Conseil de
l'Union européenne

Bruxelles, le 1er février 2022
(OR. fr, en)

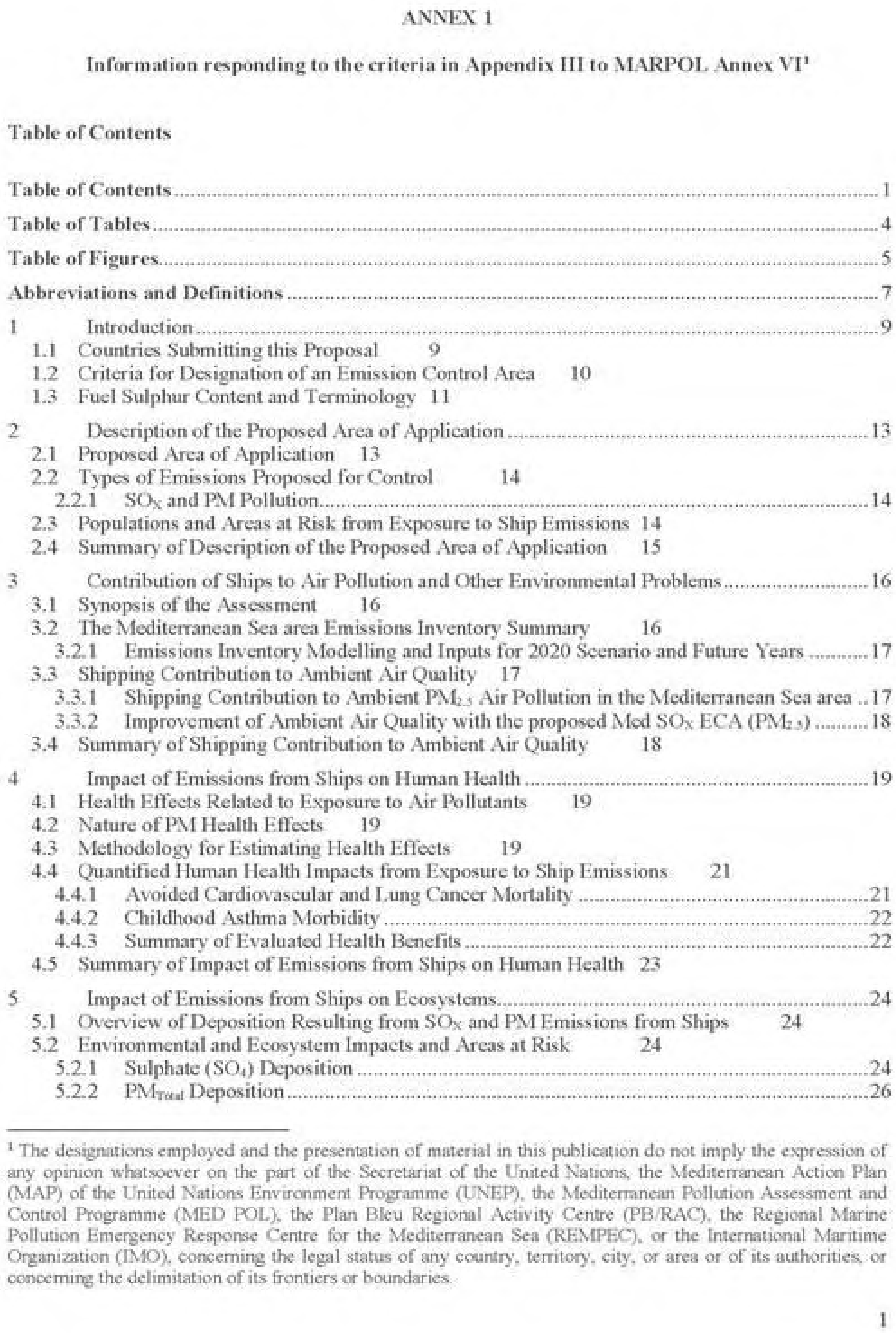
5672/22
ADD 1

MAR 19
OMI 14
ENV 77
CLIMA 38

NOTE POINT "I"

Origine:	Secrétariat général du Conseil
Destinataire:	Comité des représentants permanents (1re partie)
Nº doc. préc.:	5295/3/22 REV 3
Objet:	Préparation d'OMI/MEPC 78 (Londres, 6-10 juin 2022) – Projet de soumission des États membres et de la Commission à la 78e réunion du Comité de la protection du milieu marin de l'Organisation maritime internationale concernant une proposition pour la désignation de la mer Méditerranée dans son ensemble en tant que zone de contrôle des émissions d'oxydes de soufre – *Approbation*

Les délégations trouveront ci-joint Annexe 1.



ANNEX 1

Information responding to the criteria in Appendix III to MARPOL Annex VI[1]

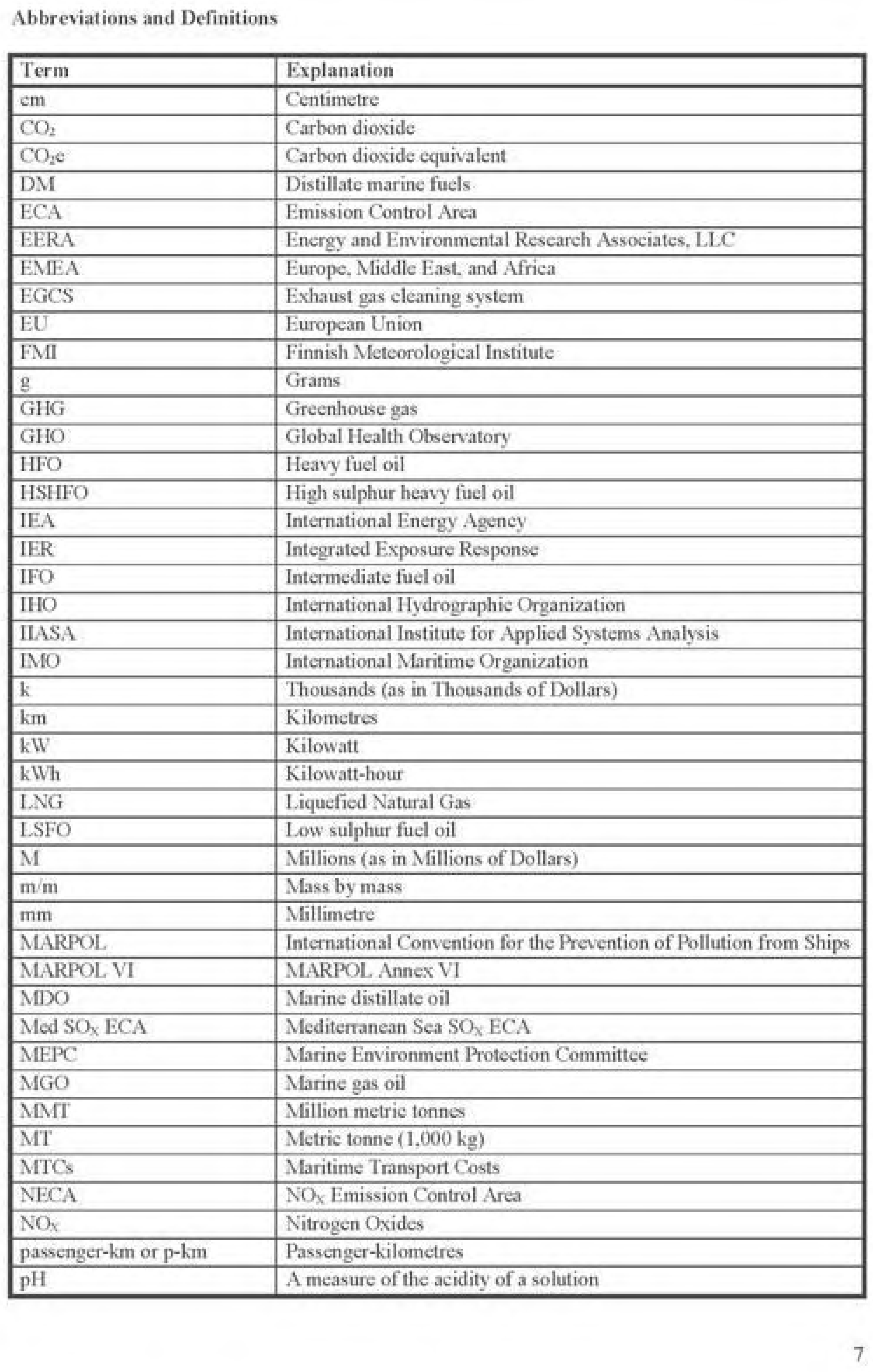
Table of Contents

---

[1] The designations employed and the presentation of material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations, the Mediterranean Action Plan (MAP) of the United Nations Environment Programme (UNEP), the Mediterranean Pollution Assessment and Control Programme (MED POL), the Plan Bleu Regional Activity Centre (PB/RAC), the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC), or the International Maritime Organization (IMO), concerning the legal status of any country, territory, city, or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

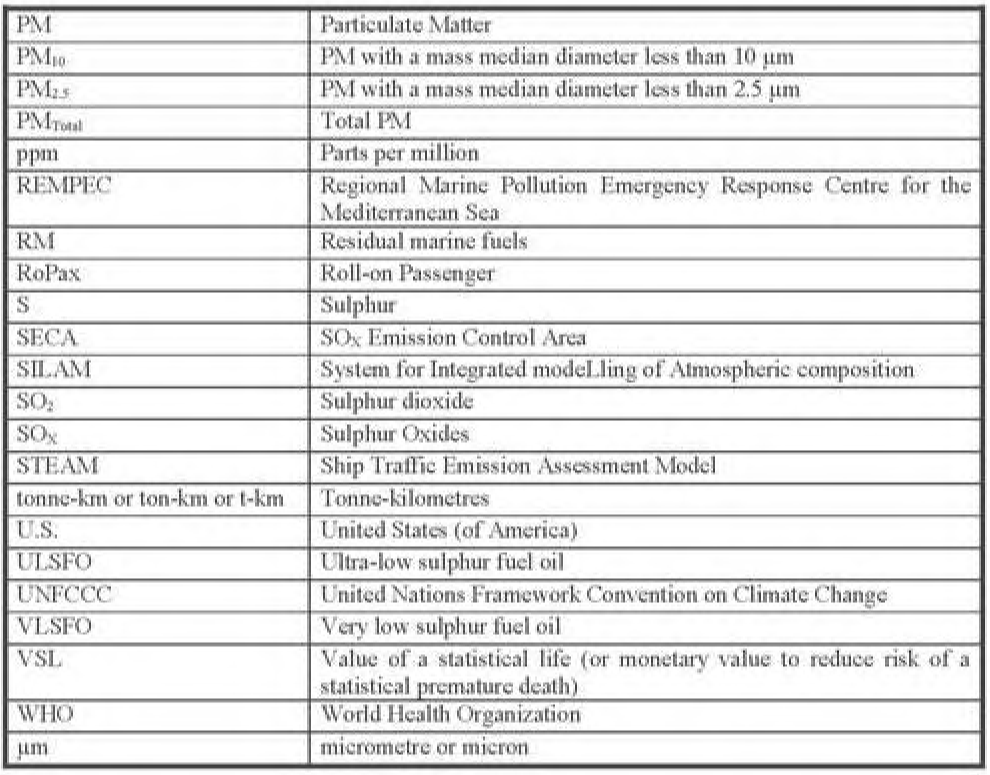
Table of Tables

Table of Figures



Abbreviations and Definitions

Term	Explanation
cm	Centimetre
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DM	Distillate marine fuels
ECA	Emission Control Area
EERA	Energy and Environmental Research Associates, LLC
EMEA	Europe, Middle East, and Africa
EGCS	Exhaust gas cleaning system
EU	European Union
FMI	Finnish Meteorological Institute
g	Grams
GHG	Greenhouse gas
GHO	Global Health Observatory
HFO	Heavy fuel oil
HSHFO	High sulphur heavy fuel oil
IEA	International Energy Agency
IER	Integrated Exposure Response
IFO	Intermediate fuel oil
IHO	International Hydrographic Organization
IIASA	International Institute for Applied Systems Analysis
IMO	International Maritime Organization
k	Thousands (as in Thousands of Dollars)
km	Kilometres
kW	Kilowatt
kWh	Kilowatt-hour
LNG	Liquefied Natural Gas
LSFO	Low sulphur fuel oil
M	Millions (as in Millions of Dollars)
m/m	Mass by mass
mm	Millimetre
MARPOL	International Convention for the Prevention of Pollution from Ships
MARPOL VI	MARPOL Annex VI
MDO	Marine distillate oil
Med SO_X ECA	Mediterranean Sea SO_X ECA
MEPC	Marine Environment Protection Committee
MGO	Marine gas oil
MMT	Million metric tonnes
MT	Metric tonne (1,000 kg)
MTCs	Maritime Transport Costs
NECA	NO_X Emission Control Area
NO_X	Nitrogen Oxides
passenger-km or p-km	Passenger-kilometres
pH	A measure of the acidity of a solution



PM	Particulate Matter
PM_{10}	PM with a mass median diameter less than 10 µm
$PM_{2.5}$	PM with a mass median diameter less than 2.5 µm
PM_{Total}	Total PM
ppm	Parts per million
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
RM	Residual marine fuels
RoPax	Roll-on Passenger
S	Sulphur
SECA	SO_X Emission Control Area
SILAM	System for Integrated modeLling of Atmospheric composition
SO_2	Sulphur dioxide
SO_X	Sulphur Oxides
STEAM	Ship Traffic Emission Assessment Model
tonne-km or ton-km or t-km	Tonne-kilometres
U.S.	United States (of America)
ULSFO	Ultra-low sulphur fuel oil
UNFCCC	United Nations Framework Convention on Climate Change
VLSFO	Very low sulphur fuel oil
VSL	Value of a statistical life (or monetary value to reduce risk of a statistical premature death)
WHO	World Health Organization
µm	micrometre or micron

1 Introduction

The information in this annex supports the proposal by Albania, Croatia, Cyprus, France, Greece, Italy, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, the Syrian Arab Republic, Tunisia, and Turkey for the designation of the Mediterranean Sea, as a whole, 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 SO_X ECA.

1.1 Countries Submitting this Proposal

The twenty-one (21) countries bordering the Mediterranean Sea – Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, the Syrian Arab Republic, Tunisia, and Turkey, which, together with the European Union, are Contracting Parties to the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean Sea (the Barcelona Convention), share a common interest in the Mediterranean Sea and in addressing emissions from ships along their coastlines.

The Contracting Parties to the Barcelona Convention adopted Decision IG.24/8 on the Road Map for a Proposal for the Possible Designation of the Mediterranean Sea, as a whole, as an Emission Control Area for Sulphur Oxides Pursuant to MARPOL Annex VI, within the Framework of the Barcelona Convention[2] **("the road map") at the Twenty-**first Ordinary Meeting of the Contracting Parties to the Barcelona Convention and its Protocols (Naples, Italy, 2-5 December 2019). They also adopted Decision IG.25/14 on the Designation of the Mediterranean Sea, as a whole, as an Emission Control Area for Sulphur Oxides (Med SO_X ECA) pursuant to MARPOL Annex VI[3] at the Twenty-second Ordinary Meeting of the Contracting Parties to the Barcelona Convention and its Protocols (Antalya, Turkey, 7-10 December 2021).

The Contracting Parties to the Barcelona Convention, which are Parties to MARPOL Annex VI, namely Albania, Croatia, Cyprus, France, Greece, Italy, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, the Syrian Arab Republic, Tunisia, and Turkey ask the Committee to consider this proposal at MEPC 78 and refer it for adoption by the Parties to MARPOL Annex VI, meeting under the auspices of MEPC 79.

As of 23 November 2021, among the Mediterranean coastal States, Albania, Croatia, Cyprus, France, Greece, Italy, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, the Syrian Arab Republic, Tunisia, and Turkey, ratified MARPOL Annex VI. Algeria, Bosnia and Herzegovina, Egypt, Israel, Lebanon, and Libya, which associate themselves with this proposal, have not yet ratified MARPOL Annex VI but are in the process of doing so (**Table 1.1-1**). All Mediterranean coastal States support the designation of the proposed Med SO_X ECA, as per Decision IG.25/14.

---

[2] Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/31706/19ig24_22_2408_eng.pdf.
[3] Available at: to be completed.

Table 1.1-1. Status of ratification of MARPOL Annex VI by Mediterranean coastal States (as of 23 November 2021)

Country	Party to MARPOL Annex VI
Albania	X
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.

1.3 Fuel Sulphur Content and Terminology

Prior to implementation, most analyses presumed marine distillate oil (MDO) would be the main fuel pathway to compliance with the IMO 2020 0.50% S m/m global sulphur cap. Subsequently, the market has met demand for 0.50% S m/m fuels using fuel blends containing several streams of residuals and lighter products, termed low sulphur fuel oil (LSFO). Very low sulphur fuel oil (VLSFO) has a maximum sulphur content of 0.50% S m/m and ultra-low sulphur fuel oil (ULSFO) has a maximum sulphur content of 0.10% S m/m. Distillate marine fuels (DM) include MDO and marine gas oil (MGO). While prior work referred to MDO as the compliant pathway for IMO 2020 0.50% S m/m fuels, the market has moved towards LSFOs as the compliant pathways, with references to MDO being in parallel to 0.50% S m/m LSFO fuels.

Generally, references to heavy fuel oil (HFO) or intermediate fuel oil (IFO) in prior work are referring **to fuels with a sulphur content ≥ 0.50% S m/m. MDO generally refers to fuels ≤ 0.50% S m/m but ≥ 0.10% S m/m, and MGO refers to fuels ≤ 0.10% S m/m.**

Terminology has varied among IMO regulations, ISO standards, and the fuel prices described in the market, further complicating the comparison of fuels and prices over time. Per resolution MEPC.320(74) on the *2019 Guidelines for consistent implementation of the 0.50% sulphur limit under MARPOL Annex VI* (IMO, 2020)[4], marine fuels are described as shown in **Table 1.3-1**.

As outlined in resolution MEPC.320(74), shipowners/operators should be aware that the viscosity of blended residual fuels (LSFOs) is such that they require heating for cleaning and combustion, and thus cannot be used in distillate-only fuel systems, with fully segregated systems for distillate fuels and LSFOs recommended. The IMO recommends that ships have a comingling procedure, with new bunkers loaded into empty tanks to the extent possible, and onboard comingling only occurring when the compatibility between the bunkers has been determined.

---

[4] https://www.imo.org/en/MediaCentre/PressBriefings/Pages/10-MEPC-74-sulphur-2020.aspx.

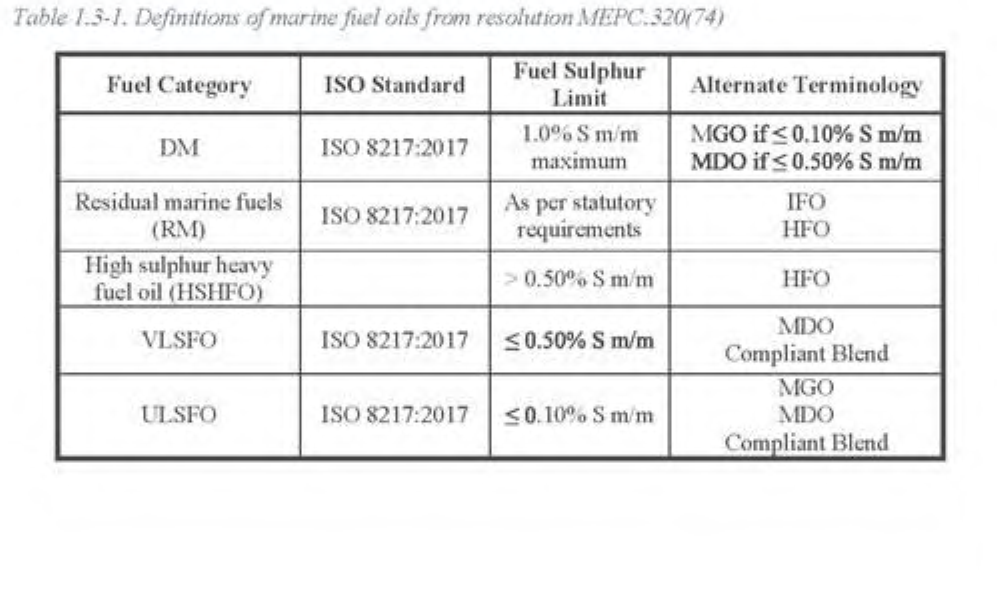


Table 1.3-1. Definitions of marine fuel oils from resolution MEPC.320(74)

Fuel Category	ISO Standard	Fuel Sulphur Limit	Alternate Terminology
DM	ISO 8217:2017	1.0% S m/m maximum	**MGO if ≤ 0.10% S m/m** **MDO if ≤ 0.50% S m/m**
Residual marine fuels (RM)	ISO 8217:2017	As per statutory requirements	IFO HFO
High sulphur heavy fuel oil (HSHFO)		> 0.50% S m/m	HFO
VLSFO	ISO 8217:2017	**≤ 0.50% S m/m**	MDO Compliant Blend
ULSFO	ISO 8217:2017	≤ 0.10% S m/m	MGO MDO Compliant Blend

12

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	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 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	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 SO_X 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[5] as being bounded on the southeast by the entrance to the Suez Canal, with the exception of the waiting area of the Suez Canal in its determined coordinates, according to the map set out in point c of **Annex 2**, 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 SO_X 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, the 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.

---

[5] https://iho.int/uploads/user/pubs/standards/s-23/S-23_Ed3_1953_EN.pdf

Figure 2.1-1: Contracting Parties to the Barcelona Convention (in grey) and proposed area of the Med SO_X ECA (in dark blue)

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.

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 **many people live near 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 SO_X ECA, in addition to populations, sites, and ecosystems in coastal locations.

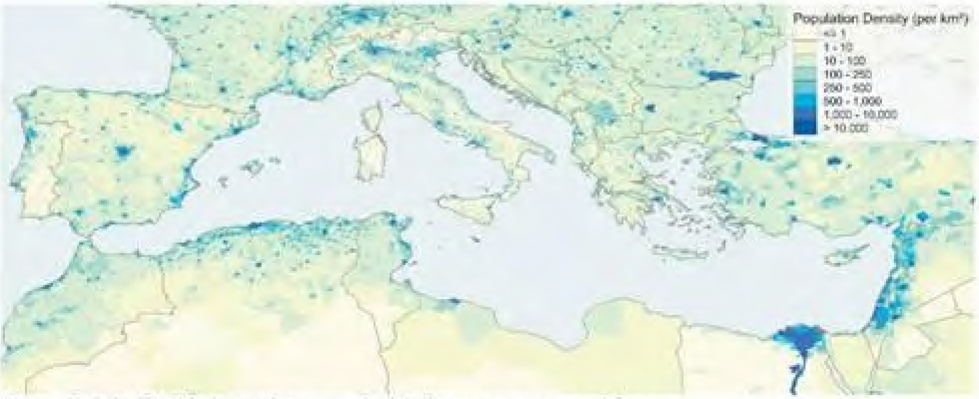


Figure 2.3-1: Gridded population in the Mediterranean coastal States

2.4 Summary of Description of the Proposed Area of Application

Based on the information presented in the previous **Section 2.1**, **Section 2.2**, and **Section 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	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

SO_X and PM emissions from ships have a significant impact on air quality in the Mediterranean Sea area. Furthermore, modelling shows that the proposed Med SO_X ECA would lead to widespread benefits throughout the Mediterranean Sea area and far inland due to the long-range nature of pollution from ships. SO_X and $PM_{2.5}$ emissions from ships would be reduced by 78.7% and 23.7%, respectively, under the proposed Med SO_X ECA, leading to health and environmental benefits through reduced environmental exposure to the pollutants. The proposed Med SO_X ECA is expected to lead to air quality improvements throughout the Mediterranean Sea region and beyond, leading to thousands of avoided premature deaths and incidences of childhood asthma annually. The proposed Med SO_X ECA will improve visibility in the region and reduce sulphate and PM deposition, both of which cause damage to sites of significant cultural heritage, and harm sensitive ecosystems and fisheries.

