VI, the [Mediterranean Sea area] overall fuel mix will switch to 95.5% MDO and 3.1% MGO, and 0.8% LNG. HFO fuel use falls to 0.6% under MARPOL VI conditions, and continues to be used by a small number of vessels currently equipped with exhaust gas cleaning systems (scrubbers). STEAM modelling outputs indicate that improvements in power system fuel economy and vessel economies of scale result in 10.8% overall fuel consumption decreases in 2020 from 2016, accompanied by fuel switching.

Under the proposed Med ECA scenario, the STEAM model estimates total fuel use equivalent to the MARPOL VI scenario, but changes to 97.7% MGO and 1% MDO fuel mix. HFO and LNG fuel usage is unchanged in the proposed Med ECA scenarios compared to the MARPOL VI fuel consumption.

Table 7.1-1. Baseline year (2016) fuel usage and projected 2020 fuel usage under MARPOL VI and the proposed Med ECA scenarios

MT	MED 2016 Baseline	MARPOL VI 2020	Proposed Med ECA 2020
Total Fuel	19,160,000	17,100,000	17,100,000
MGO	542,000	522,000	16,700,000
MDO	3,290,000	16,340,000	164,000
HFO	15,090,000	99,900	94,700
LNG	243,000	141,000	138,000

Table 7.1-2. Fuel mix percentages for the [Mediterranean Sea area] in 2016 and under MARPOL VI and the proposed Med ECA scenarios

Fuel Allocation	Pre-MARPOL VI Baseline Fuel Mix	MARPOL VI Fuel Mix	Proposed Med ECA Fuel Mix
MGO	2.8%	3.1%	97.7%
MDO	17.2%	95.5%	1.0%
HFO	78.8%	0.6%	0.6%
LNG	1.3%	0.8%	0.8%

7.2 Summary of Shipping Traffic in the Proposed Area of Application

The nature, patterns, and density of ship traffic in the proposed Med ECA have been described. These shipping patterns form the basis for fuel use and emissions inventory modelling, which is an input to air quality modelling. Thus, this proposal fulfils criterion 3.1.6 of Appendix III to MARPOL Annex VI.

8 Control of Land-Based Sources

This section presents information that addresses criterion 3.1.7 of Appendix III to MARPOL Annex VI, as quoted:

Criterion 3.1.7 — The proposal shall include a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NO_x, SO_x and particulate matter emissions affecting the human populations and environmental areas at risk that are in place and operating concurrent with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI.

8.1 Land-Based Emissions Controls of SO_x and PM in the [Mediterranean coastal States]

[PLACEHOLDER FOR ADDITIONAL DETAILS TO BE PROVIDED THROUGH ROAD MAP]

8.2 Summary of Control of Land-Based Sources

[PLACEHOLDER FOR ADDITIONAL DETAILS TO BE PROVIDED THROUGH ROAD MAP]

9 Relative Costs of Reducing Emissions from Ships

This section presents information that addresses criterion 3.1.8 of Appendix III to MARPOL Annex VI, as quoted:

Criterion 3.1.8 The proposal shall include the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade.

9.1 Overview of Estimated Costs in 2020

This document estimated compliance costs for the proposed Med ECA policy scenario using best available data along with conservative assumptions regarding fuel prices and scrubber costs, as described in later sections. The results of the cost analysis conducted for this proposal is shown in Table 9.1-1, which demonstrates that a movement to the proposed Med ECA using fuel switching would add $1.766 billion/year in 2020 ($2016) compared to simply meeting the MARPOL standard. Using scrubbers would add $1.157 billion/year. These values are highly depending on the assumed price differential between HFO, MDO, and MGO. Price differentials are described in section 9.2. As HFO price increases (i.e., as the difference between HFO price and MDO/MGO price decreases), the cost of compliance with MARPOL increases, and therefore the incremental cost of compliance with the proposed Med ECA decreases.

Table 9.1-1. Estimated costs under different [Mediterranean] regulatory and compliance scenarios

$ Billion/y / Policy Scenario	Total Cost	Compliance Cost
No Action	$9.884	N/A
MARPOL VI (0.5% S)	$13.849	$3.965
Proposed Med ECA (0.1% S)	$15.614	$1.766

9.2 Fuel Production Costs

The primary data source for fuel prices over the last decade used in this document is BunkerIndex (*20*) coupled with data from the St. Louis Federal Reserve (FRED) on LNG prices (*21*). Figure 9.2-1shows the mean weekly fuel prices ($/MT) for IFO380, IFO180, MDO, MGO, and LNG from 2009 to 2018.

Two price regimes in the bunker fuels data are noted. 2011-2015 represents a higher price regime, post-recession, while 2015-2018 shows a lower price regime (along with pre-2011). The most recent price regime is adopted for this work, as it includes the global price effects of SECA fuels, which went into effect post-2015. All prices are adjusted to 2015 constant $USD using the CPI index for fuels and fuel oil (*22*) to allow for better comparison between time series prices.

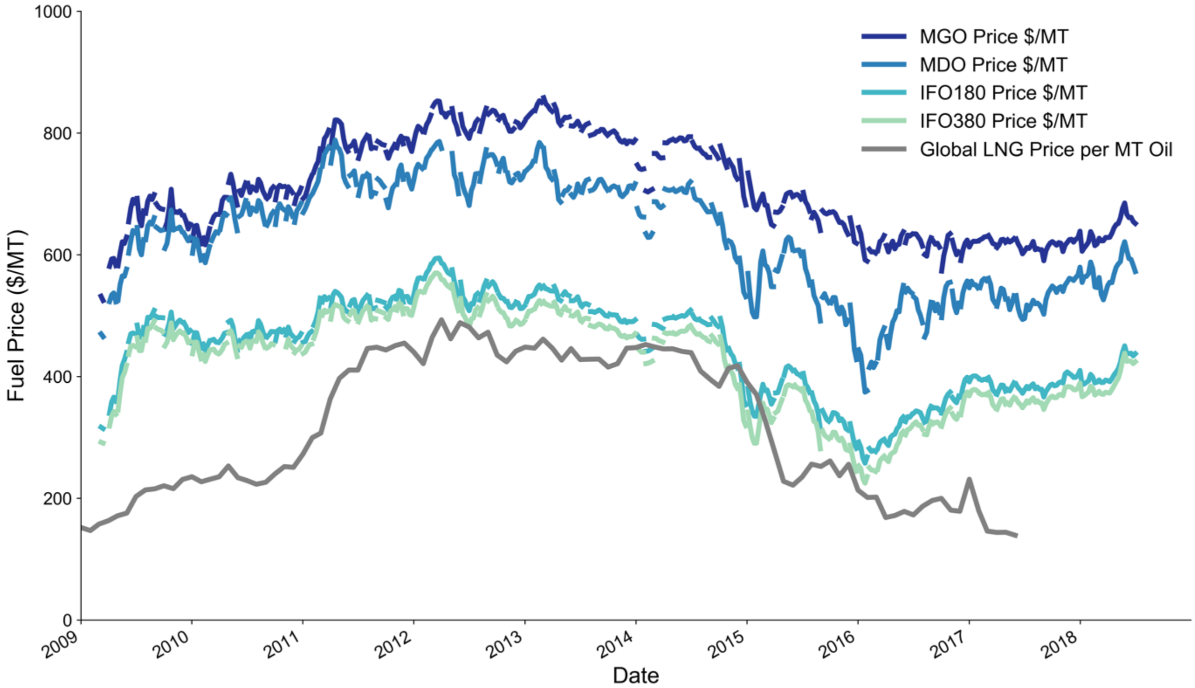

Figure 9.2-1. Bunker prices for marine bunker fuels from 2009 to 2018, resampled to mean weekly prices, in 2015 USD/MT

It is assumed that MDO is compliant with global MARPOL VI standards (0.5% S), and thus the MDO price to define the fuel price under the MARPOL VI scenario is used. It is noted that this price includes fuels that may not fall within compliance of global MARPOL VI. In all weeks observed from 2009 to 2018, MDO prices are lower than SECA-compliant MGO prices.

As shown in both Figure 9.2-1 there are periods of volatility in the absolute fuel price time series data, as well as in the ratio of the prices compared to MGO (Figure 9.2-2). The primary period of volatility in fuel prices was between September 2014 and July 2016. Prices, and their ratios, are similar before and after this time period. In the period after July 2016, IFO380 prices are 58.5% of MGO prices, and MDO prices are 87.0% of MGO prices. As of August 2018, LSFO (0.5% S compliant) prices at Rotterdam ($635.00/tonne) were priced at 96.2% of MGO prices ($656.50/tonne). Given observed fuel price differentials, our selection of MDO price represents a conservative choice for estimating an upper bound in the fuel price differentials.