3.2 The Mediterranean Sea area Emissions Inventory Summary

Lower-sulphur fuels that would be required under the proposed Med SO_X 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 0.50% S m/m to 0.10% S m/m 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 SO_X 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 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 0.50% S m/m in 2020. This proposal models default compliance with MARPOL VI to result from a switch from non-compliant fuel (average 2.40% S m/m) to MARPOL VI compliant (0.50% S m/m) fuel. All future year scenarios consider technical and economic feasibility of the proposed Med SO_X ECA to be compared with conditions defined using MARPOL VI compliant fuel.

Table 3.2-1. Baseline and 2020 scenario criteria and greenhouse gas (GHG) pollution emissions

MT	Med 2016 Baseline	MARPOL VI 2020	Proposed Med SO_X 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 SO_X 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 SO_X ECA would result in a shift from 0.50% S m/m to 0.10% S m/m marine fuel. Recognising that SECA compliance can be achieved through alternative compliance mechanisms, this document considers these mainly as part of the economic feasibility (**Section 9.3.1** and **Section 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 exhaust gas cleaning systems (EGCS), also termed scrubbers, as the primary exhaust abatement technology to meet lower-sulphur limits of the proposed Med SO_X ECA. This document models liquefied natural gas (LNG) as the advance fuel alternative to meet lower-sulphur limits of the proposed Med SO_X ECA. Acknowledging that other technologies and fuels may be specified, this document utilises an analytical framework that can be applied to investigate more specifically other compliance strategies (e.g., various EGCS 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 SO_X and PM emissions from ships have a significant impact on air quality in the Mediterranean Sea area. Furthermore, modelling shows that the proposed Med SO_X

ECA would lead to widespread benefits throughout the Mediterranean Sea area and far inland due to the long-range nature of pollution from ships.

3.3.2 Improvement of Ambient Air Quality with the proposed Med SO_X 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 SO_X 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 SO_X ECA scenario, i.e. where the proposed Med SO_X 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 µg/m³, 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.

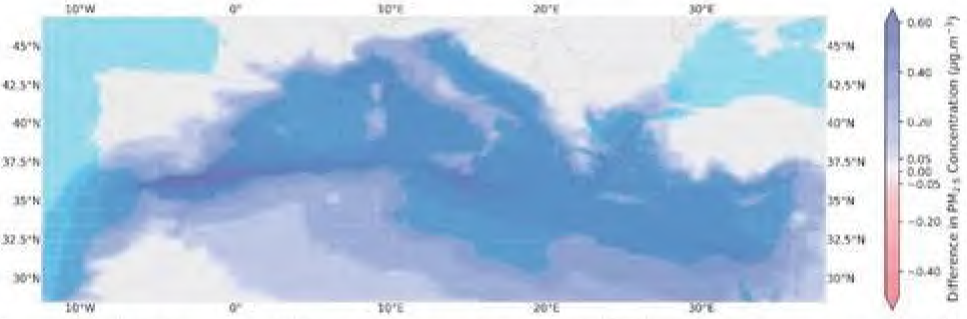


Figure 3.3-1: Difference in $PM_{2.5}$ concentration between MARPOL VI and the proposed Med SO_X ECA scenarios

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 SO_X ECA, and also benefit communities far inland. The air quality benefits of the proposed Med SO_X 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	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 SO_X ECA were estimated using the state-of-the-art health model, recently published in *Nature Communications (1)*, and referenced in document MEPC 70/INF.34. This model produces high resolution (10 km x 10 km) 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 (50 km x 50 km) 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 National **Aeronautics and Space Administration (NASA)'s Socioeconomic Data** and Applications Center (SEDAC) (*3*) were used.

4.2 Nature of PM Health Effects

PM with a mass median diameter less than 10 microns (µm) (PM_{10}) can be breathed deep into the lungs and contribute to disease. Specifically, PM with a mass median diameter less than 2.5 µm ($PM_{2.5}$) 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 (>20 µg/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 SEDAC Population of the World, Version 4.10 (*5*). These data provide gridded population counts, which were resampled to 0.1° x 0.1° resolution (~10 km x 10 km) 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 Member State of 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 SO_X ECA, we calculate avoided mortality based on the change in $PM_{2.5}$ concentration between the 2020 MARPOL VI (0.50% S m/m) scenario and the proposed Med SO_X ECA (0.10% S m/m) 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 Global Asthma Report 2014 (*15*). **For Asthma disease, the "Asthma Ever" data in the 13**-14 year-old age group reported in the 2014 Global Asthma Report 2014 (*15*) 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 (PM_{Total}) 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 SO_X 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 SO_X ECA

4.4.2 Childhood Asthma Morbidity

Childhood asthma health outcomes are improved in all Mediterranean coastal States. **Figure 4.4-2** shows the avoided childhood asthma morbidity associated with implementing the proposed Med SO_X 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 SO_X 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 SO_X 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.

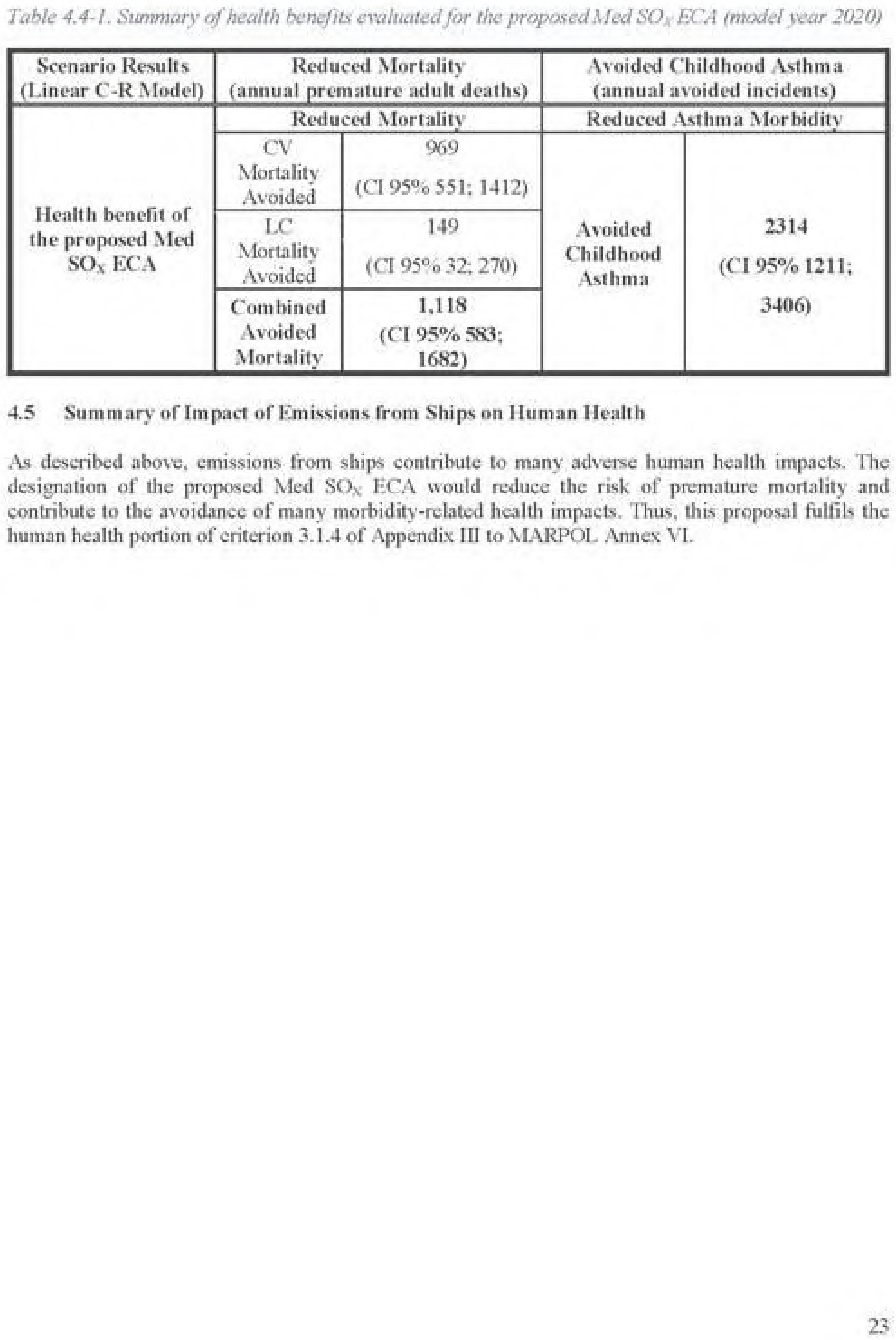


Table 4.4-1. Summary of health benefits evaluated for the proposed Med SO_X ECA (model year 2020)

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 SO_X 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 many adverse human health impacts. The designation of the proposed Med SO_X 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 **Section 3** and **Section 4**, which addresses criterion 3.1.4 of Appendix III to MARPOL Annex VI, as quoted:

Criterion 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;

5.1 Overview of Deposition Resulting from SO_X and PM Emissions from Ships

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 SO_X 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 SO_X 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 (SO_4) Deposition

Decreases in wet (**Figure 5.2-1 and Figure 5.2-2:**) and dry (**Figure 5.2-3 and Figure 5.2-4**) sulphate (SO_4) deposition associated with the proposed Med SO_X 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 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 in Algeria. The average percent decrease in dry sulphate deposition estimated for the Mediterranean Sea area is 1.95%.

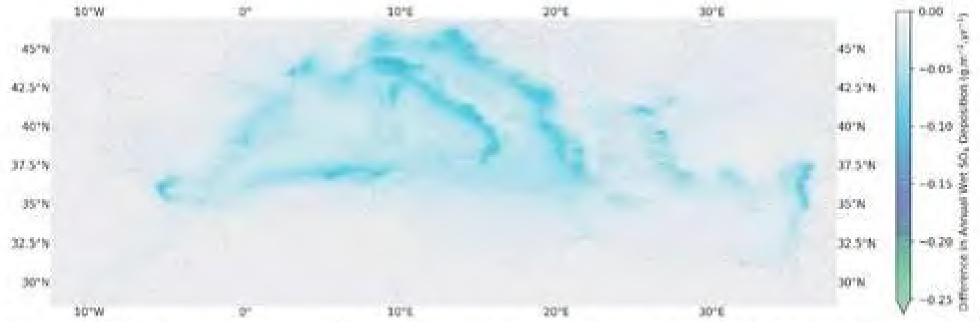


Figure 5.2-1: Decrease in annual wet sulphate deposition between MARPOL VI and the proposed Med SO_X ECA

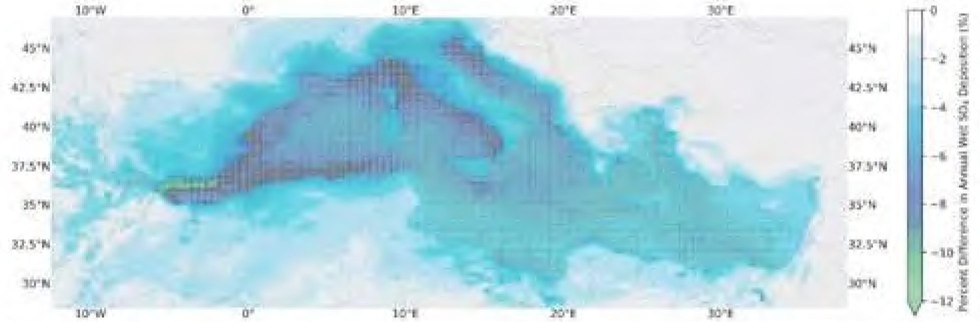


Figure 5.2-2: Percent decrease in annual wet sulphate deposition between MARPOL VI and the proposed Med SO_X ECA

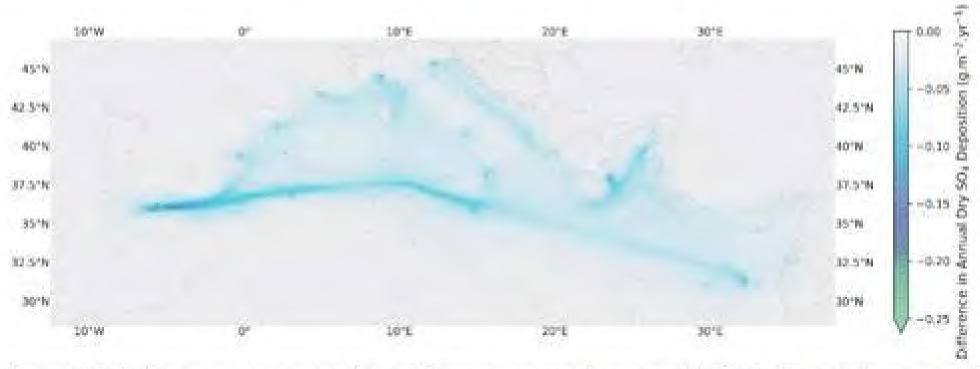


Figure 5.2-3: Decrease in annual dry sulphate deposition between MARPOL VI and the proposed Med SO_X ECA

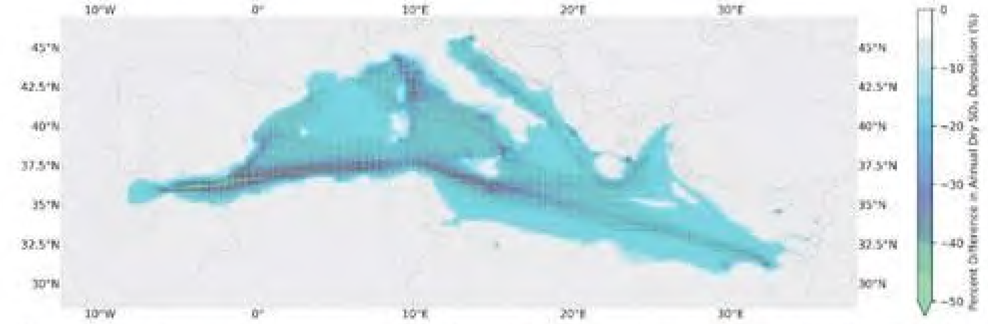


Figure 5.2-4: Percent decrease in annual dry sulphate deposition between MARPOL VI and the proposed Med SO_X ECA

5.2.2 PM_{Total} Deposition

Changes in wet (**Figure 5.2-5** and **Figure 5.2-6**) PM_{Total} deposition associated with the proposed Med SO_X 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** and **Figure 5.2-8**) 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 SO_X ECA, but shows significant geographic variation.

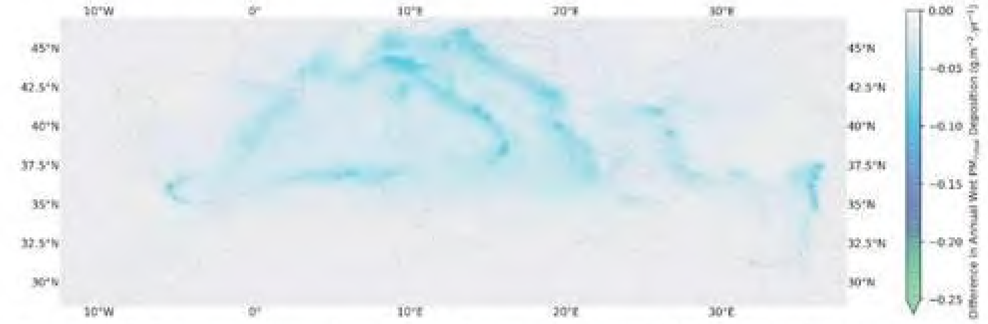


Figure 5.2-5: Decrease in annual wet PM_{Total} deposition between MARPOL VI and the proposed Med SO_X ECA

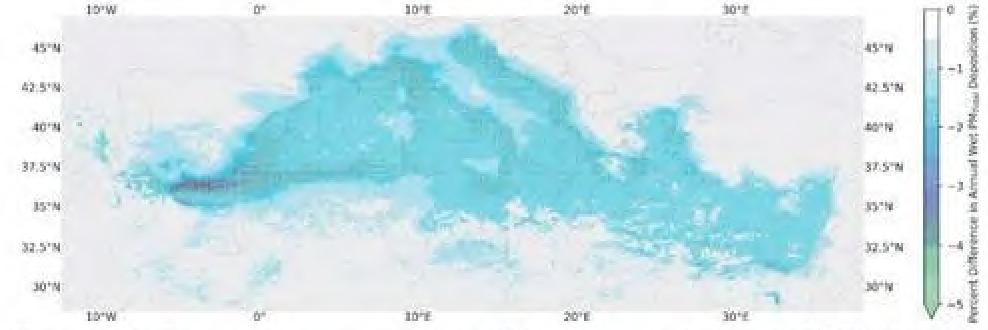


Figure 5.2-6: Percent decrease in annual wet PM_{Total} deposition between MARPOL VI and the proposed Med SO_X ECA

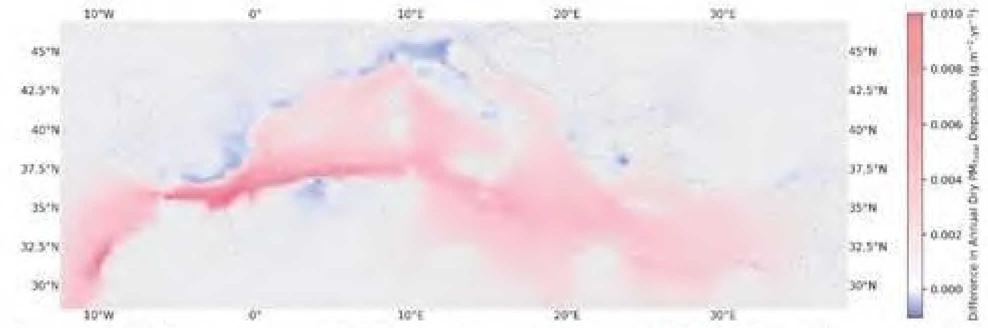


Figure 5.2-7: Change in annual dry PM_{Total} deposition between MARPOL VI and the proposed Med SO_X ECA

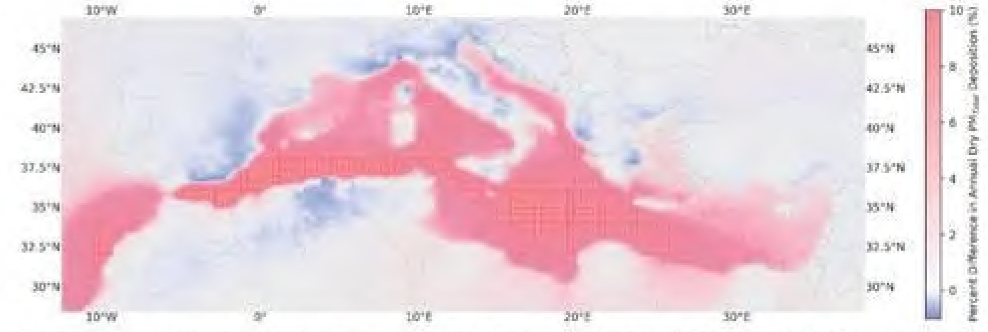


Figure 5.2-8: Percent change in annual dry PM_{Total} deposition between MARPOL VI and the proposed Med SO_X ECA

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.

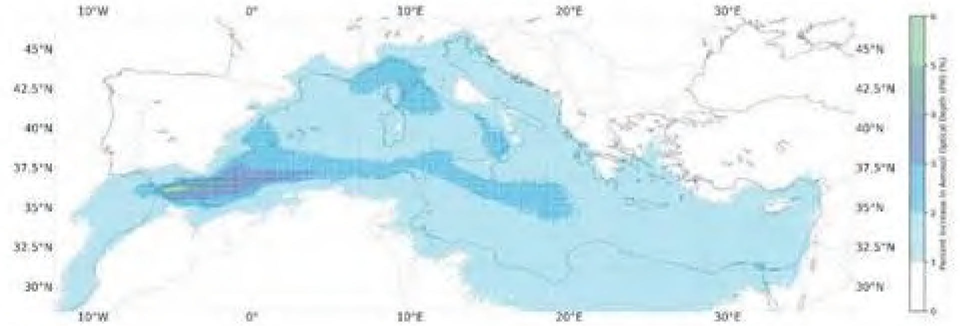


Figure 5.2-9: Percent Change in aerosol optical depth (PM species) between MARPOL VI and the proposed Med SO_X ECA

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

Deposition of $PM_{2.5}$ and toxic air compounds can contribute to create acidifying deposits, contribute to eutrophication, lead to lower pH levels in surface waters, ports, and harbours and lead to increases in heavy metals and polycyclic aromatic hydrocarbons (PAHs). Deposition can occur in either wet or dry form. Wet deposition occurs when PM, acidifying compounds, and toxic substances are deposited through precipitation, serving as cloud condensation nuclei, and dry deposition occurs when particles transmitted by atmospheric processes settle on terrestrial or marine environments. Coastal areas receive the greatest deposition of oxidised sulphur from ships, potentially up to 70%. On a country-wide basis, coastal areas of countries where this deposition from ships may occur may account for 5-70% of total sulphur deposition in Mediterranean coastal States [CITE Jonson et al 2020], depending on the country, size, and proximity to shipping traffic.

The Mediterranean is identified as a sensitive ecosystem [Turley1999] and as a region of high marine biodiversity, with more than 17,000 listed marine species occurring in the region [Coll 2010]. The Mediterranean is subject to a suite of anthropogenically driven challenges to its biodiversity, including habitat loss and degradation, fishing impacts, climate change, invasive species, and pollution [Coll 2010]. The pH of the Mediterranean Sea has been decreasing rapidly [Flecha et al 2015] with acid deposition from ships contributing to the acidification of the region [Jonson 2020, Teuchies 2020].