Additionally, it is recognised that definitions of MGO and MDO fuels vary regionally, and do not always directly map to MARPOL VI and SECA compliant fuels, respectively. This issue is addressed by selecting the maximum observed spread between HFO, MDO, and MGO in the time series data, in order to reflect the maximum observed price differential, and account for inconsistencies in fuel definitions, while overall providing a robust accounting of fuel prices.

As noted, LNG price data are provided by FRED and do not directly reflect delivered ship bunker prices, but rather global LNG fuel prices. In addition, LNG prices are converted to prices per MT of oil equivalent, but this calculation doesn't account for the fuel consumption penalty associated with using LNG in marine engines, e.g., changes in thermal efficiency and/or energy density, which entail converting LNG prices per volume or mass to prices per kWh.

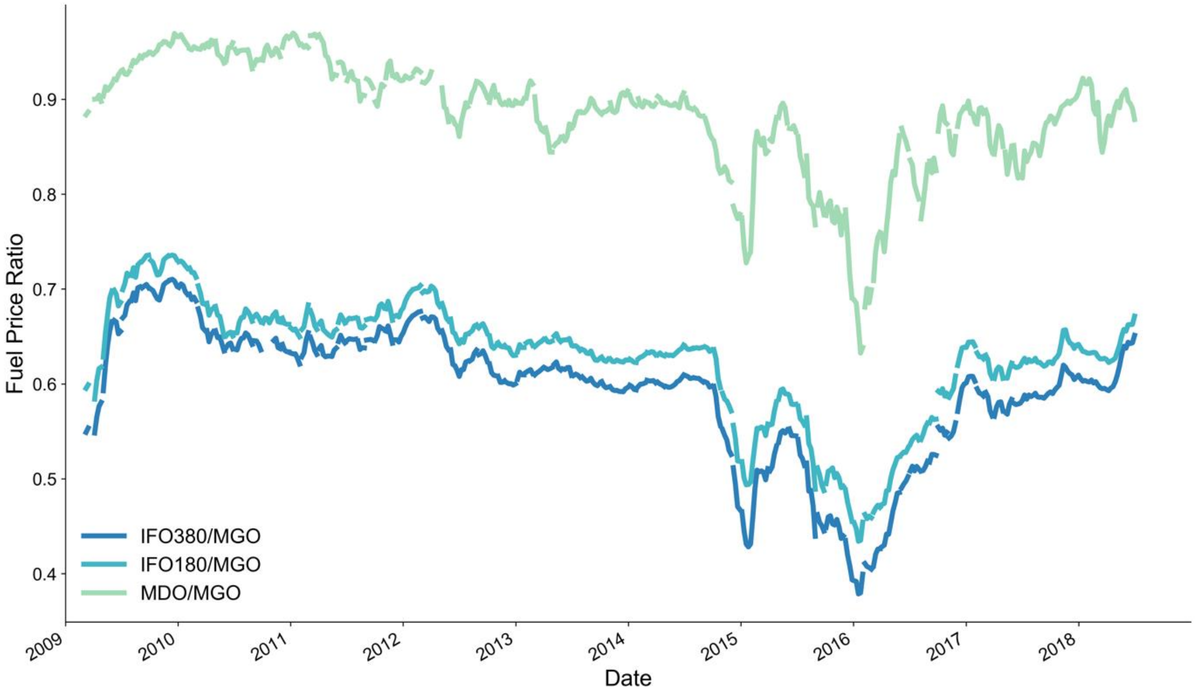

Figure 9.2-2. Price ratio of MGO to IFO380, IFO180, and MDO

9.3 Vessel Costs

9.3.1 Exhaust Gas Cleaning Adoption Analysis

Scrubbers represent one possible compliance option for the proposed Med ECA. Table 9.3-1indicates that about 5,900 vessels, some 18% of the fleet operating in the [Mediterranean Sea area], could adopt scrubbers, under a conservative 100-year investment horizon and 15% investment rate. This conservative investment horizon may be considered to describe the least cost investment option, and therefore defines the most favourable conditions for investment in exhaust gas cleaning technology. This finding is consistent with some, but not all, estimates reported in industry media or other studies, fundamentally related to investment horizon conditions assumed. Therefore, some sensitivity analyses are performed to further explore economically feasible conditions.

Table 9.3-1. Fleet counts considered for exhaust gas cleaning technology.