Deposition of $PM_{2.5}$ and other substances in ship emissions contributes to acidification of marine and freshwaters [CITE Hasselov et al., 2013, Jonson et al 2020] and terrestrial ecosystems [CITE Cerro2020]. Acidification alters biogeochemical cycles and affects aquatic and terrestrial animal and plant species [Jakovljevic et al 2019]. Furthermore, acidification of marine environments reduces the acid buffering capacity of the waters, which coupled with acidification-altered physiology and nutrient cycling, can lead to altered food chains and fish stocks [Hilmi et al 2014, Dupont and Portner, 2013]. Fisheries in the Mediterranean Sea and Black Sea generate annual revenues of USD 2.8 billion, directly employ around 250,000 people onboard fishing vessels, and feed hundreds of thousands of people in the region [FAO 2018]. Around half (47%) of fish stocks in the Mediterranean Sea are characterised as having low biomass, with another 31% characterised as having intermediate biomass, and most stocks in the region are overexploited [FAO, 2018].

Cleaner fuels may also contain fewer heavy metals and toxic chemical compounds. Air toxics include chemical compounds such as Polycyclic Aromatic Hydrocarbons (PAHs) and heavy metals, which are present in marine fuels and are released to the atmosphere during combustion. Heavy metals released during combustion of marine fuels include nickel, vanadium, cadmium, iron, lead, copper, zinc, and aluminium [Agrawal2008]. PAHs and heavy metals are known to cause several detrimental conditions in terrestrial and aquatic organisms, including physiological impairments, negatively altered growth and population dynamics, and mortality. PAHs and heavy metals are known to bioaccumulate, affecting multiple levels of trophic webs [Hasselov2020, Logan 2007], with apex predator marine mammals accumulating high levels of PAHs and metals in their tissues [Monteiro2020].

The Mediterranean coastal States are home to numerous areas of cultural heritage, including many sites thousands of years old. Wet and dry deposition of acidic substances are known to react with carbonate stone, including marble and limestones [Livingstone2016], that are found throughout the Mediterranean and widely used in the construction of cultural heritage sites [Calvo and Regueiro 2010]. The karst effect, carbonate stone naturally dissolving in rainwater since calcite is soluble in water, can be accelerated by deposition of anthropogenic air pollution. Reduced sulphur and PM emissions from ships mitigates this effect.

The Mediterranean Sea area is home to abundant biodiversity in terrestrial and aquatic ecosystems, fisheries that generate billions of dollars annually for the regional economy and employ and feed hundreds of thousands of people, and a rich cultural heritage. The benefits of the proposed Med SO_X ECA summarised in **Section 5.4** and **Table 5.4-1** show widespread reductions in wet and dry sulphate and PM deposition, as well as improved visibility. The implications of reductions in sulphate and PM deposition are clear. The proposed Med SO_X ECA will lead to improved ecosystem health and fisheries, reduced impacts to the sensitive biodiversity in the region, and improved longevity of important sites of cultural heritage in the region.

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 SO_X ECA

Environmental Benefit Proxy	Relative Range of Change (%)
Wet sulphate deposition	1 to 15 % reduction
Dry sulphate deposition	1 to 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 SO_X 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

Criterion 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 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.

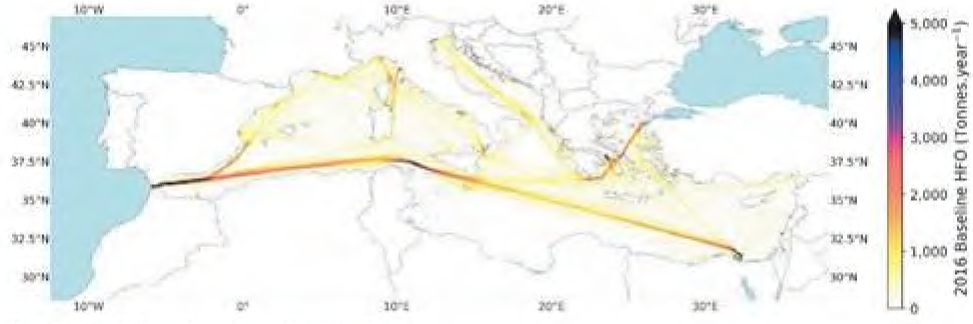


Figure 7.1-1: Baseline 2016 HFO fuel use

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 EGCSs. 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 SO_X 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 SO_X ECA scenarios compared to the MARPOL VI fuel consumption (**Table 7.1-2**).

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

MT	Med 2016 Baseline	MARPOL VI 2020	Proposed Med SO_X 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 SO_X ECA scenarios

Fuel Allocation	Pre-MARPOL VI Baseline Fuel Mix	MARPOL VI Fuel Mix	Proposed Med SO_X 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 SO_X 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	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

8.1 An Identification of Existing Land-Based Measures for the Control of SO_X and PM Emissions in the Mediterranean Coastal States

This section presents a systematic review of air quality and pollution abatement policies undertaken country-by-country for the Mediterranean coastal States that are Contracting Parties to the Barcelona Convention.

All Mediterranean coastal States have adopted measures for the control of emissions from land-based sources. The extent and implementation of these measures varies across the region, with European Union (EU) standards representing the strictest standards for ambient air quality and emission reductions. In total, the effect of land-based regulations has led emissions from transport and non-transport sources in the Mediterranean coastal States overall to decline by around half since 1975, with larger reductions on a country-by-country basis.

Land-based measures include those that regulate stationary and mobile sources of pollution on land. Analysis of land-based measures is presented in three phases. First, a systematic review of available public policies, laws and regulations identifies the set of policies, by country, aimed at reducing SO_X and PM pollution from land-based sources. Land-based sources of pollution include stationary sources, such as power generation facilities and industrial plants, and mobile sources, such as trucks, cars, and buses. Land-based emissions also include non-point source emissions, though those are typically not relevant for anthropogenic sulphur dioxide (SO_2) and $PM_{2.5}$ emissions. Second, analysis of emission inventory data identifies sectoral reductions in SO_2 and PM emissions. Third, analysis of regional data from air quality monitoring stations identifies compliance with $PM_{2.5}$ standards.

Criterion 3.1.7 of Appendix III to MARPOL Annex VI requires a description of the control measures taken by the proposing parties to address land-based sources of SO_X and PM emissions affecting human populations. This section presents a synthesis of national and international-level policies, describing land-based efforts for SO_X and PM abatement in the Mediterranean coastal States that are Contracting Parties to the Barcelona Convention, including those relevant to transportation and stationary sources. Existing measures are reported on a country-by-country basis, where available.

The Contracting Parties to the Barcelona Convention are Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, the Syrian Arab Republic, Tunisia, Turkey, and the European Union. There are eight countries that are both Contracting Parties to the Barcelona Convention and Member States of the European Union. These countries are Croatia, Cyprus, France, Greece, Italy, Malta, Slovenia, and Spain.

Country-level descriptions are included in the following sections and summarised in **Table 8.1-1**, denoting the presence of laws and regulations related to stationary and mobile source control of SO_2 and $PM_{2.5}$.

Table 8.1-1. Land-based measures identified at the country-level for SO_2 and $PM_{2.5}$ pollution control

Country	Member State of the European Union	Transportation	Stationary Sources
Albania	Candidate country	X	X
Algeria		X	
Bosnia and Herzegovina		X	X
Croatia	X	X	X
Cyprus	X	X	X
Egypt		X	X
France	X	X	X
Greece	X	X	X
Israel		X	X
Italy	X	X	X
Lebanon		X	X
Libya		X	
Malta	X	X	X
Monaco		X	X
Montenegro	Candidate country	X	X
Morocco		X	X
Slovenia	X	X	X
Spain	X	X	X
Syrian Arab Republic		X	
Tunisia		X	X
Turkey	Candidate country	X	X

8.1.1 Albania

Albania is in the process of applying to become a Member State of the European Union. Albania has been prioritising measures to align national air quality legislation with EU policies and has fully transposed the EU Directive 2008/50/EC into national law by the adoption of law no.162/2014 "On protection the ambient air quality" and DCM No. 352 dated 29.04.2015 "On air quality assessments and requirements concerning certain pollutants" that prescribes reference methods for air quality assessment. On 21 March 2007 Decision 147, governing the sulphur content in fuels, was adopted. Decision 147 limited the sulphur content of fuels to 10 ppm, aligned with the EU standards.

8.1.2 Algeria

The average fuel sulphur content for transportation gasoline fuels is 100 - 150 ppm and diesel is restricted to 2,500 ppm in Algeria[6]. This is equivalent to Euro 3/III emission standards for gasoline, and Euro 1/I standards for diesel. Only new vehicles leaving the factory are admitted for sale in Algerian territory.

---

[6] https://wedocs.unep.org/bitstream/handle/20.500.11822/25233/FuelQualityEmissionStandardDevelopments.pdf?sequence=3&isAllowed=y.

8.1.3 Bosnia and Herzegovina

Ambient air quality standards in Bosnia and Herzegovina are aligned with EU standards, though implementation and enforcement of the legal framework for air quality are in development (UN 2017). The Law on Air Protection (OG FBiH No. 33/03, 4/10) provides for monitoring of emissions from stationary sources, development of monitoring plans, and the development of monitoring networks. Furthermore, Continuous emissions measurement at large combustion plants is provided for in Article 18.

8.1.4 Egypt

The primary law governing air pollution in Egypt is Law 4/1994[7]. Under Law 4, Article 35, the law provides that emissions of air pollutants should not exceed those permitted by the regulations. Law 4 does not specify those standards, directly, and they are instead prescribed by executive regulations. The Draft Executive Regulation for Law 9/2009 sets out the ambient air quality standards for Egypt as shown in **Table 8.1-2**.

Table 8.1-2. PM_{10} and SO_2 ambient air quality standards in Egypt

Pollutant	Period	Standard
PM_{10}	24h	150 µg/m^3
	1yr	100 µg/m^3
$PM_{2.5}$	24h	100 µg/m^3
	1yr	70 µg/m^3
SO_2	1h, Industrial	300 µg/m^3
	1h, Urban	350 µg/m^3
	24h, Industrial	125 µg/m^3
	24h, Urban	125 µg/m^3
	1yr, Industrial	50 µg/m^3
	1yr, Urban	60 µg/m^3

In 2004 the national air quality strategy framework was formulated by Egypt in collaboration with USAID in order to improve urban air quality (World Bank 2013). Egypt implemented legislation requiring catalytic converters in imported vehicles and has endorsed the use of compressed natural gas (CNG) as a transportation fuel due to its lower pollutant emissions profile (Abbass, Kumar, and El-Gendy 2018). Egypt implemented a strategy to address the issue of open waste burning and as of 1994 the cement industry has been subject to emissions regulations set by Law 4/1994 (Abbass, Kumar, and El-Gendy 2018).

8.1.5 European Union

The European Union introduced their first air quality directive in 1970. Since then, the EU has implemented policymaking to improve air quality, by controlling the emission of pollutants to the atmosphere, improving quality of transport fuels, and cross-sectoral environmental protection measures. Clean air policy is based on three central tenets:

1. Ambient air quality standards;
2. National emission reduction commitments; and
3. Emission and energy efficiency standards for key sources of air pollution.

The air quality legislations of Croatia, Cyprus, France, Greece, Italy, Malta, Slovenia, and Spain are fully aligned and harmonised with European Union legislation, described in this section.

---

[7] http://www.eeaa.gov.eg/en-us/laws/envlaw.aspx.

The Clean Air Programme for Europe[8] is aimed at tackling poor air quality in the short term through a range of measures, including light-duty diesel engines, tightening existing legislation, enhancing technical capabilities, and the ambient air quality directive. In the long term, the Clean Air Programme for Europe is expected to reduce premature mortality by 37% and reduce ecosystem damage through eutrophication by 21% in 2025.

There are eight countries that are both Contracting Parties to the Barcelona Convention and Member States of the European Union. These countries are Croatia, Cyprus, France, Greece, Italy, Malta, Slovenia, and Spain. The national legislations of these countries fully transpose and are fully harmonised with the EU legal provisions.

Recently, the EU has undertaken the 2019 European Green Deal (COM/2019/640 final), **Europe's** 2030 climate ambition (COM(2020) 562) and the Sustainable and Smart Mobility Strategy (COM(2020) 789 final, SWD(2020) 331 final), and undertakes to act on a set of environmental policies, including climate change, biodiversity loss, circular economy, oceans health, including to reduce pollution from ships. Under the Green deal, the ongoing revision of the Ambient Air Quality Directive (AAQD) will set increasingly stringent standards for air quality and provide guidance for facilitating meeting those standards. A recent report from the European Environment Energy Agency shows significant proportion of the burden of disease in Europe continues to be attributed to environmental pollution resulting from human activity[9]. To address this, in June 2021 the EU will adopt the Zero Pollution Action plan.

Marine vessels are included in EU policymaking. On the sea-going vessel side, the EU Sulphur Directive (Directive 2016/802) requires that vessels calling any European ports have an obligation to switch to 0.10% S m/m at berth for calls longer than 2 hours. This obligation to use less polluting fuel oil in the ports, is in force since 2005 (Directive 1999/32). Additional to the at-berth requirement, prior to IMO 2020 going into effect, passenger vessels on regular service were required to use 1.50% S m/m fuels. On the port side, the Fuel EU Maritime initiative[10] and the revision of the Alternative Fuel Infrastructure Directive the Alternative Fuel Directive will contain mandatory provisions for shore power and alternative fuels to significantly reduce ship emissions in ports as well as coastal areas.

8.1.5.1 EU Ambient Air Quality Standards

The Ambient Air Quality Directive (2008/50/EC) sets limits for atmospheric concentrations of pollutant species in the EU, including SO_2 and airborne PM_{10} and $PM_{2.5}$. These standards are implicitly linked with transport and stationary source emission standards (EEA 2020b).

Ambient Air Quality Directives require Member States of the European Union to assess air quality in their territories and implement plans to maintain compliant air quality or reduce emissions and improve air quality in regions where standards are not met.

Atmospheric concentrations of PM_{10}, $PM_{2.5}$, and SO_2 are each governed by the EU Ambient Air Quality Directives and are subject to the temporal standards laid out in **Table 8.1-3**.

---

[8] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52013DC0918&from=EN.
[9] https://www.eea.europa.eu/publications/healthy-environment-healthy-lives.
[10] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12312-FuelEU-Maritime-.

Table 8.1-3. Selected EU Ambient Air Quality Directive pollution concentration standards

Pollutant	Period	Concentration	Notes
PM_{10}	1 Day	50 µg/m³ limit	For no more than 35 days per year
	Calendar Year	40 µg/m³ limit	
$PM_{2.5}$	Calendar Year	25 µg/m³ limit	
		20 µg/m³	Concentration exposure obligation
SO_2	1 Hour	350 µg/m³ limit	For no more than 24 hours per year
		500 µg/m³	Alert threshold for 3 hours in 100 km² zone
	1 Day	125 µg/m³ limit	For no more than 3 days per year

8.1.5.2 EU National Emission Reduction Commitments

National emission reduction commitments were established in the 2016 National Emission Ceilings (NEC) Directive (EU 2016), which require Member States of the European Union to develop air pollution control measures to meet their commitments[11]. Under the NEC Directive the EU-28 committed to dropping SO_2 emissions from 24,747 Gg[12] in 1990 to 2,031.4 Gg in 2018, and $PM_{2.5}$ emissions from 1,981.7 Gg in 1990 to 1,253.5 Gg in 2018 (**Figure 8.1-1**). These commitments represent emission reductions of 91.8% for SO_2 and 36.7% for $PM_{2.5}$ (UNECE 2019).

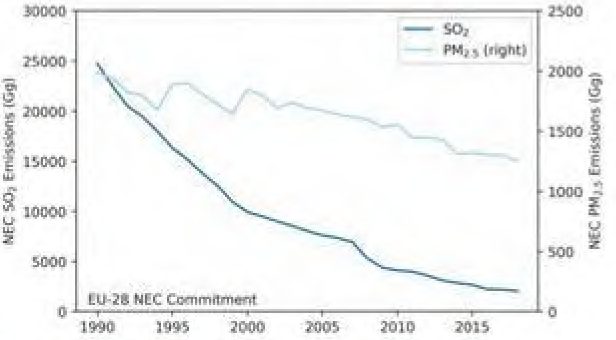


Figure 8.1-1: EU-28 National Emission Ceiling Commitments 1990-2018

All Member States of the European Union are working to remain in compliance with their NEC commitments for SO_2. Cyprus is the only Member State of the European Union and Contracting Party to the Barcelona Convention that is not on track to meet their 2020 commitment for SO_2. Additionally, Cyprus and Slovenia are not on track to meet their $PM_{2.5}$ commitments in 2020 (European Commission 2020). Spain is projected to comply with their NEC commitments for $PM_{2.5}$ for 2020 under their existing policies and measures, and with their 2030 commitments under the additional measures scenario[13]. The 2nd Clean Air Outlook[14] has shown prospects for the air pollution situation in the EU up to 2030 and beyond.

---

[11] https://www.eea.europa.eu/data-and-maps/dashboards/necd-directive-data-viewer-3.

[12] 1 Gg = 1,000 metric tons.

[13] https://eur-lex.europa.eu/resource.html?uri=cellar:7199e9c2-b7bf-11ea-811c-01aa75ed71a1.0007.02/DOC_2&format=PDF.

[14] https://ec.europa.eu/environment/air/clean_air/outlook.htm.

8.1.5.3 Emission and Energy Efficiency Standards

EU Directive 98/70/EC lays out initial emission standards for petrol and diesel fuels intended for the use of vehicle propulsion. Under articles 3 and 4, the directive requires a maximum sulphur content of 10 mg/kg (10 ppm) for petrol and diesel fuels in Member States of the European Union.

Since 1 January 2016, large combustion plants have been regulated in the EU through the Industrial Emissions Directive (IED) (2010/75/EU), which imposes minimum requirements for emissions of nitrogen oxides (NO_X), SO_2 and dust. Under IED 2010/75/EU combustion plants are required to use the best available techniques (BATs), or equivalent techniques for emission control. As emission limits are tied to BATs, which are updated over time, there is not any overarching prescriptive standard beyond those referenced in BAT reference documents (BREFs).

Energy efficiency is governed by the Energy Efficiency Directive (2012/27/EU) in the EU, which sets out an energy efficiency goal of 20% by 2020, relative to the 2005 baseline. The Energy Efficiency Directive was revised upwards in 2018 (EU Directive 2018/2002), setting a new energy efficiency target of 32.5% by 2030, including an annual reduction of 1.5% in national energy sales. In 2017, 16 states were aligned with their energy consumption trajectories, which if maintained, would allow those states to meet their 2020 final energy targets. Overall, final energy consumption in the EU-28 was 5.7% lower in 2017 than in 2005[15].

Policies related to large combustion plants (LCPs) decreased total fuel use in the EU by one fifth, while thermal capacity increased by one tenth between 2004 and 2015. Facilities with more LCPs powered by solid and liquid fuels were generally less efficient than LCPs with a greater share of biomass and natural gas. These policies led to a 77% decrease in SO_2 emissions from 2004 to 2015[16].

8.1.6 Israel

The Clean Air Law[17] came into effect in January 2011 in Israel (Ministry of Environmental Protection 2019). The law provides a comprehensive framework for the reduction and prevention of air pollution by establishing emission limits, creating a system for permitting emissions, publishing air quality data and forecasts, and monitoring air pollutants. The Clean Air Law set an average ambient air concentration of SO_2 at an average of 350 $\mu g/m^3$ over an hour, 50 $\mu g/m^3$ over a 24-hour period and 20 $\mu g/m^3$ annually. PM_{10} average limits were set at 50 $\mu g/m^3$ over a year and 130 $\mu g/m^3$ over 24 hours. (Negev, 2020)

On the transport side, vehicle emission standards are aligned with EU standards, with diesel and petrol sulphur content limited to 10 ppm.

8.1.7 Lebanon

In the transportation sector, Decree 8442/2002 defines the sulphur standards for gasoline at 0.05% (500 ppm) by weight, and diesel oil at 0.035% (350 ppm), as amended by decree No. 3795 dated 30/6/2016 stating the modification of the table No. 3 in the law No. 8442, by requiring an additional test the ratio/percentage of FAME biodiesel up to a maximum limit not exceeding 7% volumetric on the applicable laboratory tests for Diesel Oil according to the test method ASTM D7371 or ASTM D7963; along with additional laws designed to reduce air pollution from the transport sector by

---

[15] https://www.eea.europa.eu/data-and-maps/indicators/final-energy-consumption-by-sector-11/assessment.

[16] https://www.eea.europa.eu/data-and-maps/data/industrial-reporting-under-the-industrial-2.

[17] https://main.knesset.gov.il/Activity/Legislation/Laws/Pages/LawPrimary.aspx?t=lawlaws&st=lawlaws&lawitemid=2000055.

discouraging imports of older vehicles (Law 341, Law 380, and Law 453) and incentivise the use of public transport (Decree 8941/2012)) (MoE 2017).

In the energy and industrial sectors, MoE Decision 8/1-2001 defines emission limits for stack emissions and effluents from new and existing combustion plants and industrial establishments generating emissions.

Ambient air quality standards for Lebanon are shown in **Table 8.1-4**.

Table 8.1-4. PM_{10} and SO_2 ambient air quality standards in Lebanon

Pollutant	Period	Standard
PM_{10}	24h	80 µg/m³
SO_2	1h	350 µg/m³
	24h	120 µg/m³
	1yr	80 µg/m³

8.1.8 Libya

Libya has been heavily affected by regime change in recent years. Air pollution in Libya has previously been regulated under Article 10-17 of law no. 15 of 2003 (UNEP 2015a). Environmental law 15 stipulates that vehicles pass internal combustion and fuel quality tests, though exhaust gas tests are not performed. UNEP identify a 10,000-ppm sulphur limit in Libya, though they also note that the dominant fuel in the market has a sulphur content of 1,500 ppm.

8.1.9 Monaco

Sustainable development in Monaco is reflected in Act No. 1.456 of 12/12/2017 concerning the Environment Code, which covered all aspects of pollution, energy, and environmental management (Principaute de Monaco 2019). Under the Kyoto Protocol, Monaco set a target of improving energy efficiency by 20% by 2020 and transitioning 20% of final energy consumption to renewable sources. Furthermore, Monaco has set a goal to be carbon neutral by 2050, with an interim goal of 50% by 2030, compared to 1990 levels.

In Part II of the Code of the Sea, Chapter V specifies that all ships equipped with diesel engines must use fuels compliant with 0.10% S m/m standards, or alternatively be equipped with closed loop EGCS.[18]

8.1.10 Montenegro

Montenegro is a candidate country for entry into the EU and is in the process of integrating EU legislation into the system of national laws. Once a member of the EU, air quality policies in Montenegro will be harmonised with the EU system of laws.

In 2010 Montenegro enacted the Law on Air Protection (OG 25/10, 40/11) to define a framework for air protection. The law lays out a range of measures for improving air quality, including setting emission limits for stationary and mobile sources and setting national emission ceilings for specific pollutants (UNECE 2015). Where air quality targets are not met, regional authorities should adopt air

---

[18] https://journaldemonaco.gouv.mc/en/Journaux/2018/Journal-8393/Ordonnance-Souveraine-n-7.004-du-20-juillet-2018-relative-a-la-prevention-de-la-pollution-de-l-atmosphere-par-les-navires-et-completant-certaines-dispositions-du-Code-de-la-mer.

quality plans to mitigate emissions.

Montenegro has also enacted a 2005 law on Integrated Prevention and Control of Environmental Pollution (OG 80/5, 54/09, 40/11), which lays out the policies for permitting potential sources of environmental pollution.

8.1.11 Morocco

As of 2018, the maximum sulphur content in gasoline fuels in Morocco was 50 ppm, and 15 ppm for diesel[19]. Morocco has also implemented a set of urban transportation initiatives aimed at reducing GHG emissions by up to 50 MMT CO$_2$e (carbon dioxide equivalent). These strategies include tramway extensions, modal shifts to low carbon transport systems, and expansion of alternative fuels and renewable energy.

Though details on the air quality benefits of these programs are not available, they will likely have beneficial effects on air quality in Morocco, in addition to quantified GHG benefits.

8.1.12 Syrian Arab Republic

The energy sector in the Syrian Arab Republic has been heavily affected by conflict, which caused damage and destruction to energy infrastructure, including production plants, treatment facilities, and pipelines. Furthermore, the energy sector has been affected by economic sanctions imposed on the country. In parallel with these events the Syrian Arab Republic has seen CO$_2$ emissions from the energy sector drop from around 75 MMT CO$_2$e in 2011 to around 30.5 MMT CO$_2$e in 2016. Similarly, energy demand has fallen by over 50% from 25 MMT in 2011 to 10 MMT in 2016.

The Syrian Arab Republic adopted national ambient air quality standards in 2011 and in 2012 under Environment Law No. 12. Though fuel sulphur limits are high in the Syrian Arab Republic (6,500 ppm) (UNEP 2015b), the Syrian Arab Republic is engaging a transportation strategy to mitigate emissions in the transport sector emission standards, improved fuel quality, and encouraging the use of gas powered buses and alternatively fuelled vehicles (Syrian Arab Republic 2018).

8.1.13 Tunisia

Article 8 of Tunisia's Air Pollution and Noise Emissions Law No. 88-91 dictates that any industrial, agricultural, or commercial establishment as well as any individual or corporate entity carrying out activity that may cause pollution to the environment is obliged to eliminate or reduce discharges. Tunisia is a member of ISO and adopted ISO 14,000 series standards[20].

As of 2018, the maximum sulphur content in gasoline fuels in Tunisia was < 10 ppm[21], and diesel sulphur content is limited to 50 ppm. Tunisia has an import restriction on vehicles over 5 years old.

8.1.14 Turkey

In the transport sector, Euro 6 vehicle 6 emission standards became applicable in Turkey in 2017, and fuel sulphur is aligned with EU directives and regulated at 10 ppm (UNEP 2015c).

According to information provided by Turkey for this report, the Ministry of Environment and Urbanisation started to prepare strategical air quality maps to facilitate the decision-making process. Clean Air Action Plans of the provinces are being monitored electronically for the measures taken for air quality.

---

[19] See footnote 13.

[20] http://www.infoprod.co.il/country/tunis2i.htm.

[21] See footnote 13.

In order to comply with the EU regulations, Turkey is integrating the policies under the topic of air quality step-by-**step into national legislation. The "Technical Assistance for Transposition of the** Large Combustion Plants Directive for Better Air Qual**ity" Project was resulted on addressing the** compliance status and needs of large combustion plants under the scope of the industrial emissions directive (IED). In this project, an inventory of large combustion plants in Turkey, a web-based database for reporting and RIA report were prepared.

The "Support to the Implementation of Integrated Pollution Prevention and Control Directive in Turkey" (IPPC) project, has been conducted by MoEU during 2011-2014. In order to determine the compliance status of installations in Turkey with the IED, sectoral projects (large combustion plants, **automotive, cement, iron and steel, glass, and paper) were conducted. According to Turkey's** correspondence for this report, review of the waste management sector is underway.

The **"Project for Determination of Industrial Emissions Strategy of Turkey in Accordance with Integrated Pollution Prevention and Control (DIES Project)" started in 2020. The DIES Project aims** to increase the technical and institutional capacity of the competent authorities for the effective implementation of the IPPC approach in Turkey in line with the EU Industrial Emissions Directive.

8.2 Assessment of the SO_X and PM Emission Reductions from Land-Based Measures

Evaluation of emissions abatements, based on national level inventories, uses two primary data sources, the Emissions Database for Global Atmospheric Research (EDGAR)[22] (Crippa et al. 2020), and data from the European Environment Agency (EEA)[23]. EEA consolidated national total and **sectoral emissions of air pollutants consistent with the European Union's air pollutant emission** inventory methodology for submission to the Convention on Long-range Transboundary Air Pollution (LRTAP). Pollutants relevant to this analysis include both SO_X and $PM_{2.5}$. The EEA LRTAP inventories represent the most up-to-date and best available estimates for emissions activity by the Member States of the European Union. Both EDGAR and EEA datasets delineate inventories such that we can evaluate stationary and mobile source emissions.

EDGAR data are useful for comparing emissions in the Mediterranean Sea area for a few reasons. First, the data source is consistent, meaning that similar methodologies are applied for all regions, reducing the potential for bias or inaccuracies when comparing emission estimates generated using different methodologies. Second, the time series available from EDGAR is long, with data available from 1975 to 2015. While this data series does not cover the most recent years, it does allow for analysis and discussion of long-run trends in emissions. Third, the data set is highly pedigreed, developed by the European Commission Joint Research Centre (JRC), and peer reviewed (Crippa et al. 2020) over many years, leading to a high level of confidence in the quality of the data. EDGAR emission estimates are calculated using a technology-based emission factor approach, where sector-specific country-level emissions are estimated by species based on geospatially gridded inventories of human activity. EDGAR data are used to describe time trends in emissions when country-level inventories are unavailable. Where EEA LRTAP inventory data are available those emission estimates are presented using solid lines graphs. For the Mediterranean coastal States where EEA LRTAP data are not available, EDGAR emission estimates are presented using dashed line graphs.

Land based emission reduction policies, and their associated emission reductions, are then put in the context of air quality changes, using station-level geospatial data available from the 2018 World Health Organisation (WHO) Air Quality Database[24]. Station-level data from 2016, the most recent complete year of data available, are plotted geospatially county-by-country to illustrate areas of compliance with WHO $PM_{2.5}$ **guidelines (≤ 10 µg/m³) and EU standards (≤ 25 µg/m³)**. Time series

---

[22] https://data.europa.eu/doi/10.2904/JRC_DATASET_EDGAR.

[23] https://www.eea.europa.eu/data-and-maps/dashboards/air-pollutant-emissions-data-viewer-3.

[24] https://www.who.int/airpollution/data/en/.

data for countries in the European Union are also evaluated against EU standards and WHO guidelines.

8.3 An Assessment of the SO_X and PM Emission Reductions from Land-Based Measures

Criterion 3.1.7 of Appendix III to MARPOL Annex VI (MEPC.176(58)) requires a description of the control measures taken by the proposing parties to address land-based sources of SO_X and PM emissions affecting human populations. This section presents results from analysis of trends in national-level emissions, in order to describe land-based efforts for SO_X and PM abatement. The trends discussed in this section focus on land-based transportation specific emissions[25], and emissions from all land-based sources, not including waterborne navigation[26] or aviation[27].

EDGAR data show that overall SO_2 emissions from all sources, not including waterborne transportation[28], are falling among the Mediterranean coastal States that are Contracting Parties to the Barcelona Convention. From a peak of 9,567 Gg in 1980, SO_2 emissions fell to 5,068 Gg in 2015, an overall reduction of 47% compared to the peak emissions. Emission reductions are non-uniform in the region, however, with the downward trend being driven by larger reductions in Member States of the European Union. Meanwhile, overall emissions of SO_2 from other Mediterranean coastal States are flat or slightly increasing since around the year 2000.

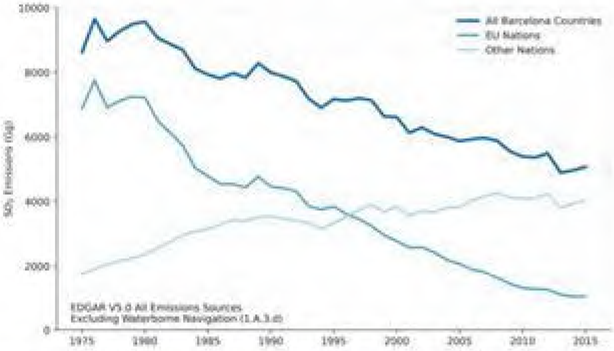


Figure 8.3-1: All sources of SO_2 emissions among Mediterranean coastal States that are Contracting Parties to the Barcelona Convention

Looking in more detail at the transportation sector, excluding waterborne transit as well as aviation, EDGAR data show that overall transport related SO_2 emissions have fallen in recent years in the Mediterranean coastal States that are Contracting Parties to the Barcelona Convention. Overall emissions of SO_2 have fallen from 222 Gg in 1978 to 70 Gg in 2015, an overall reduction of over 68%.

---

[25] IPCC sectors 1.A.3.b, 1.A.3.c, and 1.A.3.e.

[26] IPCC emission sector code 1.A.3.d.

[27] IPCC emission sector code 1.A.3.a.

[28] IPCC emission sector code 1.A.3.d.

Figure 8.3-2: Transport emissions of SO_2 in the Mediterranean coastal States that are Contracting Parties to the Barcelona Convention (excluding waterborne navigation and aviation)

Figure 8.3-1 and **Figure 8.3-2** show a large overall reduction in SO_2 emissions among the Mediterranean coastal States that are Contracting Parties to the Barcelona Convention, both in stationary sources and the transportation sector. These results show that, regionally, the Mediterranean coastal States that are Contracting Parties to the Barcelona Convention are undertaking land-based measures to control land-based sources of SO_2 and $PM_{2.5}$ emissions. The following sections provide a brief overview of the country-specific trends in emissions.

As shown in **Figure 8.3-2**, SO_2 emissions from the transportation sector have fallen across the region, in both the Member States of the European Union and other Mediterranean coastal States. SO_2 emissions from the Member States of the European Union have fallen to very low levels in recent years, and emissions from other Mediterranean coastal States decreased until 2005 and are not increasing since.

8.3.1 Regional Ambient Air Quality Observations

Figure 8.3-3: Mean annual air quality ($PM_{2.5}$ $\mu g/m^3$) observed at coastal observation stations (within 100 km of the coastline)

Figure 8.3-3 shows mean annual ambient air quality ($PM_{2.5}$ μg/m^3) observed at stations within 100 km of the coastline of the Mediterranean Sea from the World Health Organization's Ambient Air Pollution, Concentrations of fine particulate matter ($PM_{2.5}$) database[29]. Subsequent sections present country-level observations from the WHO data, where available, and do not limit observations solely to those stations withing 100 km of the coastline. The WHO data are the most complete set of observations for the Mediterranean coastal States, with 2016 as the most recent year of data available. All maps shown in this section are based on the WHO Ambient Air Quality database. As shown, air quality in the region varies greatly, with many coastal stations $PM_{2.5}$ concentrations exceeding WHO guidelines of 10 μg/m^3. Country-level time series data shown in this section are derived from station-level data provided by the European Environment Agency[30].

Figure 8.3-4 shows a histogram of station counts by their annual $PM_{2.5}$ concentrations. Most coastal observing stations report ambient measurements that do not meet WHO guidelines of 10 μg/m^3, with only 19.9% of stations meeting that threshold. The EU standard is set at 25 μg/m^3, which 94.4% of stations do comply with. Notably, the geographic distribution of stations is non-uniform, with a high concentration of monitoring stations in northern and western Mediterranean coastal States, and comparatively lower numbers in southern and eastern Mediterranean coastal States. As such, measurements at these air quality observations are best taken in context, with consideration for the differences in sampling between the Mediterranean coastal States.

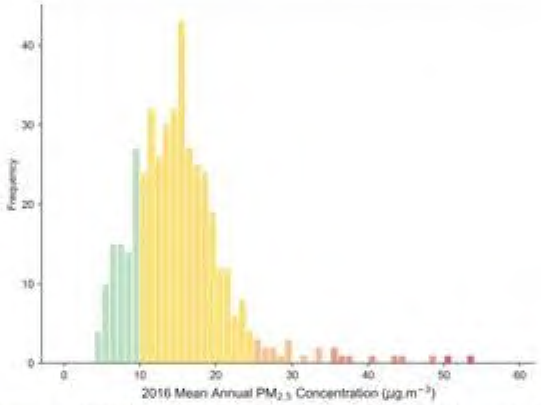


Figure 8.3-4: Histogram of WHO mean annual air quality ($PM_{2.5}$ μg/m^3) observed at coastal observation stations (within 100 km of the coastline)

8.3.2 Albania

Transportation related emissions of SO_2 in Albania peaked in 1980 at 0.94 Gg and have subsequently declined to very low levels (0.008 Gg in 2015). The trend in SO_2 emission reductions has been

---

[29] https://www.who.int/data/gho/data/indicators/indicator-details/GHO/concentrations-of-fine-particulate-matter-(pm2-5).

[30] https://www.eea.europa.eu/data-and-maps/data/aqereporting-8.

consistent since 1999 and demonstrates a high level of control of SO_2 emissions from transportation sources. In total emissions in 2015 had declined by over 99% relative to their peak in 1980.

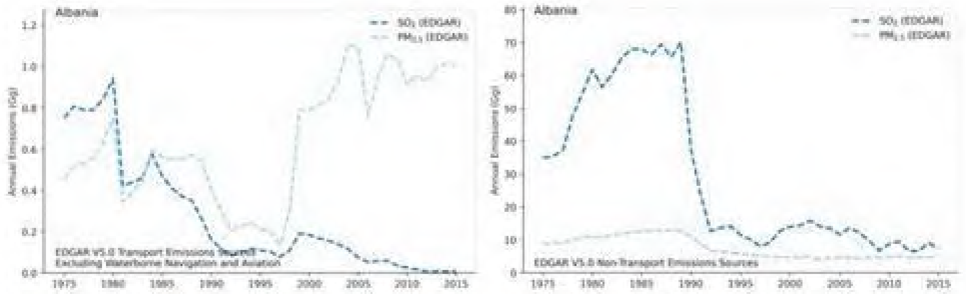


Figure 8.3-5: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Albania

Transportation related $PM_{2.5}$ emissions have not followed a similar trajectory to SO_2 emissions in Albania. After 1997 $PM_{2.5}$ emissions grew sharply, though they have remained flat since the mid-2000s.

All sources of SO_2 emissions fell sharply in Albania after 1990 and have remained flat since then. This reduction in SO_2 was accompanied by a similar decline in non-transport $PM_{2.5}$, which has also remained flat in Albania since around the year 2000 (**Figure 8.3-5**).

Mean annual $PM_{2.5}$ concentrations from 2016 (**Figure 8.3-6**) show that all stations meet EU $PM_{2.5}$ concentrations (<25 µg/m^3), though all three stations do exceed WHO $PM_{2.5}$ guidelines (<10 µg/m^3).

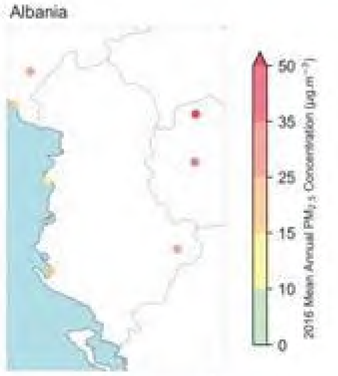


Figure 8.3-6: WHO mean annual $PM_{2.5}$ concentration observations in Albania (2016)

8.3.3 Algeria

Transportation related emissions of SO_2 in Algeria peaked in 1991 at 27.70 Gg followed by a decline to 8.26 Gg in 2005, a 70% reduction over that time period. The trend in SO_2 emissions has been rising since 2005, to 12.93 Gg in 2015, equivalent to a 53.3% reduction compared to 1991 peaks.

Transportation related $PM_{2.5}$ has also grown in Algeria since 1975.

All source emissions of SO_2 declined in later years, from 2012 to 2015, though the general trend in both SO_2 and $PM_{2.5}$ emissions in Algeria is upward (**Figure 8.3-7**).

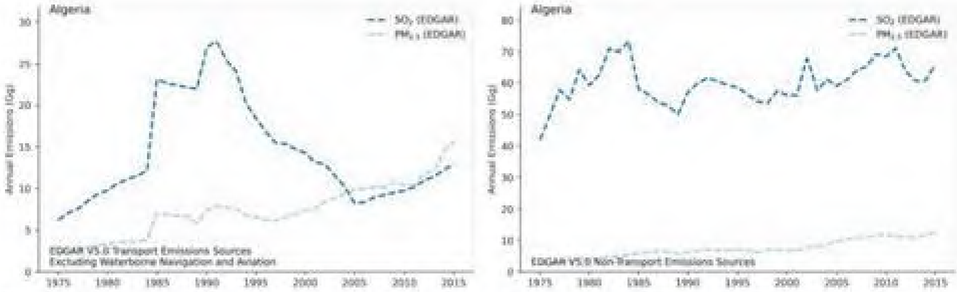


Figure 8.3-7: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Algeria

8.3.4 Bosnia and Herzegovina

Transportation related emissions of SO_2 in Bosnia and Herzegovina peaked in 1979 at 1.74 Gg and have subsequently declined to very low levels (0.01 Gg in 2015). The trend in SO_2 emission reductions has been consistent since 1999 and demonstrates a high level of control of SO_2 emissions from transportation sources. In total emissions in 2015 had declined by over 99% relative to their peak in 1979. Transportation-related emissions of $PM_{2.5}$ have declined since 2010, though they have increased slightly since 1975.

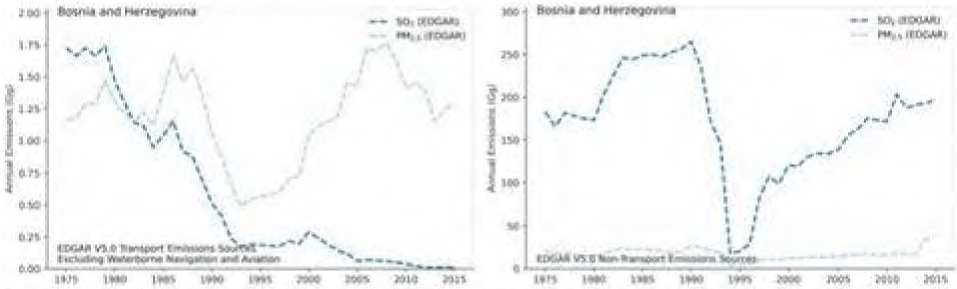


Figure 8.3-8: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Bosnia and Herzegovina

Overall emissions of $PM_{2.5}$ have been low in Bosnia and Herzegovina, since 1975, however overall SO_2 emissions have been rising steadily since 1994 (**Figure 8.3-8**).

Mean annual $PM_{2.5}$ concentrations from 2016 (**Figure 8.3-9**) show that 1 of 5 stations in Bosnia and Herzegovina meets EU $PM_{2.5}$ concentrations (<25 μg/m³), and concentrations at all stations exceed WHO $PM_{2.5}$ guidelines (<10 μg/m³).

Figure 8.3-9: WHO mean annual $PM_{2.5}$ concentration observations in Bosnia and Herzegovina (2016)

8.3.5 Croatia

Transportation related emissions of SO_X in Croatia peaked (over this time series) in 2003 at 5.95 Gg and have subsequently declined to very low levels (0.03 Gg in 2018). The trend in SO_X emission reductions has been consistent since 2003 and demonstrates a high level of control of SO_X emissions from transportation sources.

Non-transport emissions of $PM_{2.5}$ have been flat in Croatia since 1990 and non-transport SO_X declined around >90% from 1990 levels. Non-transport emissions of SO_X declined from 162.83 Gg in 1990 to 10.25 Gg in 2018 (**Figure 8.3-10**).

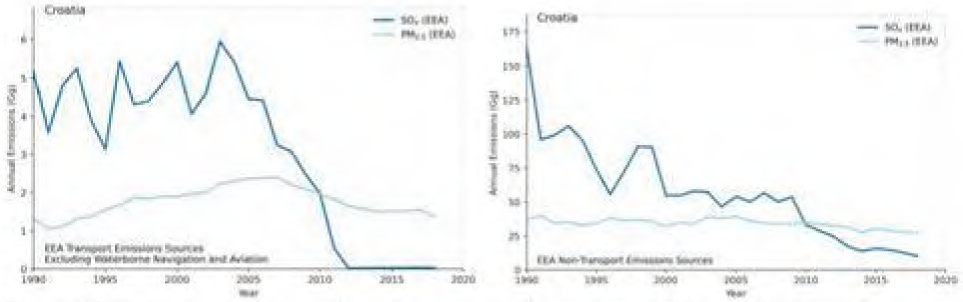


Figure 8.3-10: Transport (left) and non-transport (right) emissions of SO_X and $PM_{2.5}$ in Croatia

Mean ambient $PM_{2.5}$ concentrations in Croatia (**Figure 8.3-11**) have been compliant with EU ambient air quality standards since 2013, though the 95% confidence interval has had an upper bound above

25 µg/m³ since 2014, and country-wide average concentrations have been greater than the WHO guidelines since the data series began (EEA 2020a).

Looking at station measurements, shown in **Figure 8.3-12** the data show that 4 of 12 stations in Croatia are compliant with WHO guidelines for $PM_{2.5}$, and 8 of 12 stations are compliant with EU $PM_{2.5}$ regulations.

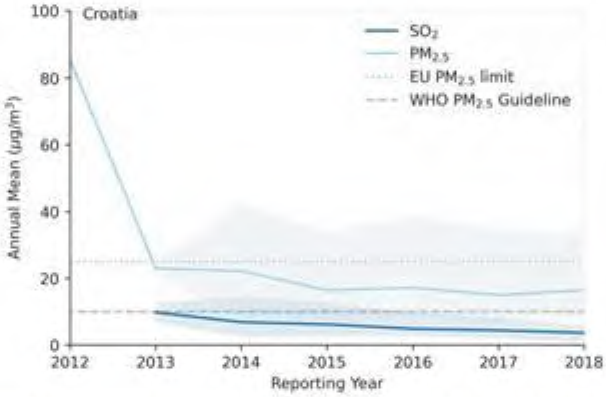


Figure 8.3-11: Annual mean concentrations of SO_2 and $PM_{2.5}$ in Croatia (shaded areas show 95% CI)

Figure 8.3-12: WHO mean annual $PM_{2.5}$ concentration observations in Croatia (2016)

8.3.6 Cyprus

Transportation related emissions of SO_X in Cyprus peaked in 1999 at 7.32 Gg and have subsequently declined to low levels (0.01 Gg in 2018). The trend in SO_X emission reductions saw a sharp drop beginning around the year 2001. These results demonstrate control of SO_X emissions from transportation sources.