	Fleet Count	Percent of Total Fleet
Scrubbers	5,915	18%
No Scrubbers	27,248	82%

Table 9.3-2 shows the expected scrubber investment rates over a range of investment horizons. Investment decisions are typically confidential business information, and thus the decision is parameterised over a range of investment lifetimes. 39 vessels are identified as currently operating with scrubbers in the [Mediterranean Sea area], and this number is not expected to change under a 1-year investment horizon. If scrubber costs are amortised over 10 years the results show that scrubber installations would increase by a factor of ten, from 39 to 464. Assuming a 15-year investment horizon, the results indicate that 3.7% of the fleet might invest in a scrubber, and save the fleet over $260 million

Table 9.3-2. Cost analysis relating scrubber capital costs and investment years to the percent of the fleet using scrubbers.

Investment years	Feasible Scrubber Use, Capital included		
	Proposed Med ECA Compliance Savings ($Billions)	**Number of Scrubbers**	**Percent of Fleet Using Scrubbers**
None	$0.61	39 in 2020	0.0%
1	$0.00	0	0.0%
5	$0.02	53	0.2%
10	$0.10	464	1.4%
11	$0.13	632	1.9%
12	$0.15	767	2.3%
14	$0.19	1,010	3.0%
15	$0.26	1,226	3.7%
20	$0.37	1,888	5.7%
25	$0.47	2,702	8.1%
30	$0.53	4,155	12.5%
50	$0.60	5,726	17.3%
100	$0.61	5,915	17.8%

Table 9.3-3 shows that scrubber may be feasible for vessels that spend a greater amount of time inside the [Mediterranean Sea area] (and/or other SECA region). Scrubbers require increased capital investment but use lower cost fuels, and economic feasibility increases with more cost-saving operation using lower cost fuels. These results agree with previously published work (*23*). These results indicate that, under and unlimited (100-year) investment horizon scrubber scenario, 5,900 vessels (~18% of the [Mediterranean] fleet) might be expected to invest in scrubbers, while a majority of the fleet (82%) may determine that fuel switching remains the least cost option.

Table 9.3-3. Use of scrubbers by vessel type under the proposed Med ECA scenario.

Vessel Type	No Scrubber		Scrubber Adoption	
	Average Operating Hours [h] in Med	**Ship Count**	**Average Operating Hours [h] in Med**	**Ship Count**
Cargo ships	1,356	6,875	5,172	458
Container ships	756	1,146	3,464	915
Cruisers	879	62	4,400	118
Fishing vessels	1,472	1,000	3,683	268
Misc.	1,202	6,749	4,148	1,183
Passenger ships	1,513	649	3,457	294
RoPax vessels	2,213	177	6,404	361
Service ships	1,265	652	3,910	207
Tankers	1,049	3,586	5,096	723
Unknown	370	5,875	2,469	1,190
Vehicle carriers	749	477	5,597	198
Grand Total	**1,039**	**27,248**	**4,027**	**5,915**

9.3.2 Alternative Fuels

Alternative fuels and advanced power systems may offer economically feasible alternatives for SECA compliance, particularly if the net costs of these systems are lower than switching to SECA fuel. Of course, additional reasons beyond cost-savings within a SECA may support investment in vessels using advanced fuels, but this document evaluates only decision criteria for advanced power and fuel technologies within the scope of evaluating SECA compliance costs. Moreover, some alternative fuels may present other environmental trade-offs beyond SECA compliance through very low sulphur content in the fuel, which merit consideration beyond the scope of this document.

A variety of fuels and power configurations could be considered. These include, but are not limited to: a) liquefied natural gas (LNG); b) methanol marine fuels; c) hydrogen fuel; d) hybrid propulsion systems that may include wind-assist, fuel cells, energy storage technologies, etc. Given that LNG is a fuel currently used on a significant number of vessels, and across many vessel types, data are most available to conduct economic feasibility assessment using LNG as an example.

Increased installation costs are compared with fuel cost savings based on price differential between MGO and LNG. This analysis is applied to older vessels, selected to be at or beyond typical replacement ages in 2020. Therefore, this analysis is applied to replacement of end of life vessels and new build vessels as they enter the fleet. If a vessel net costs of complying with SECA conditions are lower using LNG, then that vessel is considered to be economically feasible. The fraction of the fleet that is replaced or replacement eligible based on age in 2020 is evaluated, and the fraction of those vessels for which LNG would be economically feasible is evaluated.

The approach may be considered to serve as a screening tool for economic feasibility of LNG conversion, which is known through fleet adoption experience to be technically feasible. Further analyses of infrastructure, energy supply, and regional economic conditions would be required for specific fleet operator or port selection of alternative fuels.

The average fuel cost savings for vessels could be greater than 30%, given the higher costs of MGO fuel and lower costs of LNG used in this document (Table 9.3-4). Where the average LNG installation premium is lower than the present value of the potential capital investment window derived from fuel cost savings, this document identifies approximately 3,900 vessels to be feasible candidates for alternative fuels (Table 9.3-5). Some of these vessels included smaller service vessels, fishing vessels, etc.; it is recognised that conversion of these locally operating and networked vessel operations may include infrastructure and co-fleet investment decisions not captured here. Therefore, this is presented in a summary of larger commercial transport and cruise vessels considered to be feasible for alternative fuel operation under the conditions and assumptions applied in this document. Fleet adoption rates shown in Table 9.3-4 exclude fishing vessels, passenger ferries, service ships, miscellaneous, and unknown vessel types. Table 9.3-5 presents a summary of overall fleet counts combining all ships. Under the base input conditions, about 11%-12% of the fleet operating in the [Mediterranean Sea area] could feasibly consider alternative fuels for cost-saving compliance with the proposed Med ECA.

Table 9.3-4. Summary of alternative fuel economic feasibility analysis for major vessel types in the [Mediterranean Sea area]

Vessel Type	Count of Feasible Vessels	Percent of Vessel Type	Average Age	Average Fuel Cost Savings (Percent)	Average LNG Installation Premium ($ Million)	Capital Investment Window ($ Million)
Cargo ships	890	12%	33	32%	$1.0	$2.5
Container ships	130	6%	28	33%	$4.0	$11.9
Cruisers	45	25%	37	37%	$5.5	$20.0
RoPax vessels	220	41%	35	40%	$3.9	$19.0
Tankers	260	6%	30	36%	$1.3	$4.1
Vehicle carriers	79	12%	33	39%	$2.6	$12.0
Total[1]	**1,624**	**11%**				

Table 9.3-5. Fleet counts considered for alternative fuel replacement, and the number that could reduce SECA compliance costs

Feasibility Category	Fleet Count	Percent of Total Fleet
Salvage age (>20 yrs.) circa 2020	19,700	59.3%
Alternative Fuel-cost Feasible	3,900	11.8%
Other Criteria Necessary	15,800	47.5%

The economic feasibility of alternative fuels will be sensitive to several inputs, primarily to the fuel-price differential between SECA compliant fuel and the alternative fuel (LNG in this analysis). Table 9.3-6 illustrates this through sensitivity analysis that exercises the LNG fuel price from no-cost ($0) through a price equal to SECA fuel. As illustrated, fleet adoption rates from nearly 17% to 0% are dependent upon the net savings of installing power systems for and operating alternative fuels. The shaded row represents the results of this analysis using fuel prices described in section 9.2. Regional compliance cost savings with the proposed Med ECA through adoption of economically feasible alternative fuels could be in the range of $1.4 Billion per year based on fuel prices described in section 9.2.

Table 9.3-6. Cost analysis relating LNG price and LNG-MGO price differential to the percent of the fleet (all vessel types) adopting alternative fuel

LNG Price[1]	LNG-MGO Price Δ	Proposed Med ECA Cost with LNG Alternative ($ Billion per year)	Proposed Med ECA Savings with LNG ($ Billion per year)	Fleet Percent Adoption[2]
$0	$858	$13.4	$2.2	16.7%
$50	$808	$13.5	$2.1	16.1%
$100	$758	$13.7	$2.0	15.5%
$200	$658	$13.9	$1.7	14.0%
$300	$558	$14.2	$1.4	12.3%
$327	$531	$14.2	$1.4	11.8%
$350	$508	$14.3	$1.3	11.3%
$400	$458	$14.4	$1.2	10.2%
$450	$408	$14.6	$1.1	9.2%
$600	$258	$14.9	$0.7	5.1%
$700	$158	$15.2	$0.4	2.5%
$800	$58	$15.5	$0.2	0.2%
$858	$0	$15.6	$0.0	0.0%

9.3.3 Comparison of Vessel-Specific Costs

Costs of compliance for different types of vessels can also be estimated. Table 9.3-7 provides results of these costs for MARPOL VI, the proposed Med ECA, and the proposed Med ECA with scrubbers. Results show that per vessel costs are largest for the biggest most powerful vessels, which include cruise ships, RoPax vessels, containers, and vehicle carriers. The columns represent total costs under each scenario; annual cost increases would be the difference between column prices, e.g., for Cruisers the difference between the proposed Med ECA average cost and MARPOL VI average cost would be about $550k per year. As noted in Table 9.3-7, the additional per-vessel average cost increase compared to compliance with MARPOL 2020 is modest, and would likely not impose any undue burden of compliance on industry.