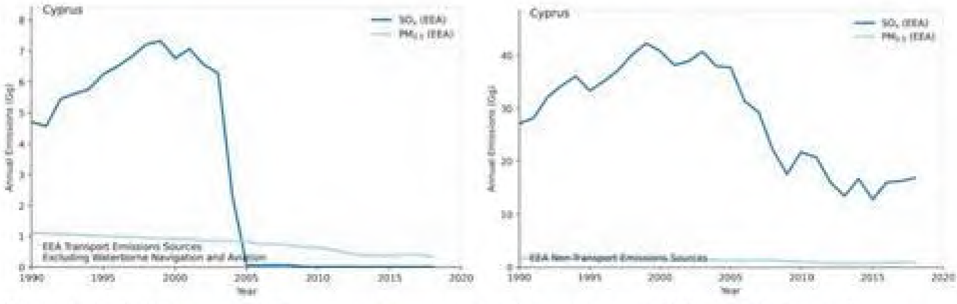


Figure 8.3-13: Transport (left) and non-transport (right) emissions of SO_X and $PM_{2.5}$ in Cyprus

Non-transport emissions of SO_X also peaked in 1999 at 42.23 Gg, and subsequently declined to 16.83 Gg in 2018 (**Figure 8.3-13**).

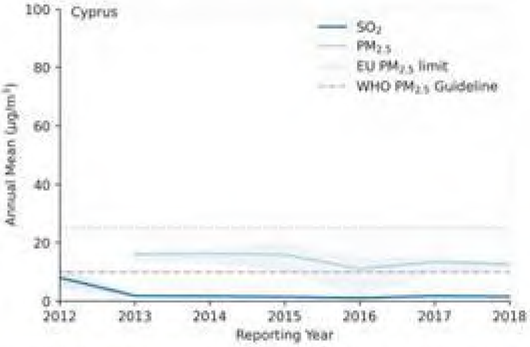


Figure 8.3-14: Annual mean concentrations of SO_2 and $PM_{2.5}$ in Cyprus (shaded areas show 95% CI)

As shown in **Figure 8.3-14**, country-level mean concentrations of SO_2 and $PM_{2.5}$ in Cyprus are in compliance with EU ambient air quality standards, however they do not meet WHO guidelines. Station-level measurements (**Figure 8.3-15**), support the annual data, demonstrating that no stations in Cyprus had annual mean $PM_{2.5}$ concentrations less than 10 µg/m³ in 2016.

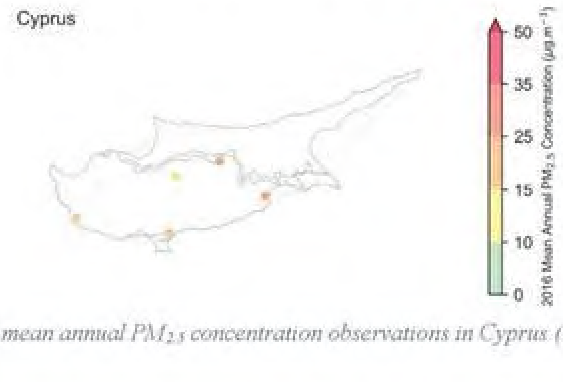


Figure 8.3-15: WHO mean annual $PM_{2.5}$ concentration observations in Cyprus (2016)

8.3.7 Egypt

Transportation related emissions of SO_2 in Algeria peaked in 1991 at 29.73 Gg followed by a decline to 10.28 Gg in 2005, a 65.4% reduction over that time period. The trend in SO_2 emissions has been rising since 2005, to 13.59 Gg in 2015, equivalent to a 54% reduction compared to 1991 peaks. The trend in non-transport emissions of SO_2 and $PM_{2.5}$ has been growing since 2004 in Egypt (**Figure 8.3-16**).

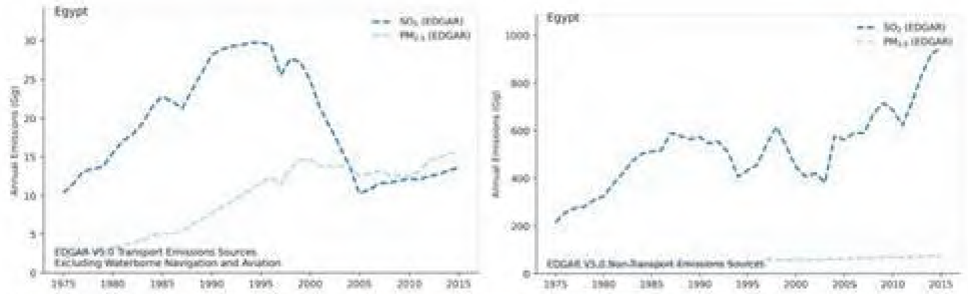


Figure 8.3-16: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Egypt

8.3.8 France

Transportation related emissions of SO_X in France peaked at 158.94 Gg in 1993 and have subsequently declined to 0.84 Gg in 2018. The trend in SO_X emission reductions has been consistently downward since 1993. These results demonstrate control of SO_X emissions from transportation sources. In total emissions in 2015 had declined by over 80% relative to 1991. Emissions for SO_X from non-transport sources have declined from 1,225.28 Gg in 1991 to 133.36 Gg in 2018 (**Figure 8.3-17**).

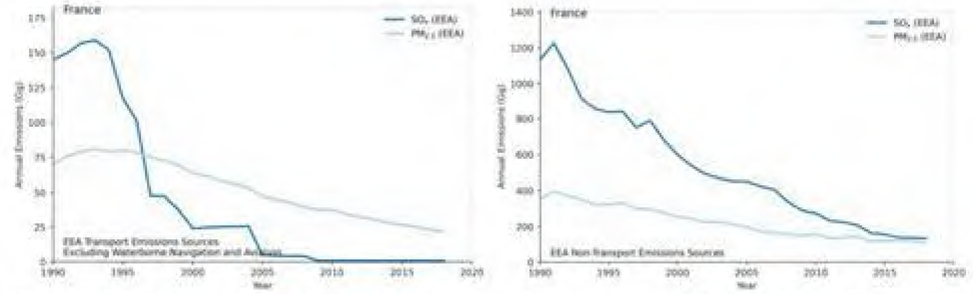


Figure 8.3-17: Transport (left) and non-transport (right) emissions of SO_X and $PM_{2.5}$ in France

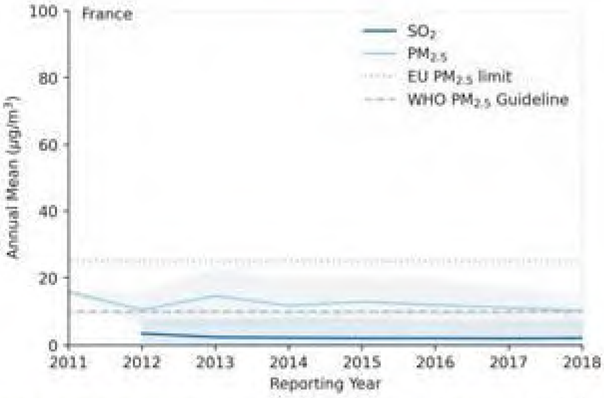


Figure 8.3-18: Annual mean concentrations of SO_2 and $PM_{2.5}$ in France (shaded areas show 95% CI)

As shown in **Figure 8.3-18**, country-level mean concentrations of SO_2 and $PM_{2.5}$ meet EU ambient air quality standards (EEA 2020a), but do not meet WHO $PM_{2.5}$ guidelines. Station-level data show that all stations in France met EU $PM_{2.5}$ standards in 2016, but just 65 of 282 (23%) stations in France met WHO $PM_{2.5}$ guidelines of 10 μg/m^3. Notably, stations along the southern cost of France saw some of the highest $PM_{2.5}$ concentrations in the country (**Figure 8.3-19**).

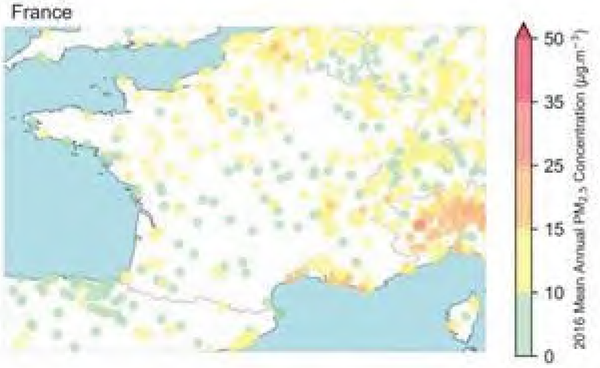


Figure 8.3-19: WHO mean annual $PM_{2.5}$ concentration observations in France (2016)

8.3.9 Greece

Transportation related emissions of SO_X in Greece peaked in 1994 at 21.85 Gg and have subsequently declined to low levels (0.14 Gg in 2018). These results demonstrate a high level of control of SO_X emissions from transportation sources. Non transport source gradually increased until their peak at 548.41 Gg in 2005, after which emissions fell rapidly to 64.12 Gg in 2018 (**Figure 8.3-20**).

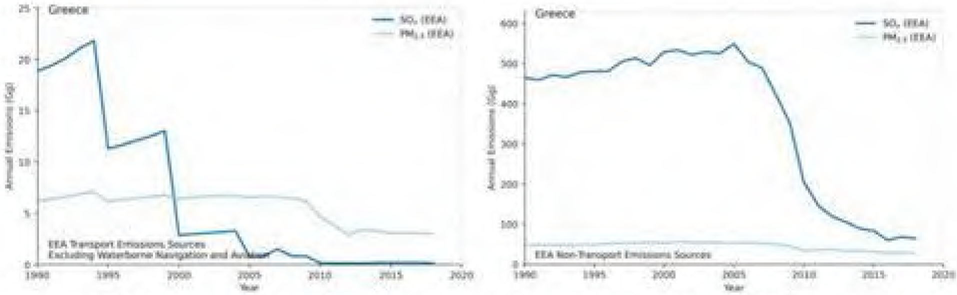


Figure 8.3-20: Transport (left) and non-transport (right) emissions of SO_X and $PM_{2.5}$ in Greece

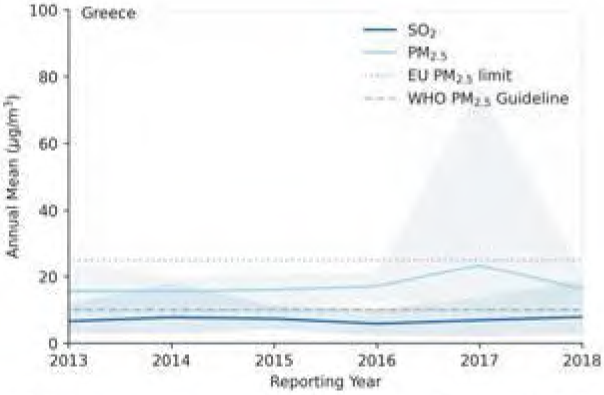


Figure 8.3-21: Annual mean concentrations of SO_2 and $PM_{2.5}$ in Greece (shaded areas show 95% CI)

As shown in **Figure 8.3-21**, country-level mean concentrations of SO_2 and $PM_{2.5}$ in Greece meet EU ambient air quality standards, though the 95% CI for 2017 does not meet the EU standard of 25 µg/m^3 for $PM_{2.5}$, and $PM_{2.5}$ concentrations do not meet WHO guidelines (EEA 2020a). Station-level data (**Figure 8.3-22**) show that all stations in Greece met EU $PM_{2.5}$ standards in 2016, but no stations met WHO $PM_{2.5}$ guidelines of 10 µg/m^3.

Figure 8.3-22: WHO mean annual $PM_{2.5}$ concentration observations in Greece (2016)

8.3.10 Israel

Prior to 1990, SO_2 emissions in Israel were flat. From 1989 to 1997 SO_2 emissions increased 90% to 11.84 Gg. Since 1997 Israel has seen a strong and consistent annual decline in SO_2 emissions falling to 4.17 Gg in 2015, a 64.8% drop since the 1997 peak. Emissions of $PM_{2.5}$ and SO_2 from transport sources have both declined in 2000 in Israel, and non-transport SO_2 emissions have declined overall by over 80% since 2000 (**Figure 8.3-23**).

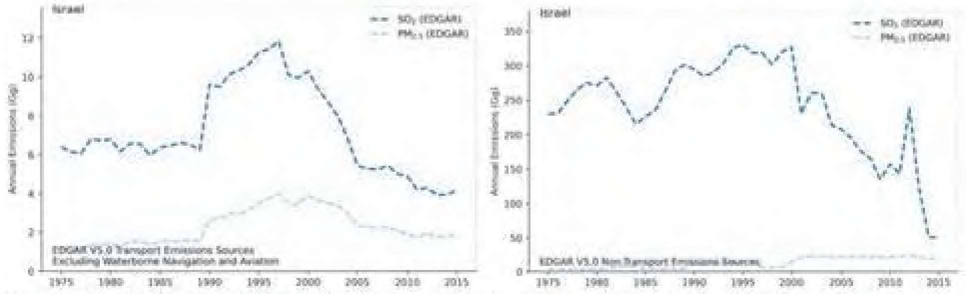


Figure 8.3-23: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Israel

8.3.11 Italy

Transportation related emissions of SO_X in Italy peaked in 1992 at 135.71 Gg and have subsequently declined to very low levels (0.41 Gg in 2018). The annual trend in SO_X emission reductions has been consistently downward since 1992. These results demonstrate a high level of control of SO_X emissions from transportation sources. In total emissions in 2015 had declined by over 99% relative to 1979. Emissions for SO_X from non-transport sources have declined significantly, from 1,574.99 Gg in 1990 to 87.60 Gg in 2018 in Italy (**Figure 8.3-24**).

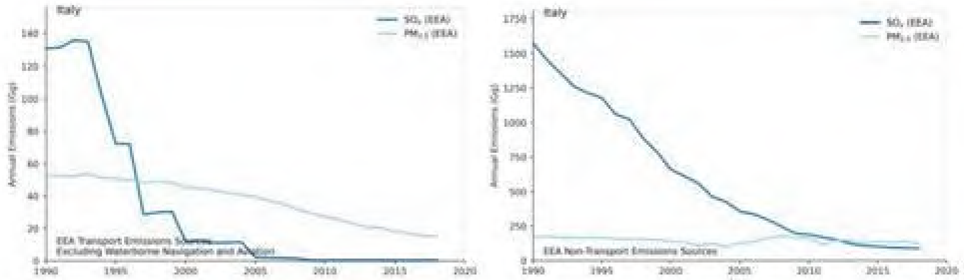


Figure 8.3-24: Transport (left) and non-transport (right) emissions of SO_X and $PM_{2.5}$ in Italy

As shown in **Figure 8.3-25**, country-level mean concentrations of SO_2 and $PM_{2.5}$ in Italy meet EU ambient air quality standards (EEA 2020a), though the country-level annual means do not meet WHO $PM_{2.5}$ guidelines. Station-level data (**Figure 8.3-26**) show that 320 of 334 (95.8%) stations in Italy met EU $PM_{2.5}$ standards in 2016, but just 36 of 334 (10.85) of stations met WHO $PM_{2.5}$ guidelines of 10 μg/m³.

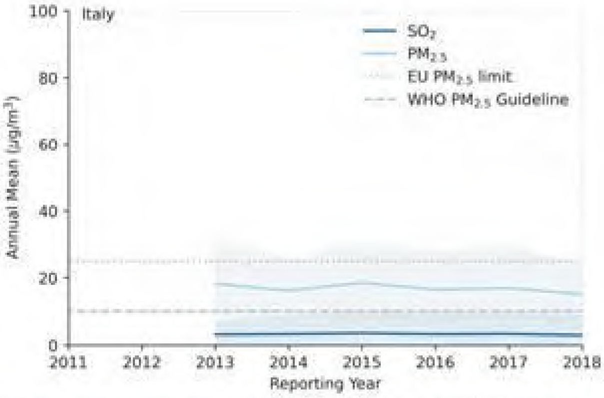


Figure 8.3-25: Annual mean concentrations of SO_2 and $PM_{2.5}$ in Italy (shaded areas show 95% CI)

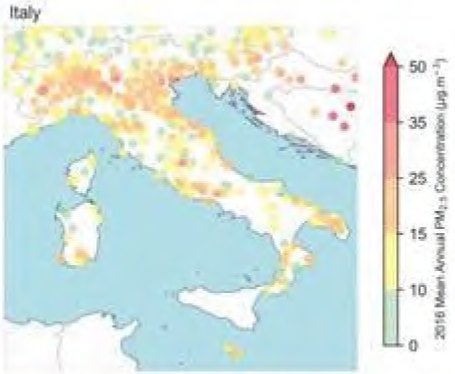


Figure 8.3-26: WHO mean annual $PM_{2.5}$ concentration observations in Italy (2016)

8.3.12 Lebanon

From 1988 to 1998 SO_2 emissions from transportation sources increased 184% from 0.90 Gg to 2.56 Gg. Since 1998, annual SO_2 emissions in Lebanon have mostly declined, to 0.97 Gg in 2015, roughly the same as levels prior to the increase seen in the 1990s. While transport SO_2 emissions have declined, non-transport emissions have grown in Lebanon since 1975 (**Figure 8.3-27**).

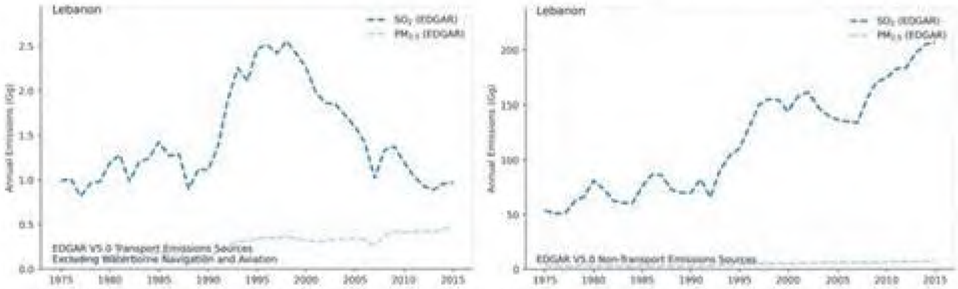


Figure 8.3-27: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Lebanon

8.3.13 Libya

Transportation related SO_2 emissions in Libya have seen a strong decline since their peak at 12.76 Gg in 1996. By 2015, transportation SO_2 emissions in Libya had fallen to 4.03 Gg, a decrease of 68%. Transportation-related $PM_{2.5}$ emissions have declined since 2010, and non-transport SO_2 and $PM_{2.5}$ have both shown declines since the mid-2000s in Libya (**Figure 8.3-28**).

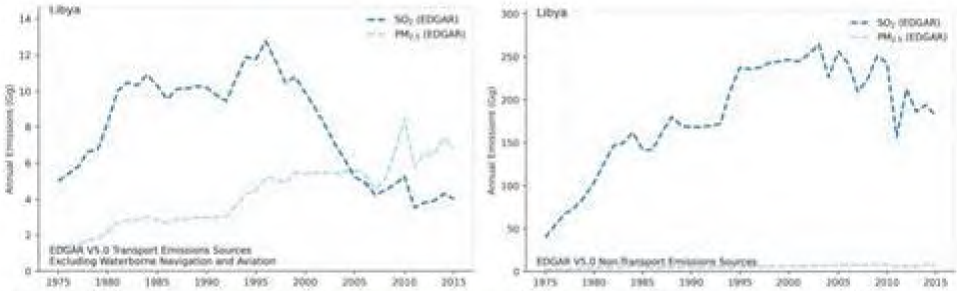


Figure 8.3-28: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Libya

8.3.14 Malta

SO_X transportation emissions in Malta have been 0.005 Gg per year since 2005. Non-transport emissions of SO_X have fallen from 12.61 Gg in 2007 to 0.15 Gg in 2018 (**Figure 8.3-29**).

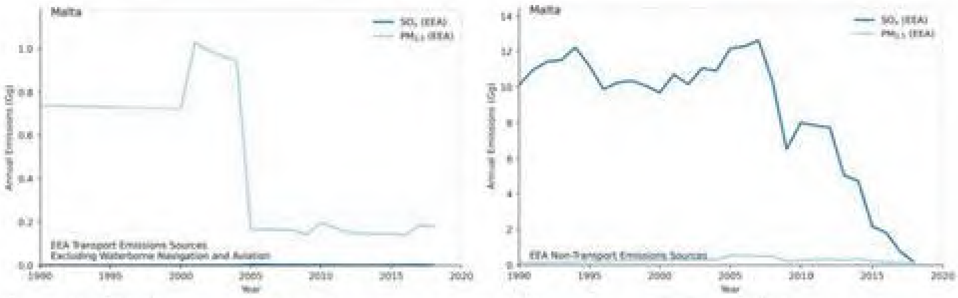


Figure 8.3-29: Transport (left) and non-transport (right) emissions of SO_X and $PM_{2.5}$ in Malta

As shown in **Figure 8.3-30**, country-level mean concentrations of SO_2 and $PM_{2.5}$ in Malta meet EU ambient air quality standards (EEA 2020a), but with the exception of 2017, exceed WHO guidelines. Station-level data (**Figure 8.3-31**) show that all 5 stations in Malta met EU $PM_{2.5}$ standards in 2016, but just 1 of 5 stations met WHO $PM_{2.5}$ guidelines of 10 µg/m³.

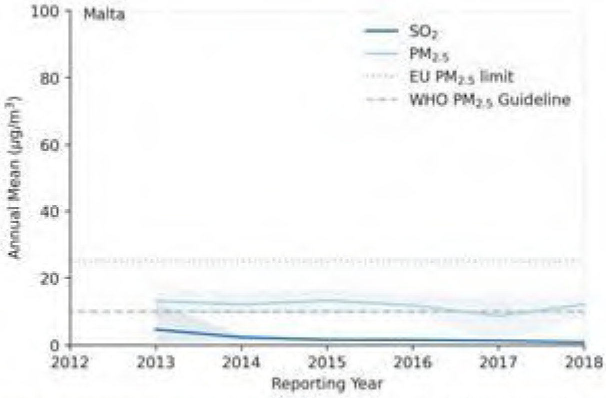


Figure 8.3-30: Annual mean concentrations of SO_2 and $PM_{2.5}$ in Malta (shaded areas show 95% CI)

Figure 8.3-31: WHO mean annual $PM_{2.5}$ concentration observations in Malta (2016)

8.3.15 Monaco

No data were available from EDGAR or EEA regarding emissions estimates for Monaco. Station level data (**Figure 8.3-32**) show that the single monitoring station reported by the WHO in Monaco meets EU standards but does not meet the WHO guideline of 10 µg/m³ for annual average $PM_{2.5}$ concentrations.

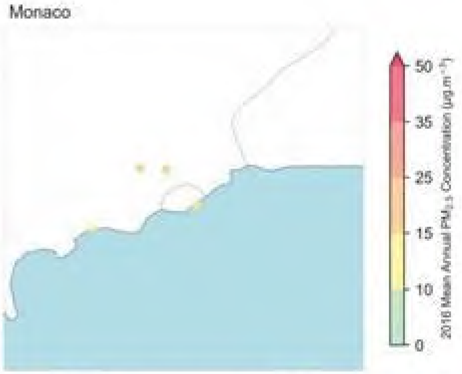


Figure 8.3-32: WHO mean annual $PM_{2.5}$ concentration observations in Monaco (2016)

8.3.16 Montenegro

Transportation related emissions of SO_2 in Montenegro peaked in 1979 at 3.77 Gg and have subsequently declined to very low levels (0.039 Gg in 2015). The overall annual trend in transportation SO_2 emission reductions has been downward since 1978, with a few exceptions in the early 1990s and 2007. These results demonstrate a high level of control of SO_2 emissions from transportation sources. In total transportation SO_2 emissions in 2015 had declined by 99% relative to 1979. Non-transport emissions of SO_2 have declined in Montenegro since 1991 (**Figure 8.3-33**).