Table 9.3-7. Summary of average annual compliance cost per vessel by type

Vessel Type	Ship Count	2020 MARPOL VI Average Cost	Proposed Med ECA Average Cost	Proposed Med ECA + Scrubber Average Cost
Cargo ships	7,333	$290,000	$327,000	$325,000
Misc.	7,932	$48,400	$54,000	$52,200
Passenger ships	943	$70,600	$79,300	$74,100
Tankers	4,309	$681,000	$763,000	$750,000
Unknown	7,065	$24,500	$27,400	$26,300
Service ships	859	$110,000	$123,000	$118,000
Fishing vessels	1,268	$30,500	$34,100	$32,900
Vehicle carriers	675	$1,550,000	$1,760,000	$1,650,000
Cruisers	180	$3,280,000	$3,830,000	$3,540,000
RoPax vessels	538	$2,920,000	$3,280,000	$2,970,000
Container ships	2,061	$2,340,000	$2,640,000	$2,540,000

9.4 Cost to Shipping Industry in Comparison with Land-Based Measures

The North American ECA application (MEPC 59/6/5) suggests that the costs of SO_x reductions from land-based sources has ranged from $249 to $7,474 per metric ton (2018 USD). The Shadow Prices Handbook, published by CE Delft (*24*) estimates the costs of SO_x abatement at between €5,645 and €11,308 per metric ton, or $6,461 to $12,943 per metric ton (2018 USD) in the Netherlands based on emissions in 2008. These estimates are supported by another study which found land-based sulphur abatement costs to vary between €600 and €13,000 per metric ton (*25*), or $690 to $14,950 per metric ton of SO_x. The Shadow Prices Handbook finds PM abatement costs of between €2,600 and €56,540 (2018€) per metric ton or $2,976 to $64,717 /MT PM (2018 USD). This analysis find a central estimate for PM abatement of $94,000/MT PM, which is aligned with the cost-effectiveness of PM abatement for the North American ECA, but is greater than the upper end of the Shadow Prices Handbook. This analysis finds a central estimate for SO_x abatement of $8,900/MT SO_x, which is aligned well with the Shadow Prices Handbook, and indicates that SO_x abatement cost-effectiveness from the proposed Med ECA would be comparable to or better than the cost effectiveness of land-based SO_x emission reductions. Note that the costs described above refer to the cost effectiveness of the switch from Baseline fuels in 2016 to SECA compliant fuels in 2020. If only considering the step from MARPOL VI 0.5% S fuels, the cost effectiveness of PM and SO_x abatement becomes $155,000 /MT $PM_{2.5}$ and $13,400 /MT SO_x. This shows that SO_x abatement from ships is cost effective compared to land-based sources.

9.5 Cost-Effectiveness of Quantified Benefits

Similar to previous SECA analyses, the same cost was assigned across each of these dimensions, which over-assigns the cost per unit benefit given that the same cost is achieving all of these benefits. See Methods and Data Section 3.4 for further discussion. Table 9.5-1, Figure 9.5-1, and Figure 9.5-2 summarise the results. For example, the proposed Med ECA without scrubbers is shown to cost about $1.58M per avoided annual death, if all the costs of the proposed Med ECA are assigned to the avoided mortality estimates. This cost comes down to $1.035M/avoided death under a scrubber scenario.

Table 9.5-1. Cost-effectiveness of quantified benefits

Benefit Type	MARPOL VI	Proposed Med ECA	Proposed Med ECA with Scrubbers
Control Target			
Abated SO_x emissions	$7,730 /MT SO_x	$13,400 /MT SO_x	$8,750 /MT SO_x
Abated $PM_{2.5}$ emissions	$80,300 /MT $PM_{2.5}$	$155,000 /MT $PM_{2.5}$	$101,000 /MT $PM_{2.5}$
Health Outcome			
Avoided mortality	$0.263 M/Δ Mortality	$1.580 M/Δ Mortality	$1.035 M/Δ Mortality
Avoided childhood asthma	$14 k/Δ Morbidity	$763 k /Δ Morbidity	$500 k/Δ Morbidity

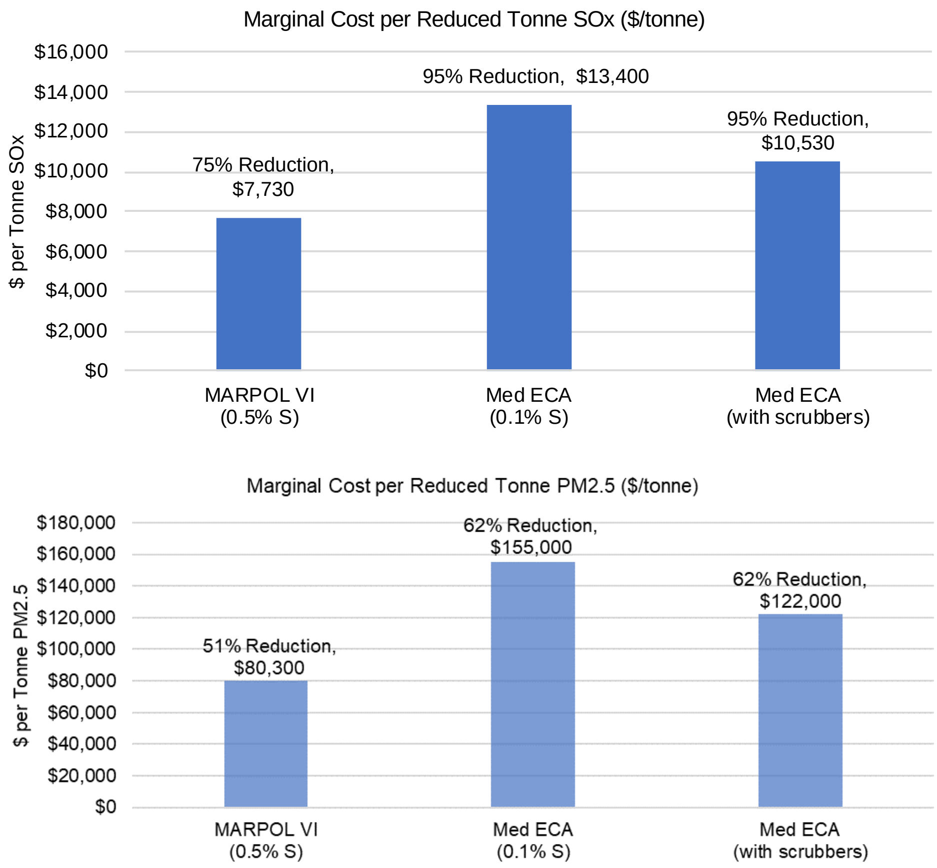

Figure 9.5-1. Control cost-effectiveness of SO_x and $PM_{2.5}$ reductions based on prices in this document

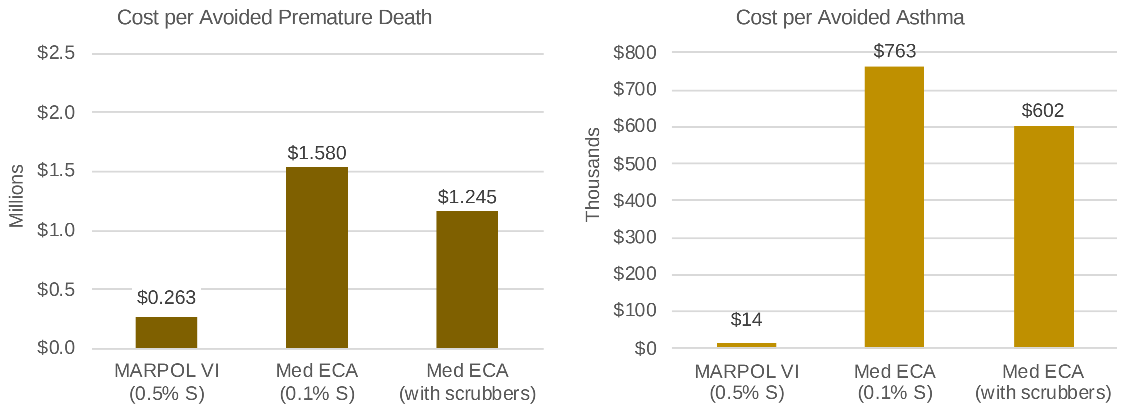

Figure 9.5-2. Cost-effectiveness of health outcomes in terms of avoided premature mortality and avoided childhood asthma