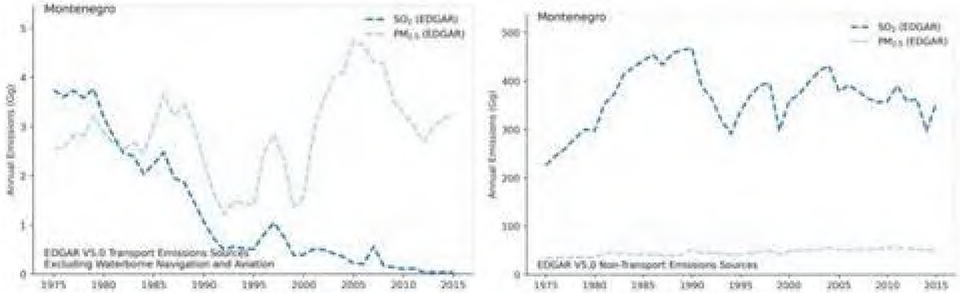


Figure 8.3-33: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Montenegro

Station level data (**Figure 8.3-34**) show that mean annual $PM_{2.5}$ concentrations at 1 of 3 reporting stations in Montenegro met EU standards of 25 µg/m³ in 2016.

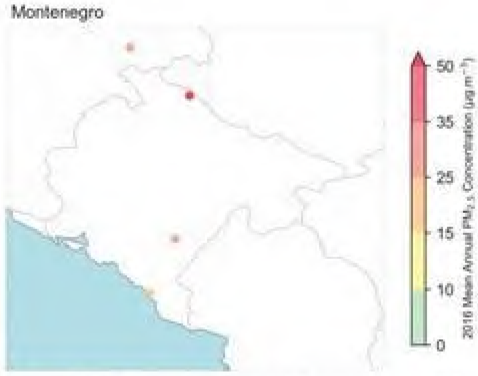


Figure 8.3-34: WHO mean annual $PM_{2.5}$ concentration observations in Montenegro (2016)

8.3.17 Morocco

Prior to 1988, SO_2 emissions from the transport sector in Morocco were flat. From 1989 to 1995 SO_2 emissions increased 105% to 9.84 Gg. Since 1995 Morocco has seen a strong decline in SO_2 emissions falling to 3.53 Gg in 2005, before rising to 4.9 Gg in 2015. Non-transport $PM_{2.5}$ has declined in Morocco since 2004, though non-transport SO_2 emissions have been rising steadily in Morocco since 1975 (**Figure 8.3-35**).

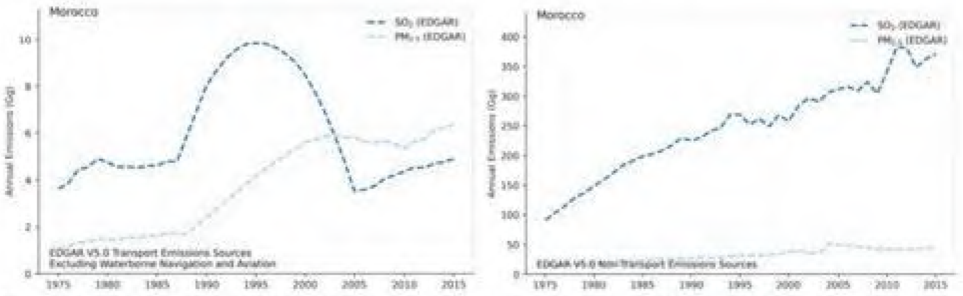


Figure 8.3-35: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Morocco

Station level data (**Figure 8.3-36**) show that no stations in Morocco were compliant with WHO $PM_{2.5}$ guidelines in 2016, with 3 of 6 stations meeting the 25 μg/m³ standard.

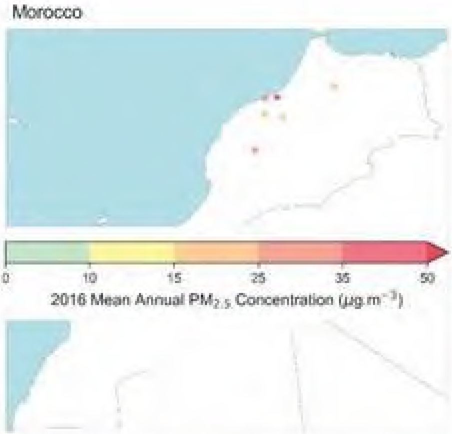


Figure 8.3-36: WHO mean annual $PM_{2.5}$ concentration observations in Morocco (2016)

8.3.18 Slovenia

SO_X emission in the transportation sector have declined from 7.29 Gg in 1994 to 0.04 Gg in 2018. Both transport and non-transport $PM_{2.5}$ have fallen in Slovenia since 2009, along with large overall reductions in SO_X. Non-transport SO_X fell from 194.04 Gg in 1990 to 4.74 Gg in 2018 (**Figure 8.3-37**).

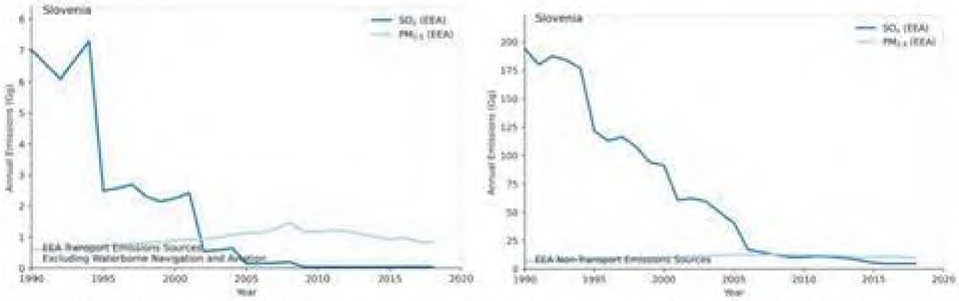


Figure 8.3-37: Transport (left) and non-transport (right) emissions of SO_X and $PM_{2.5}$ in Slovenia

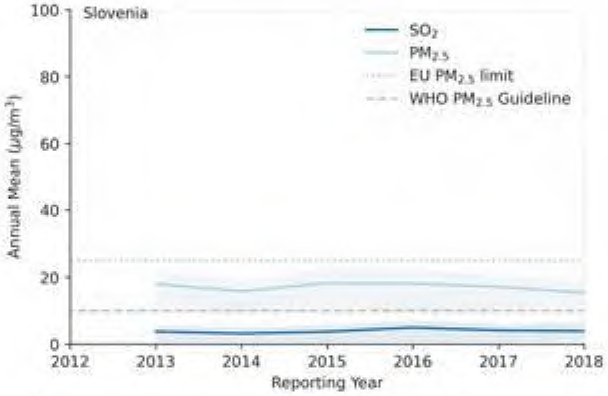


Figure 8.3-38: Annual mean concentrations of SO_2 and $PM_{2.5}$ in Slovenia (shaded areas show 95% CI)

Figure 8.3-39: WHO mean annual $PM_{2.5}$ concentration observations in Slovenia (2016)

As shown in **Figure 8.3-38**, mean concentrations of SO_2 and $PM_{2.5}$ in Slovenia meet EU ambient air quality standards (EEA 2020a), but exceed WHO guidelines for $PM_{2.5}$ (10 µg/m³). Station level data (**Figure 8.3-39**) show that 1 of 14 stations in Slovenia met WHO $PM_{2.5}$ guidelines in 2016, while 13 of 14 stations met EU standards (25 µg/m³).

8.3.19 Spain

SO_X emission in the transportation sector have declined in Spain since their peak in at 63.36 Gg in 1994 to 0.43 Gg in 2018. Non-transport emissions of SO_X have fallen significantly since the early 1990s (**Figure 8.3-40**).

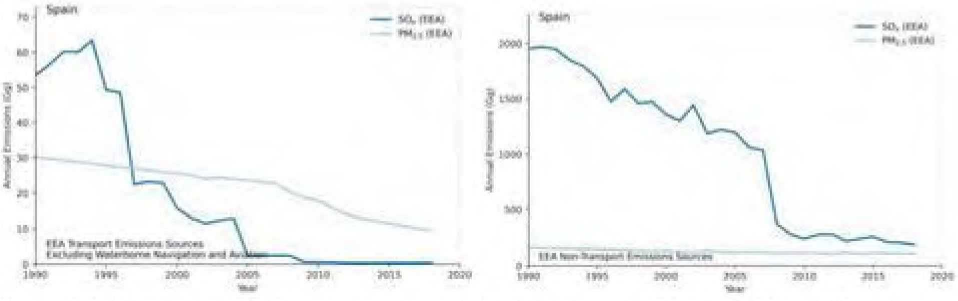


Figure 8.3-40: Transport (left) and non-transport (right) emissions of SO_X and $PM_{2.5}$ in Spain

As shown in **Figure 8.3-41**, mean country-level concentrations of SO_2 and $PM_{2.5}$ in Spain meet EU ambient air quality standards (EEA 2020a), and are slightly above WHO guidelines (10 µg/m³), with a mean annual concentration of 10.3 µg/m³ in 2018. Station-level data (**Figure 8.3-42**) show that 163 of 252 (64.7%) stations in Spain met WHO guidelines in 2016, and all stations met EU $PM_{2.5}$ standards.

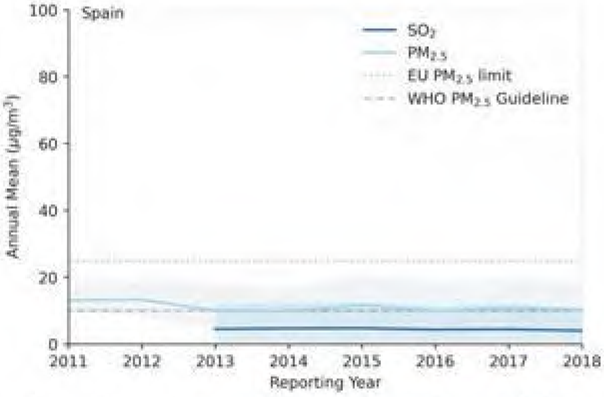


Figure 8.3-41: Annual mean concentrations of SO_2 and $PM_{2.5}$ in Spain (shaded areas show 95% CI)

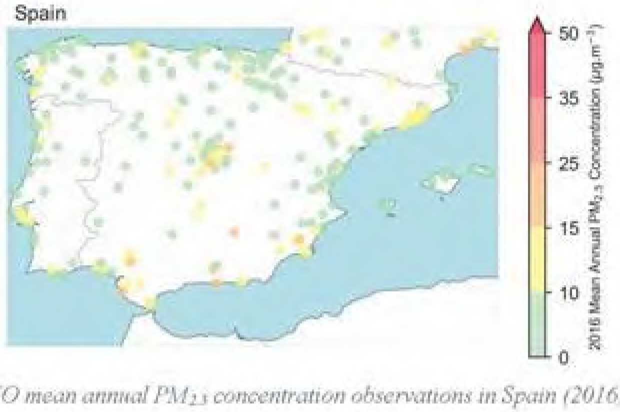


Figure 8.3-42: WHO mean annual $PM_{2.5}$ concentration observations in Spain (2016)

8.3.20 Syrian Arab Republic

SO_2 emission in the transportation sector have declined by 84% in the Syrian Arab Republic since their peak in 1991 (10.12 Gg). Emissions of SO_2 from the transport sector were 1.61 Gg in 2015. Both transport and non-transport related emissions of SO_2 and $PM_{2.5}$ have fallen significantly in the Syrian Arab Republic since around 2008 (**Figure 8.3-43**).

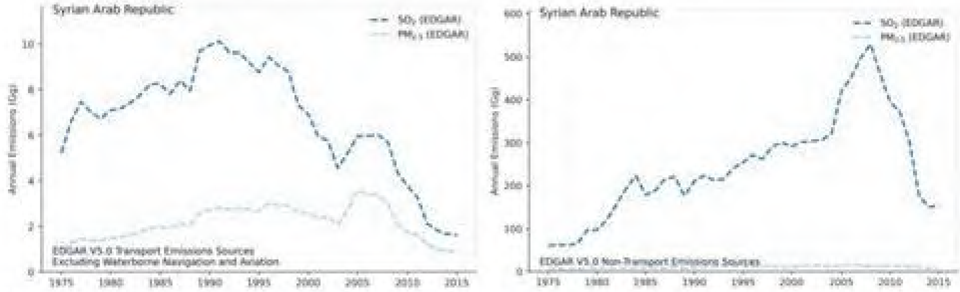


Figure 8.3-43: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in the Syrian Arab Republic

8.3.21 Tunisia

SO_2 emission in the transportation sector peaked at 5.47 Gg in 1995 in Tunisia and have since declined by 65.6% to 1.88 Gg in 2015. Emissions of SO_2 in the transport and non-transport sectors have declined significantly in Tunisia since their respective peaks, though $PM_{2.5}$ emissions in have continued to grow in both areas (**Figure 8.3-44**).

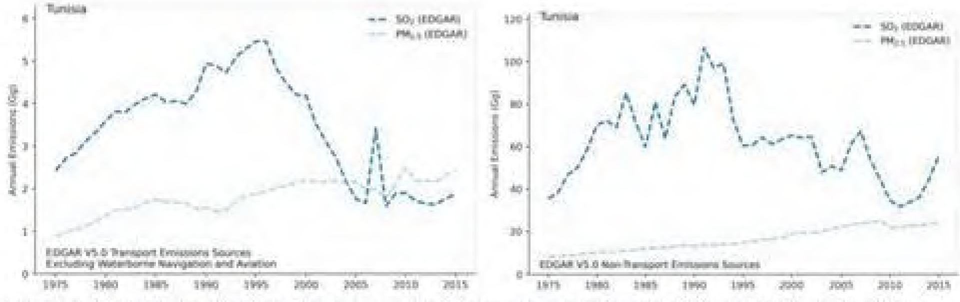


Figure 8.3-44: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Tunisia

8.3.22 Turkey

SO_2 emissions have declined overall in Turkey since 1986, though they did increase slightly from 2011 to 2015. SO_2 emissions from the non-transport sectors have been flat or slightly declining since the late 2000s. Similarly, emissions of $PM_{2.5}$ in both the transport and non-transport sectors have been flat since the late 1990s (**Figure 8.3-45**).

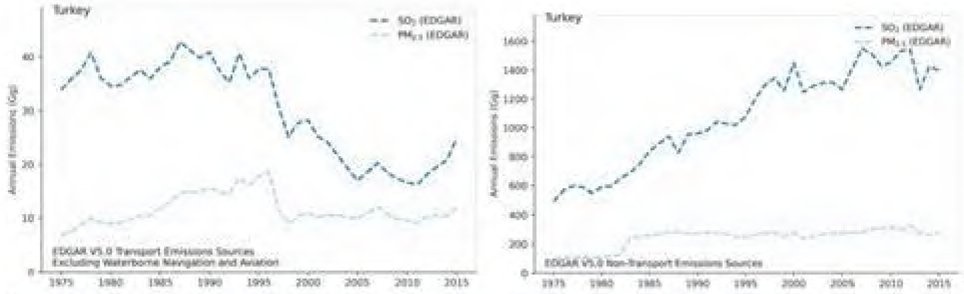


Figure 8.3-45: Transport (left) and non-transport (right) emissions of SO_2 and $PM_{2.5}$ in Turkey

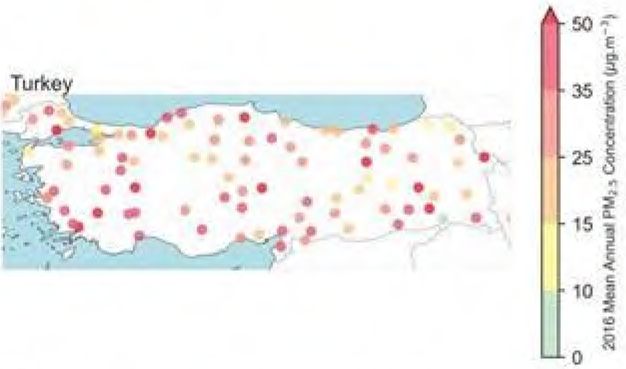


Figure 8.3-46: WHO mean annual $PM_{2.5}$ concentration observations in Turkey (2016)

Station-level data (**Figure 8.3-46**) show that just 1 of 87 stations reported by the WHO in Turkey meets WHO $PM_{2.5}$ guidelines, and 29 of 87 (33%) meet EU annual mean $PM_{2.5}$ standards (25 µg/m^3).

8.4 Summary of Control of Land-Based Sources

All Mediterranean coastal States have adopted measures in some form for the control of emissions from land-based sources. The extent and implementation of these measures varies across the region, with European Union standards representing the strictest standards for ambient air quality and emission reductions. In total, emissions from transport and non-transport sources in the Mediterranean coastal States have nearly halved (decline >46%) since 1975.

Air quality policies enacted by the Contracting Parties to the Barcelona Convention have led to reduced emissions and improved air quality in many locations the Mediterranean Sea region. However, coastal monitoring stations near major ports and routes with heavy shipping traffic continue to exceed WHO standards, with 80% of the air quality monitoring stations in the region within 100 km of the coastline not meeting WHO guidelines of 10 µg/m^3 for $PM_{2.5}$.

9 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 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 SO_X ECA policy scenario using best available data along with conservative assumptions regarding fuel prices and EGCS costs, as described in later sections. The results of the cost analysis conducted for this proposal demonstrates that a movement to the proposed Med SO_X ECA using fuel switching would add $1.761 billion/year in 2020 ($2016) compared to simply meeting the MARPOL standard. Using EGCSs would add $1.157 billion/year. These values are highly depending on the assumed price differential between 0.50% S m/m and 0.10% S m/m fuels. Price differentials are described in **Section 9.2.**

9.2 Fuel Costs

This section discusses the available history of fuel prices in the Mediterranean Sea area, and also in a global context. This section focuses on prices of HFO with a sulphur content of up to 3.50% m/m, LSFO with a sulphur content of 0.50% m/m that is compliant with IMO 2020 MARPOL VI regulations, and fuels with a sulphur content of 0.10% m/m that is compliant with MARPOL VI ECA regulations, referred to VLSFO or MGO. Costs of production and transport are embedded in sale prices that are used in these analyses. Fuel prices here reflect reported MGO prices, and thus we use MGO as the terminology to describe Med SO_X ECA compliant fuel prices, though the prices of MGO and VLSFO are closely aligned. We also include data on price differentials and comparison with global oil barrel prices.

This report uses terminology from the International Energy Agency (IEA) statistics that include refinery fuel labels, e.g., gas/diesel. The term gas/diesel is used in this report primarily because the fuel availability scope deals necessarily if not centrally with refining supply and demand including non-marine demand for gas/diesel. Gas/diesel includes all distillate marine fuels (DM) and distillate non-marine fuels in **Table 1.3-1**. For the purposes of clarity, IEA reported statistics for gas/diesel do not include natural gas or natural gas products, which are reported in separate data series.

9.2.1 Low Sulphur Fuel Oil (0.50% S m/m)

The price histories described below are for both the Europe, Middle East, and Africa (EMEA) area average as well as the World average. Prices are based on indexes provided by Bunker Index[31].

Figure 9.2-1 shows the time series of LSFO prices for the EMEA region and worldwide average. The two data series track one another closely, with global LSFO prices $46/MT greater than EMEA prices on average. Though the time series are abbreviated, due to the relatively recent availability of LSFO in global markets, EMEA LSFO fuel prices varied greatly, ranging from a minimum of $197/MT to a maximum of $666/MT. The median LSFO price for the EMEA region since November 2011 is $344/MT.

---

[31] https://bunkerindex.com

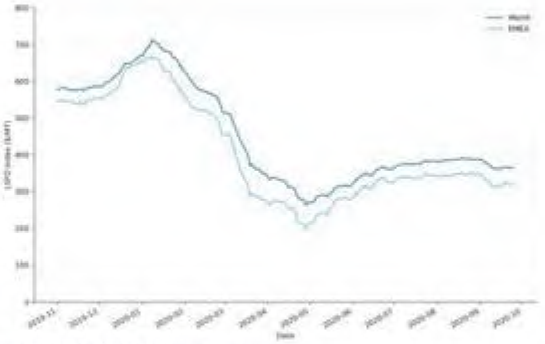


Figure 9.2-1: World and EMEA LSFO price indexes

9.2.2 Marine Gas Oil (0.10% S m/m)

Figure 9.2-2 shows the time series of MGO prices for the EMEA region and worldwide average. As with LSFO prices, world average MGO prices are typically greater than EMEA MGO prices. The average price differential between world and EMEA MGO prices is $50/MT, which is closely aligned with the world and EMEA differential for LSFO prices. MGO fuel prices have been volatile since 2016, ranging from $297/MT to $777/MT, with a median price of $443/MT, and a range of 2.6x from the low to the high values.

Figure 9.2-2: World and EMEA MGO price indexes

Prior to the IMO 2020 0.50% S m/m fuel rules going into effect, HFO fuel prices were similarly volatile. From 2008 to December 2019, HFO prices ranged from $152/MT to $742/MT, a range of 4.9x from the lowest price to the highest price.

9.2.3 Price differentials

While total costs are useful to understand total price impacts, fuel price differentials are important for evaluating the additional costs of the Med SO_X ECA compared to 0.50% S m/m fuels, i.e. the delta in price between 0.50% S m/m and 0.10% S m/m fuels. As shown in **Figure 9.2-3**, pricing data on LSFO is available from November 2019. EMEA and World price differentials have been closely aligned since January 2020.

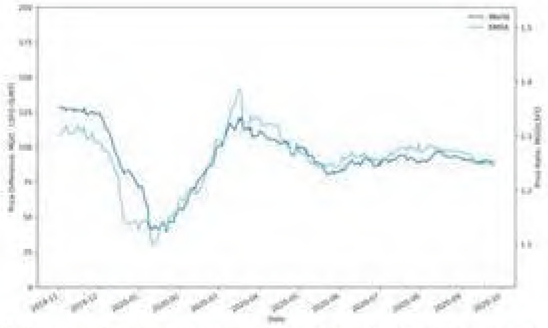


Figure 9.2-3: Price difference between MGO and LSFO for EMEA and World prices

The price differential between MGO and LSFO has stabilised since June 2020 at around $95/MT in the EMEA region. Over the period of available data (November 2019 to October 2020), the median difference is also $95/MT, corresponding with the period of price stabilisation post June 2020.

The ratio of MGO price to LSFO in the EMEA region has ranged from 1.05 to 1.51, with a median value of 1.29, i.e., the price increase from LSFO to MGO is between 5% and 51%, with a central value of 29%.

The ratio of prices is especially important to consider when evaluating the costs of the proposed Med SO_X ECA. While fuel prices are in constant flux, following fluctuations in crude oil prices, the price differential between MGO and LSFO is comparatively stable, post the period of adjustment in early 2020. Therefore, the price differential between the two fuels allows for robust analysis of the marginal costs of the proposed Med SO_X ECA, i.e. the additional costs of the proposed regulation.