9.5.1 Mortality benefit-cost analysis (Lung Cancer and Cardiovascular causes)

A benefit-cost analysis should compare the net monetised benefits for all mitigation and costs for all compliance actions. No prior proposal to designate a SECA under MARPOL VI have presented analyses that monetise all benefits. Prior proposals to designate regional SECAs under MARPOL Annex VI have generally presented cost-effectiveness justifications for benefits of dominant concern or made reference to a concept termed "critical loads", which generally means the maximum tolerable environmental exposure that a region's ecosystem (in whole or part).

VSL is the monetary value of small changes in mortality risks, scaled up to reflect the value associated with one expected fatality in a large population. This project identified a key resource, published in the peer-reviewed literature in 2017, that performs a state-of-practice analysis of VSL that includes nearly all [Mediterranean coastal States] (*26*).

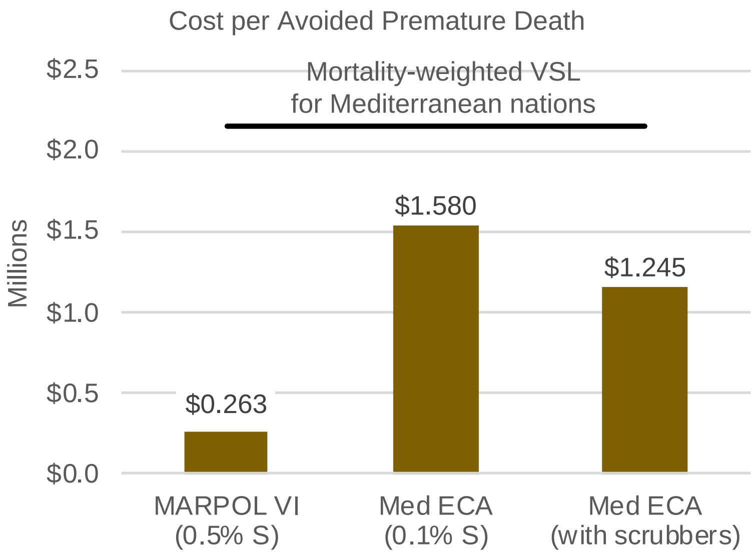

Figure 9.5-3. Comparison of the proposed Med ECA cost per avoided mortality and the [Mediterranean] weighted VSL

9.6 Economic Impacts on Shipping Engaged in International Trade

[PLACEHOLDER FOR ADDITIONAL ELEMENTS TO BE PROVIDED THROUGH ROAD MAP]

As noted above in Table 9.3-7, the additional per-vessel average cost increase compared to compliance with MARPOL 2020 is modest, and would likely not impose any undue burden of compliance on industry. The increased average cost for a container ship is $300,000, equivalent to an average increase of $3 per container for a 10,000 TEU vessel transiting the proposed Med ECA ten times a year. The largest increase would be for cruise ships, which would see additional annual costs of $550,000. Based on a 3,000 passenger cruise ship operating for 200 days in the [Mediterranean], this would represent an increase of less than $1 per day per passenger.

9.7 Summary of Costs of Reducing Emissions from Ships

In conclusion, the proposed Med ECA will be effective at achieving SO_x and PM emissions reductions for the given costs, imposing reasonable economic impacts to the international shipping industry. Therefore, this proposal fulfils criterion 3.1.8 of Appendix III to MARPOL Annex VI.

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ANNEX 2

Description of the proposed Med ECA

[The area of application of the proposed Med ECA includes waters internal to the Mediterranean Sea, as defined by the International Hydrographic Organization.

Specifically, the proposed Med ECA includes all waters bounded by the coasts of Europe, Africa, and Asia, and

a. The western entrance to the Straits of Gibraltar, defined as a line joining the extremities of Cape Trafalgar, Spain (36°11'N, 6°02'W) and Cape Spartel, Morocco (35°48'N, 5°55'W);

b. The Dardanelles, defined as a line joining Mehmetcik Burnu[7] (40°03'N, 26°11'E) and Kumkale Burnu (40°01'N - 26°12'E); and

c. The northern entrance to the Suez Canal.]

[7] Burnu (Turkish) = Cape