9.2.4 Crude Prices

Crude barrel prices, which are feedstocks for marine fuels, were also analysed based on available time series data from EIA[32]. Results for two product areas, West Texas Intermediate (WTI) and Brent, together describe the range of global crude oil prices. These are shown in **Figure 9.2-4**, with WTI and Brent oil prices per barrel shown on the right axis. Note that the axes are scaled[33] such that either axis may be used for all data series depending on whether the reader is interested in fuel prices in $/MT or $/bbl.

---

[32] https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm.

[33] Assuming 1 bbl = 0.1364 MT.

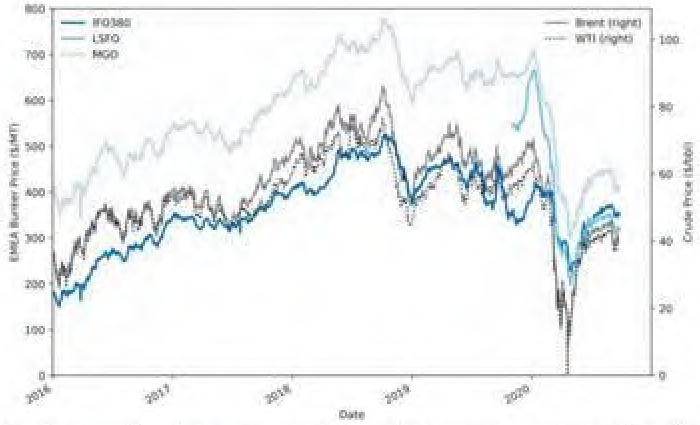


Figure 9.2-4: World prices for global oil price (Brent, WTI) and marine fuels (IFO 380, LSFO, MGO) in $/MT (left axis) and $/bbl (right axis)

The data in **Figure 9.2-4** clearly demonstrate the relationship of global oil prices to marine bunker fuels. The Pearson correlation coefficients for marine bunkers and crude oil prices are shown in **Table 9.2-1**. The correlation coefficients show a high degree of correlation between all species in the table, and a strong correlation between Brent and WTI fuel prices and marine bunker prices.

Table 9.2-1. Pearson correlation coefficients between marine bunker prices and crude oil prices

	IFO380	LSFO (0.50% S m/m)	MGO (0.10% S m/m)	Brent	WTI
IFO380	1.000	0.752	0.895	0.866	0.801
LSFO (0.50% S m/m)	0.752	1.000	0.990	0.932	0.875
MGO (0.10% S m/m)	0.895	0.990	1.000	0.961	0.913
Brent	0.866	0.932	0.961	1.000	0.972
WTI	0.801	0.875	0.913	0.972	1.000

While the price differential associated with the transition from 0.50% S m/m fuel to 0.10% S m/m fuels is equivalent to around $95/MT of fuel, the shipping industry has regularly seen volatility in fuel prices greater than that fuel price differential, regularly adjusting freight rates to accommodate fuel price volatility.

9.2.5 Statistical summary of fuel prices

The central fuel prices for 0.50% S m/m fuels and 0.10% S m/m fuels used in this analysis are $344/MT and $443/MT, corresponding to the median values of the common data series available for the two fuel species (**Table 9.2-2**). These prices will be used as the central estimates for modelling voyage costing, freight rate pricing, and commodity price effects.

Table 9.2-2. Statistical summary of marine fuel prices evaluated (inclusive dates)

EMEA USD per tonne	>0.50% S m/m		0.50% S m/m	0.10% S m/m	
	IFO 380		LSFO	MGO/ULSFO	
Date period	2008-04 to 2020-09	**2019-11 to 2020-09**	**2019-11 to 2020-09**	2016-01 to 2020-09	**2019-11 to 2020-09**
Minimum	$ 152	**$ 227**	$ 197	$ 297	$ 297
10th percentile	$ 269	**$ 277**	**$ 263**	$ 409	**$ 363**
25th percentile	$ 342	**$ 317**	**$ 308**	$ 482	**$ 403**
Median	$ 450	**$ 349**	$ 344	$ 579	$ 443
75th percentile	$ 594	**$ 370**	**$ 541**	$ 660	**$ 642**
90th percentile	$ 645	**$ 398**	**$ 608**	$ 709	**$ 666**
Maximum	$ 743	**$ 421**	**$ 666**	$ 777	**$ 710**

9.2.6 Fuel Availability

Sufficient refinery capacity and production exists to meet fleet demand for 0.10% S m/m fuel under the Med SO_X ECA. Available supply is sufficient to meet demand, even considering a range of estimates and growth rates for fleet fuel use. This finding is prior to consideration the additional compliance pathway using EGCS, which may further reduce demand for 0.10% S m/m fuels. Therefore, adoption of EGCS technologies or alternative fuels among vessels where this is economically feasible reinforces the robustness of the primary finding by diversifying demand to include non-compliant petroleum fuels and other fuels with intrinsically lower sulphur content. Projections of excess (or spare) capacity further indicate that supply will continue to be available, perhaps with greater spare capacity for production than previously evaluated in earlier studies.

This analysis frames the fuel availability question at the regional scale, then considers major bunkering countries with ports adjacent to the Mediterranean Sea area, then considers all major bunkering countries, then considers all countries that are major producers of product relevant to supply, then considers world production and production capacity. We evaluate potential fuel availability at each scale, recognising that international shipping depends on world markets for fuel availability in the Mediterranean Sea area.

Figure 9.2-5 shows that refinery capacity to produce gas/diesel[34] fuel is greater than consumption demand (including marine bunkers) at all scales, including among the Mediterranean coastal States. As shown, at the regional scales of the Mediterranean coastal States and inclusive of adjacent neighbouring countries, **Figure 9.2-5** shows that current production of gas/diesel is not sufficient to meet current consumption demand; Mediterranean coastal States that are Contracting Parties to the Barcelona Convention, in fact, import gas/diesel from other countries to satisfy market demand for gas/diesel. In other words, while refineries in these countries have capacity to produce more middle distillates, the economically optimal configuration produces more of other refining products for export, allowing the market to purchase gas/diesel on the global market. This is typical profit-maximising behaviour by refineries in a global petroleum market. **Figure 9.2-6** shows that refinery capacity to produce fuel oil and production of fuel oil exceeds demand, consistent with the by-product status of residual oils. Refinery production of fuel oil fails to meet consumption only under the conditions where bunker estimates are maximised. Combining fuel oil and gas/diesel, both refinery capacity estimates and production statistics demonstrate that supply exceeds consumption demand at all scales except that Mediterranean coastal States that are Contracting Parties to the Barcelona

---

[34] This report uses terminology from IEA statistics that include refinery fuel labels, e.g., gas/diesel. Gas/diesel includes all distillate marine fuels (DM) and distillate non-marine fuels. For the purposes of clarity, IEA reported statistics for gas/diesel do not include natural gas or natural gas products, which are reported in separate data series.

Convention must trade products, as shown in **Figure 9.2-7**. Therefore, sufficient fuel availability of both gas/diesel and fuel oil is available for provision of 0.10% S m/m fuels for the Med SO_X ECA through the combination of distillate fuels, and blended products to product low-sulphur residual fuels.

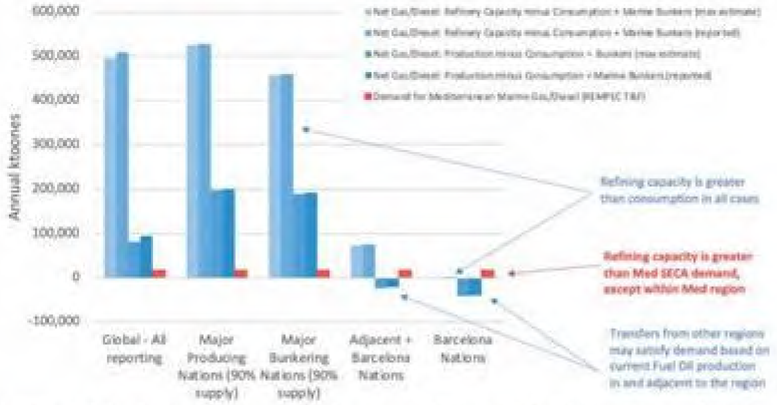


Figure 9.2-5: Net refining capacity to produce gas/diesel is greater than consumption demand, sufficient for Med SO_X ECA supply

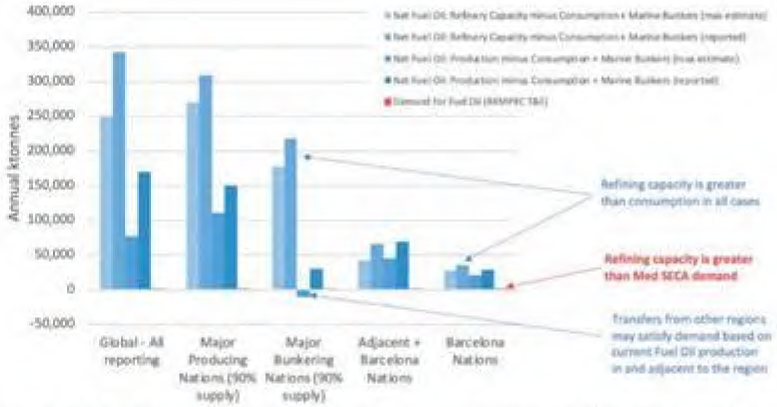


Figure 9.2-6: Net refining capacity for and production of fuel oil exceeds consumption demand, including marine bunkers

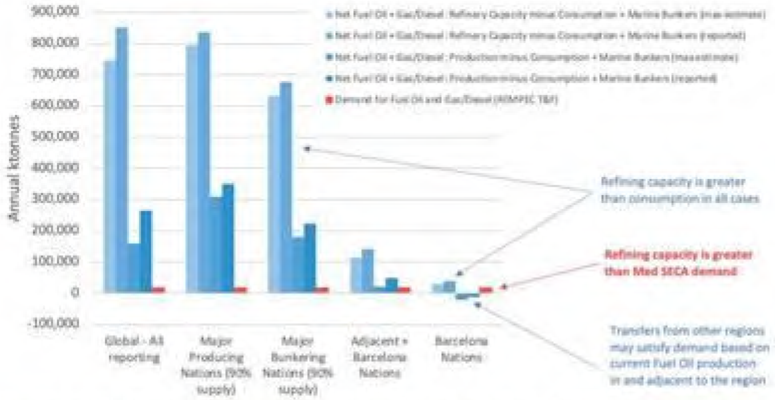


Figure 9.2-7: Net refining capacity for and production of fuel oil and gas/diesel exceeds consumption demand

9.3 Vessel Costs

9.3.1 Exhaust Gas Cleaning Adoption Analysis

EGCSs represent one possible compliance option for the proposed Med SO_X ECA. **Table 9.3-1** indicates that about 5,900 vessels, some 18% of the fleet operating in the Mediterranean Sea area, could adopt EGCSs, 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
EGCSs	5,915	18%
No EGCSs	27,248	82%

Table 9.3-2 shows the expected EGCS 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 EGCSs in the Mediterranean Sea area, and this number is not expected to change under a 1-year investment horizon. If EGCS costs are amortised over 10 years, the results show that EGCS 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 EGCS and save the fleet over $260 million.

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

	Feasible EGCS Use, Capital included		
Investment years	**Proposed Med SO_X ECA Compliance Savings ($Billions)**	**Number of EGCSs**	**Percent of Fleet Using EGCSs**
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 EGCS may be feasible for vessels that spend a greater amount of time inside the Mediterranean Sea area (and/or other SECA region). EGCSs 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 EGCS scenario, 5,900 vessels (~18% of the Mediterranean fleet) might be expected to invest in EGCSs, while most of the fleet (82%) may determine that fuel switching remains the least cost option.

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

Vessel Type	No EGCS		EGCS Adoption	
	Average Operating Hours [h] in the Mediterranean	Ship Count	Average Operating Hours [h] in the Mediterranean	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**

Efforts continue to investigate potential negative effects of EGCS discharges, particularly untreated effluents, on the marine environment and biota. These negative impacts may result in near-term and long-term economic effects by modifying ecosystem balances. Publicly available studies are providing emerging evidence that is confirming concerns about untreated effluents from EGCSs. Studies indicate that EGCS may improve the air quality in harbour cities and at sea but will shift atmospheric pollution to the marine water body (Schmolke et al., 2020). **"While a single ship with an** installed scrubber may pose limited, local risk to marine ecosystem health, a global shipping **community employing scrubbers to meet air emission limits is of serious concern"** (Hassellöv et al., 2020). EGCS washwater is found to be acidic with elevated concentrations of metals and other contaminants (Teuchies, Cox, Van Itterbeeck, Meysman, & Blust, 2020). Increased acidification, i.e., pH decreases, are recognized, with larger pH changes occurring in areas of high traffic density on the scale of climate-related pH changes (Dulière, Baetens, & Lacroix, 2020). From a cost-methodology perspective, costs are not well differentiated between closed- and open-loop EGCS systems. The above adoption rates use cost estimates that may prove optimistic if future EGCS require more costly design for closed- or hybrid-operations. Therefore, there is no indication that this quantitative approach to evaluating socio-economic impacts would produce findings of greater adoption rates.

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 SO_X 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 SO_X 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 SO_X ECA Cost with LNG Alternative ($ Billion per year)**	**Proposed Med SO_X 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 SO_X ECA, and the proposed Med SO_X ECA with EGCSs. 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 SO_X 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 SO_X ECA Average Cost	Proposed Med SO_X ECA + EGCS 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

Criterion 3.1.8 of Appendix III to MARPOL Annex VI requires a description of the relative costs of reducing emissions from ships when compared with land-based controls. This section presents results from international experience with pollution abatement control costs. Detailed information on control costs is not available on a country-by-country basis, and analysis of results from international studies show that the range of expected control costs, on a per-unit pollution abated basis, are generally in good agreement, indicating that international experiences with control costs are similar.

9.4.1 Estimates of Cost Effectiveness

There is a large variety of technology and operational choices available for pollution abatement. For sulphur abatement, these options fall under four broad categories: the use of low sulphur fuel, fuel desulphurisation, combustion processes, and desulphurisation of the exhaust gasses. The costs of these technologies, and the associated emission reductions, may be estimated in a range of ways. First, engineering estimates look specifically at technology and operating costs, and associated changes in emissions levels. Engineering approaches are useful when applied to specific plants but can raise issues when applied broadly to an industry, due to the many and varied compositions of individual plants. Another method of estimating environmental regulatory compliance costs is to survey **industry, asking facilities' their direct capital and operational costs to reduce pollution. Again, this** methodology is challenged, as issues with sample size, response rate, and difficulty in accurately separating costs associated with different pollution species challenge the results.

A 1999 report by IIASA for the European Commission (European Commission 1999), estimates that the costs of abating SO_2 range from $586 to $860/MT SO_2. Recent work in China (Zhang et al. 2020) estimates potential emissions abatement of 19.2 million tonnes of SO_2 from switching to renewable energy technologies at a cost of 92.5 billion CNY (Chinese Yuan), or 4,818 CNY/MT SO_2 abated, equivalent to around $730/MT SO_2 abated.

The United States Environmental Protection Agency (EPA) is in the process of updating their Air Pollution Control Cost Manual. Section 5 of that report identifies the most recently available technologies and costs for removing acidifying gases, such as SO_X, from emissions. The U.S. EPA manual provides an engineering example of the cost effectiveness, akin to the MAC, of a wet FGD (flue gas desulphurisation) unit on a 500 MW coal facility at $681/MT SO_2 abated, and $945/MT SO_2 for a dry FGD unit on a similar sized plant. For a wet-packed tower absorber the U.S. EPA report estimates $636/MT SO_2. Notably, these engineering examples are just that, calculations for specific example facilities, but they align well with other literature estimates to provide an additional reference for the abatement costs.

9.4.2 Shadow Prices of Pollution

Another approach to estimating costs of pollution controls is to measure indirect and revealed costs. Using econometric techniques to identify revealed rather than stated pollution abatement costs, abatement costs which are more indicative of the total cost of regulatory compliance may be estimated. One such approach that is widely applied is to use shadow prices.

The shadow price is the opportunity cost of incremental reductions in pollutant species in terms of reductions in production output. Shadow prices in the USA for SO_2 abatement from coal power plants range from $1,806 - $18,018 / MT SO_2 (Swinton 1998; Färe et al. 2005) and from $2,044 - $21,749 / MT SO_2 for industrial processes in the USA, Korea and China (Coggins and Swinton 1996; Turner 1995; Boyd, Molburg, and Prince 1996; Lee, Park, and Kim 2002; Tu 2009; He and Ou 2017).

CE Delft publishes a Shadow Price Handbook (CE Delft 2010) which finds SO_2 shadow prices of $6,461 - $12,943 / MT SO_2 and PM_{10} **shadow prices of €2,300 –** 50,000 / MT PM_{10}. The CE Delft Environmental Prices Handbook estimates that the environmental cost, not the abatement cost, of SO_2 **pollution is €**24,900 / MT SO_2, while the environmental cost of $PM_{2.5}$ **is €79,500 / MT SO_2** (CE Delft 2018), values which well-exceed the land-side abatement costs.

A 2014 study of OECD economies found that the shadow prices for PM_{10} abatement were highly variable, ranging from $5,079/ MT PM_{10} to $295,832 / MT PM_{10} (in 2005$), with a mean and median of $99,500 / MT PM_{10} and $82,161 / MT PM_{10}, respectively (Dang and Mourougane 2014).

Table 9.4-1. Marginal SO_2 abatement costs ($/MT) adapted from Mekaroonreung and Johnson (2012)

Study	Average Price of SO_2 abatement ($/ton)
(Färe et al. 2005)	76 – 142
(Mekaroonreung and Johnson 2012)	201 – 343
(Coggins and Swinton 1996)	292
(EPA 2009) - Stationary	300 – 6,000
(Mekaroonreung and Johnson 2012)	509 – 2,020
(European Commission 1999)	586 – 860
(Zhang et al. 2020)	730
(Turner 1995)	826
(Färe et al. 2005)	1,117 – 1,974
(Boyd, Molburg, and Prince 1996)	1,703
(Lee, Park, and Kim 2002)	3,107
(EPA 2009) – On-Road	6,400 – 6,600
(CE Delft 2010)	6,461 – 12,943

Table 9.4-1 shows the range of identified SO_2 abatement costs from the literature, discussed above. The range in abatement costs is wide, ranging from $76/MT SO_2 abated to $6,600/MT SO_2 abated. Ranges this wide are consistent with the literature, as they represent a suite of technology and operational measures possible to reduce SO_2 emissions, as well as a suite of sectors, including

stationary and mobile sources, for which abatement technologies can vary greatly.

9.4.3 Estimates of Cost-Effectiveness from Prior ECA Applications

The North American ECA application (EPA 2009) lists a set of land-based source controls. The dates of the control costs span a wide range, and so may be best thought of as descriptive rather than prescriptive of current abatement costs, which are likely different due to policy changes in recent years and technology improvements. The report list costs of between \$11,000 – \$16,000 / MT PM_{10} (2006\$) for non- and on-road diesel and gasoline engine applications and a range of \$4,000 to \$46,000 / MT PM_{10} (2006\$) for stationary diesel engines. Locomotive and harbour craft costs range from \$9,300 / MT PM_{10} (2006\$) for new builds up to \$50,000 / MT PM_{10} (2006\$) for retrofits. SO_X emission abatement costs estimated by the U.S. EPA are generally lower than PM_{10} abatement costs. Stationary source SO_X abatement costs range from \$300 to \$6,000 / MT SO_X, whereas on-road SO_X abatement costs are estimated at \$6,400 / MT SO_X for heavy-duty diesel engines, and \$6,600 / MT SO_X for light duty gasoline/diesel engines.

9.4.4 Cost Effectiveness of the Med SO_X ECA

Findings from independent peer reviewed and grey literature find that ranges for PM_{10} and SO_X abatement costs are broad and overlapping. The costs assigned to removal of any single species (of either SO_X or PM) cannot be treated as fully independent, as PM and SO_X pollutant species are entwined. Therefore, though the costs are attributed to a single pollutant, in reality there will likely be co-reductions for both SO_X and PM with any abatement measure. As shown in **Table 9.4-2**, the marginal abatement costs of the proposed Med SO_X ECA are aligned with the SO_X and PM marginal abatement costs for both the base case, and the proposed SO_X ECA with EGCSs.

Table 9.4-2. Cost effectiveness of the Med SO_X ECA from the Technical and Feasibility Study

Benefit Type	**MARPOL VI**	**Proposed Med SO_X ECA**	**Proposed Med SO_X ECA with EGCSs**
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 $PM_{2.5}$

The Technical and Feasibility Study to examine the possibility of designating the Mediterranean Sea, or parts thereof, as sulphur oxides (SO_X) emission control area(s) (ECA(s)) under MARPOL Annex VI (Corbett & Carr, 2019), hereinafter referred to as the Technical and Feasibility Study, found that the proposed Med SO_X ECA has a cost effectiveness of around \$8,750 - 13,400/MT SO_X abated (**Table 9.4-2**). For comparison, the North American ECA cost effectiveness was estimated at \$1,200/MT SO_X. However, it must be remembered that the North American ECA was implemented at a time when the global fuel sulphur cap was 3.50% S m/m, and thus step down to 0.10% S m/m represented a larger step than the proposed Med SO_X ECA.

The benefit-cost ratio of the proposed Med SO_X ECA estimated in the Technical and Feasibility Study is \$1.58 million per avoided mortality. Parallel studies from France (Rouïl et al. 2019) and the European Commission (Cofala et al. 2018) find benefit-cost ratios of 3 and 4.8 respectively. The cost effectiveness of the proposed Med SO_X ECA is at the upper end of many of the stationary source abatement costs identified. However, as noted by the benefit cost-ratios, the health and environmental benefits of the proposed Med SO_X ECA are far larger than the costs.

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. **Table 9.5-1**, **Figure 9.5-1**, and **Figure 9.5-2** summarise the results. For example, the proposed Med SO_X ECA without EGCSs is shown to cost about $1.58M per avoided annual death, if all the costs of the proposed Med SO_X ECA are assigned to the avoided mortality estimates. This cost comes down to $1.035M/avoided death under a EGCS scenario.

Table 9.5-1. Cost-effectiveness of quantified benefits

Benefit Type	MARPOL VI	Proposed Med SO_X ECA	Proposed Med SO_X ECA with EGCSs
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**

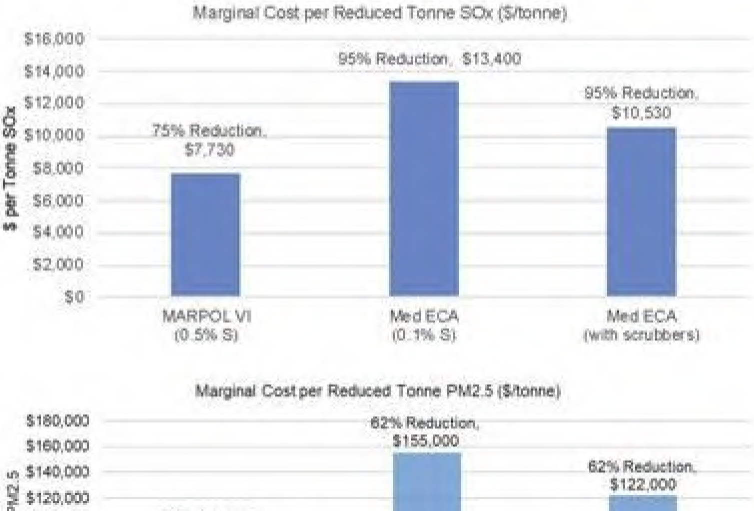


Figure 9.5-1: Control cost-effectiveness of SO_X and $PM_{2.5}$ reductions based on prices in this document

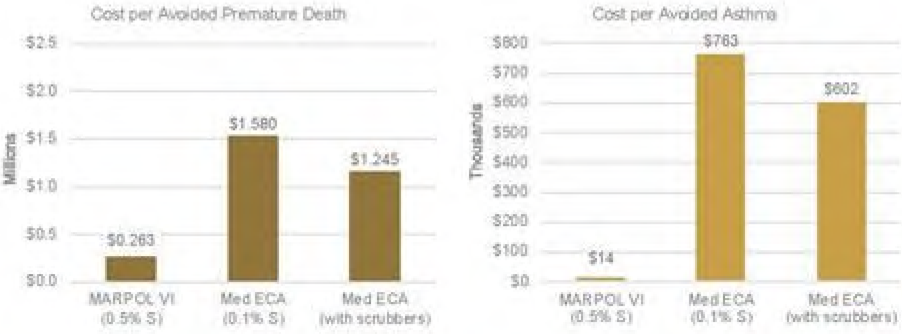


Figure 9.5-2: Cost-effectiveness of health outcomes in terms of avoided premature mortality and avoided childhood asthma

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 analysis 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*), as described in **Figure 9.5-3**.

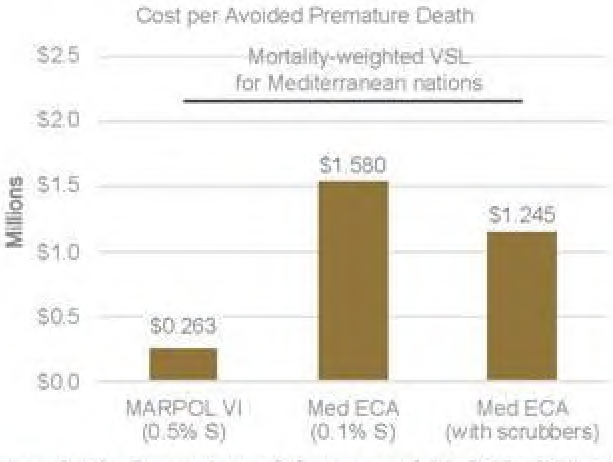


Figure 9.5-3: Comparison of the proposed Med SO_X ECA cost per avoided mortality and the Mediterranean weighted VSL

10 Economic Impacts on Shipping Engaged in International Trade

10.1 Marine freight and passenger rates

10.1.1 Freight rate assessment

Cargo-based freight rates include voyage-based fuel costs and much more. Cargo freight rates represent the cost from origin to destination including cargo handling, storage during transit, intermediate mode transfers, and mode. Voyage fuel costs are divided by the cargo load (in net tons or in net TEUs, as appropriate). The cost model multiplies by two (2) this value to account for fuel costs associated with an empty return trip. Sensitivity analysis can adjust this empty-return adjustment between a minimum value of zero (fully loaded revenue back-haul voyage) and two (no revenue back-haul). The use of the empty return adjustment, therefore, ensures more robust analysis (e.g., estimate cost impacts that may better test the null hypotheses).

Where a scenario depicts a port-to-port cargo movement, these approaches describe the net costs based on voyage costs and transfer costs. Where a scenario depicts origin-to-destination cargo movements that require land transport modes, the model would sum costs across the water leg and the land mode leg(s) of the route. The model provides generalised rates in costs per cargo distance (cargo tonne-kilometre or t-km). These generalised rates allow for efficient application to route scenarios and facilitate sensitivity analysis.

Cargo rates are derived from the Maritime Transport Costs (MTCs) statistics database maintained by the Statistics and Data Directorate of the Organisation for Economic Co-operation and Development (OECD).

"*The Maritime Transport Costs (MTC) database contains data from 1991 to the most recent available year of bilateral maritime transport costs. Transport costs are available for 43 importing countries (including EU15 countries as a custom union) from 218 countries of origin at the detailed commodity (6 digit) level of the Harmonized System 1988.*"

The database is built on data for "*a combination of shipping rates actually charged data with the UN Comtrade statistics have been used to estimate actual transport costs at the product level. The shipping rates have been collected from selected sources, such as: The United Nations Conference on Trade and Development (UNCTAD), Containerisation International, Drewry Shipping Consultants, International Grains Council (IGC), and the Baltic Exchange*".

For this work, MTCs data were extracted from the MTC database for agriculture, manufacturing, and raw material commodities for the countries and country groups listed in **Table 10.1-1**. We attempted to include all available data for Mediterranean coastal States that are Contracting Parties to the Barcelona Convention, or their representative country group.

Table 10.1-1. List of countries (and EU 15 country group) for which MTC data was queried

Countries or country group	
Albania	Malta
Algeria	Montenegro
Egypt	Slovenia
European Union (EU 15)	Syrian Arab Republic
Israel	Tunisia
Lebanon	Turkey
Libya	

Using the MTCs reported by OECD.Stat, we updated reported freight rates to 2020 dollars and converted the units to costs per tonne-km so that these could be applied to route distances to yield waterborne freight transport costs. **Figure 10.1-1** presents the median freight rates (dash markers), in box-and-whisker plots representing 25th and 75th percentiles (boxes) and 10th and 90th percentiles (whiskers). **Table 10.1-2** presents the average freight rate across by selected commodities in the extracted data. **Table 10.1-3** presents a statistical summary of freight rates including upper and lower ranges. The figure illustrates that containership freight rates are typically higher than bulk ship freight rates (although there is overlap), and that clean bulk rates are higher than dirty bulk rates. This sets an expectation that commodities with higher freight rates may be less influenced than commodities associated with lower freight rates by voyage costs (or the influence of voyage fuel cost differentials).

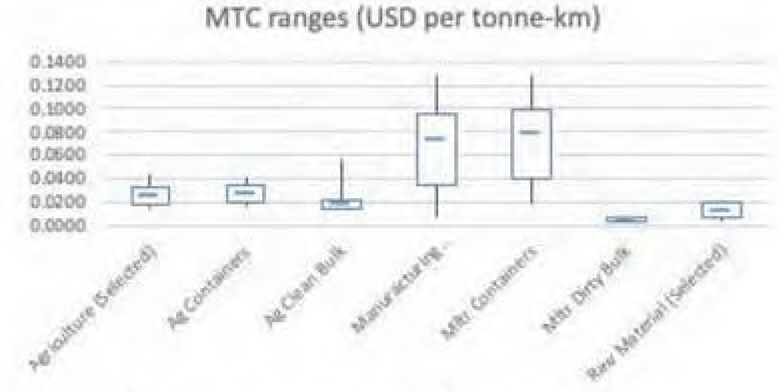


Figure 10.1-1: Plot of MTCs for commodity groups and vessel types

Table 10.1-2. Summary of MTCs by type of vessel for a selected range of commodities

	MTC by type of vessel (average USD per tonne-km)		
Commodity	**Clean bulk**	**Containers**	**Dirty bulk**
General Agriculture	**0.0397**	**0.0299**	
07: Edible vegetables and certain roots and tubers		0.0257	
08: Edible fruit, nuts, peel of citrus fruit, melons		0.0354	
09: Coffee, tea, mate, and spices		0.0278	
10: Cereals	0.0246		
12: Oil seed, oleagic fruits, grain, seed, fruit, etc, ne	0.0549		
19: Cereal, flour, starch, milk preparations and products		0.0286	
22: Beverages, spirits, and vinegar		0.0211	
General Manufacturing		**0.0794**	**0.0060**
31: Fertilizers			0.0060
47: Pulp of wood, fibrous cellulosic material, waste etc		0.0164	
48: Paper & paperboard, articles of pulp, paper, and board		0.0308	
52: Cotton		0.0486	
61: Articles of apparel, accessories, knit or crochet		0.1252	
62: Articles of apparel, accessories, not knit or crochet		0.1501	
64: Footwear, gaiters and the like, parts thereof		0.1483	
73: Articles of iron or steel		0.0354	
84: Nuclear reactors, boilers, machinery, etc		0.0522	
85: Electrical, electronic equipment		0.0616	
87: Vehicles other than railway, tramway		0.0702	
95: Toys, games, sports requisites		0.0873	
General Raw material			**0.0128**
25: Salt, sulphur, earth, stone, plaster, lime, and cement			0.0116
72: Iron and steel			0.0142

Table 10.1-3. Sensitivity analysis of MTCs by commodity group and vessel type

USD per tonne-km	**Agriculture**			**Manufacturing**			**Raw Materia l**
	Combined	Containers	Clean Bulk	Combined	Containers	Dirty Bulk	
Minimum	0.0100	0.0100	0.0132	0.0000	0.0000	0.0042	0.0023
10th percentile	0.0145	0.0172	0.0139	0.0075	0.0188	0.0042	0.0040
25th percentile	0.0180	0.0199	0.0152	0.0343	0.0393	0.0043	0.0073
Median	0.0253	0.0266	0.0173	0.0740	0.0784	0.0060	0.0128
75th percentile	0.0334	0.0339	0.0213	0.0957	0.0982	0.0074	0.0199
90th percentile	0.0434	0.0421	0.0570	0.1287	0.1289	0.0086	0.0214
Maximum	0.2461	0.1044	0.2461	0.4348	0.4348	0.0096	0.0233

10.1.2 Passenger rate assessment

Passenger rates for marine transportation in this work refers to ferry service. We do not evaluate cruise vessel passenger service because those excursions compare more with hospitality and vacation travel. Typical factors in a mode choice context include:

- **Waterborne transport of passengers is typically a "premium mode", priced higher than road** travel by personal vehicle or transit. (Perhaps priced similarly or higher than rail.)
- Waterborne passenger transport is often a complement to rail and road travel, offering connectivity via Ro-Pax. (Waterborne passenger transport rarely is competing with land-side modes.)
- Costs for passenger travel per unit (per passenger) is typically greater than cost per unit cargo. Therefore, the expected price effect from higher priced 0.10% S m/m fuel would necessarily be smaller than the price effects evaluated per unit cargo.

Therefore, analysis is focused on remote areas and island communities where modal shift is not an option for remote or island areas, as intermodal connections do not exist, or are limited. As such, all goods and passenger movements must occur either by sea or by air. Air transportation costs are higher than all other modes, and for many goods transport by air is impractical.

Passenger ferries, including RoPax vessels, operate along numerous routes in the Mediterranean Sea, as shown in **Figure 10.1-2** and **Figure 10.1-3**. As shown by the intensity of emissions in the two figures, RoPax vessels are far higher emitters of CO_2, and therefore consume greater quantities of fuel.

This work analyses a set of ten ferry routes in the Mediterranean Sea, including four national and two international routes. All ferry routes analysed are between the mainland and islands, with one additional coastwise route. One-way prices for a single adult booking deck passage were retrieved from published fare schedules for each of the routes shown in **Table 10.1-4**. The RoPax vessels serving each route were identified and representative vessel categories in the final report of the Fourth IMO GHG Study 2020 (MEPC 75/7/15) (Faber et al., 202AD), hereinafter referred to as the Fourth IMO GHG Study 2020, for fuel consumption were matched with ferry vessel characteristics (e.g., gross tons).

Table 10.1-4. Ferry routes, distances, prices, number of passengers

Ferry Route	Distance (NM)	One-way cost (EUR)	Cost (EUR/p-km)	Cost (USD/p-km)	Passengers
Naples - Cagliari	282	42.41[35]	**€ 0.0812**	$0.0967	1,845
Barcelona - Porto Torres	307	35[36]	**€ 0.0616**	$0.0733	2,794
Marseille - Algiers	421	198[37]	**€ 0.2539**	$0.3023	2,400
Piraeus - Paros	107	33[38]	**€ 0.1665**	$0.1982	1,715
Piraeus - Kos	203	52.5[45]	**€ 0.1396**	$0.1662	2,000
Piraeus - Rhodes	256	61.5[45]	**€ 0.1297**	$0.1544	2,000
Valetta - Pozzallo	53	68[39]	**€ 0.6928**	$0.8247	1,120
Mykonos - Naxos	26	14.5[40]	**€ 0.3011**	$0.3585	2,400

---

[35] https://en.tirrenia.it/ferry-sardinia/naples-cagliari/index.html.
[36] https://www.grimaldi-lines.com/.
[37] https://www.corsicalinea.com/.
[38] https://www.ferryhopper.com/.
[39] http://www.virtuferries.com

Famagusa - Mersin	112	42.93[41]	€ 0.2070	$0.2464	343
Barcelona - Genoa	352	49[42]	€ 0.0752	$0.0895	2,230

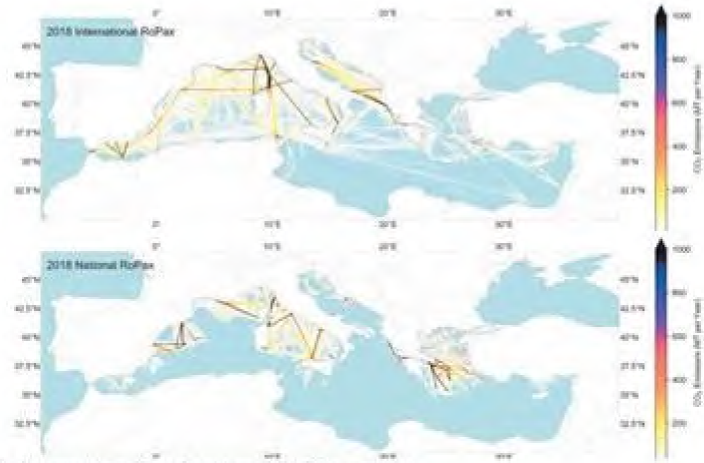


Figure 10.1-2: International and national RoPax activity

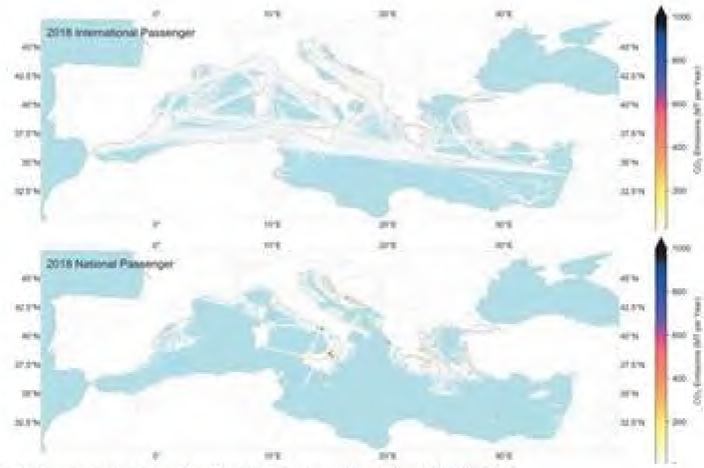


Figure 10.1-3: International and national passenger vessel activity

10.2 Land-side freight and passenger rates

Operating costs for land-side modes vary by mode, by country and by route. Using an analysis of transportation operating costs in the European Union and the U.S. produced by research collaboration funded by the European Commission (Maibach, Peter, et al., 2006), this analysis updated costs to 2020 equivalents in U.S. dollars and selected costs representative of Mediterranean coastal States for which this analysis provided data (**Table 10.2-1**).

---

[40] http://www.bluestarferries.com.
[41] https://www.akgunlerbilet.com/.
[42] https://www.gnv.it.

Table 10.2-1. Average costs per passenger-km (rail), freight ton-km (rail, LDV and HDV road)

	Rail		Road			
Country	**Passenger (in 2020 USD/p-km)**	**Freight (in 2020 USD/t-km)**	**Buses (in 2020 USD/p-km)**	**Coaches (in 2020 USD/p-km)**	**LDV freight (in 2020 USD/t-km)**	**HDV freight (in 2020 USD/t-km)**
Greece	\$0.3410	\$0.3875	\$0.0930	\$0.0930	\$4.2160	\$0.1395
Spain	\$0.1860	\$0.1085	\$0.1395	\$0.1085	\$6.7115	\$0.1860
France	\$0.3100	\$0.0930	\$0.2325	\$0.2325	\$9.2535	\$0.2635
Italia	\$0.3100	\$0.1550	\$0.1705	\$0.1395	\$8.5250	\$0.1860
Slovenia	\$0.1240	\$0.1085	\$0.0465	\$0.0310	\$4.6190	\$0.2015
EU 25 *	\$0.2635	\$0.1705	\$0.1705	\$0.1395	\$7.8275	\$0.2170

	Rail		Road			
Country	**Passenger (in 2020 USD/p-km)**	**Freight (in 2020 USD/t-km)**	**Buses (in 2020 USD/p-km)**	**Coaches (in 2020 USD/p-km)**	**LDV freight (in 2020 USD/t-km)**	**HDV freight (in 2020 USD/t-km)**
Max	\$0.3875	\$0.4495	\$0.2000	\$0.1900	\$12.9270	\$0.2945
Median	\$0.3100	\$0.1550	\$0.1100	\$0.1000	\$6.8045	\$0.2015
Mean	\$0.2550	\$0.2015	\$0.1064	\$0.0968	\$6.9680	\$0.2071
Min	\$0.0620	\$0.0620	\$0.0200	\$0.0100	\$2.4335	\$0.1085

10.3 O-D Pair Distances

This section discusses the set of route distances between identified Origin and Destination (O-D) pairs. O-D pairs were selected based on a set of criteria, first evaluating the level of observed marine traffic between origin and destination based on AIS observations, and second evaluating the economic viability of a route based on published commercial schedules between origin and destination, either independently or as part of a voyage string, calling at several other ports along the way.

Route distances for water, rail, and road routes are shown in **Table 10.3-1**. All O-D pairs were selected as having a viable water route between the two ports, however not all instances had viable rail or road connections between the ports. in cases where a viable road or rail route was unavailable the distance is shown as not available (NA). O-D routes include short-sea routes, island country routes, intra-Mediterranean routes, and routes transiting the Mediterranean. Note that while O-D port pairs are identified, these routes are intended to be representative and not deterministic or prescriptive. The routes inside, to, through, and around the Mediterranean Sea are many and varied, with the total set of O-D pairs being impossible to model.

Table 10.3-1. Water, road, and rail distances between origin and destination pairs (km)

		Water Distance (km)				
Origin	Destination	In-Med	Ex-Med	Total	Rail Distance (km)	Road Distance (km)
Port Said	Gibraltar	3,591	0	3,591	N/A	7,431
Algeciras	Fos-sur-Mer	1,367	0	1,367	1,997	1,781
Algeciras	Koper	3,126	0	3,126	3,283	3,007
Genoa	Gioia Tauro	909	0	909	1,277	1,348
Koper	Malta Freeport	1,422	0	1,422	N/A	1,955
Koper	Singapore	2,471	9,325	11,795	N/A	12,987
Port Said	Koper	2,471	0	2,471	N/A	3,498
Lisbon	Jeddah	3,591	1,917	5,508	N/A	8,602
Piraeus	Limassol	983	0	983	N/A	2,633
Port Said	Beirut	432	0	432	N/A	710
Shanghai	Rotterdam	3,591	15,964	19,555	15,267	10,881
Shanghai	Fos-sur-Mer	2,895	13,386	16,281	15,983	11,671
Port Said	Fos-sur-Mer	2,895	0	2,895	N/A	4,413
Singapore	New York	3,591	15,177	18,768	N/A	N/A
Tangier	Oran	485	0	485	1,022	745
Tangier	Tunis	1,515	0	1,515	2,531	2,221
Thessaloniki	Piraeus	500	0	500	597	580
Xiamen	Beirut	432	12,323	12,755	13,966	N/A

10.4 Commodity Prices

Food commodity prices are available from UNCTAD, as shown in **Table 10.4-1**. These commodity prices represent a range of common commodities at different economic endpoints, from raw materials, to manufacturing, building, and textile inputs, to food prices. Commodities are shown in their unit prices in USD and converted to price per metric tonne for the purposes of unit-based comparisons between commodities. Unit mass conversions are straightforward, and the mass of a 91 cm x 182 cm x 4 mm sheet of lauan plywood was assumed to be 3 kg.

Table 10.4-1. Selected food, beverage, and commodity prices ($2019) from UNCTAD

Commodity	Unit	Unit Price	Price ($/MT)
Salmon, fresh, fish-farm bred, export price, Norway	($/kg)	6.94	$6,940.0
Bananas, Central and South America, FOT, U.S. import price	($/kg)	1.14	$1,140.0
Coffee, other mild Arabicas, ex-dock EU	(¢/lb.)	125.52	$2,767.2
Tea, Kenya Mombasa/Nairobi, auction price	($/kg)	2.2	$2,200.0
Tobacco, unmanufactured, U.S. import unit value	($/MT)	4578.65	$4,578.7
Phosphate rock, Khouribga, 70% BPL, contract, FAS Casablanca	($/MT)	87.95	$88.0
Zinc, Prime Western, delivered, North America	(¢/lb.)	124.13	$2,736.6
Rubber, TSR 20, New York CIF	($/MT)	1662.17	$1,662.2
Plywood, Africa & SE Asia, Lauan, 3-ply, 91 cm x 182 cm x 4 mm, wholesale Tokyo*	(¢/sheet)	500.93	$1,669.8
Fine wool, 19 Micron, AWEX auction price, Australia	($/MT)	14183.23	$14,183.2

** assumes one 4-mm plywood sheet = 3 kg*

10.5 Socio-economic effects modelling

This section describes the methodological approach for describing fuel consumption and changes in fuel costs, identifying major shipping lanes and corridors, and evaluating mode shift potential and economic costs affect marine freight rates, provide economic signal related to potential mode shift.

Methods in this analysis are grounded in economic principles that:

i) cost changes may be reflected in the rates that suppliers present to demanders, i.e., supplier costs are passed on to the buyers embedded within market prices; and
ii) demand may be affected where the price signal changes along with demand elasticity for transport service and/or for the delivered product.

There are three stages of analysis available to evaluate socio-economic impact of price changes resulting from adoption of Med SO_X ECA fuels complying with 0.10% S m/m limits. This section describes each of these three stages. First, the relative effect of fuel price is evaluated in terms of voyage costs, which engages the EERA cost model (**Section 10.5.1**). The second stage considers how freight rates, which generally are inclusive of services and transport in addition to waterborne voyage costs, may be impacted by changes in voyage costs. To do this, we assemble published data on freight rates and evaluate how voyage costs are reflected in freight rates (**Section 10.5.2**). Third, freight rates embedded in the purchase prices of a commodity or product need to be evaluated for potential direct change in product prices and potential for indirect effects on consumption demand (**Section 10.6**).

10.5.1 Voyage cost evaluation

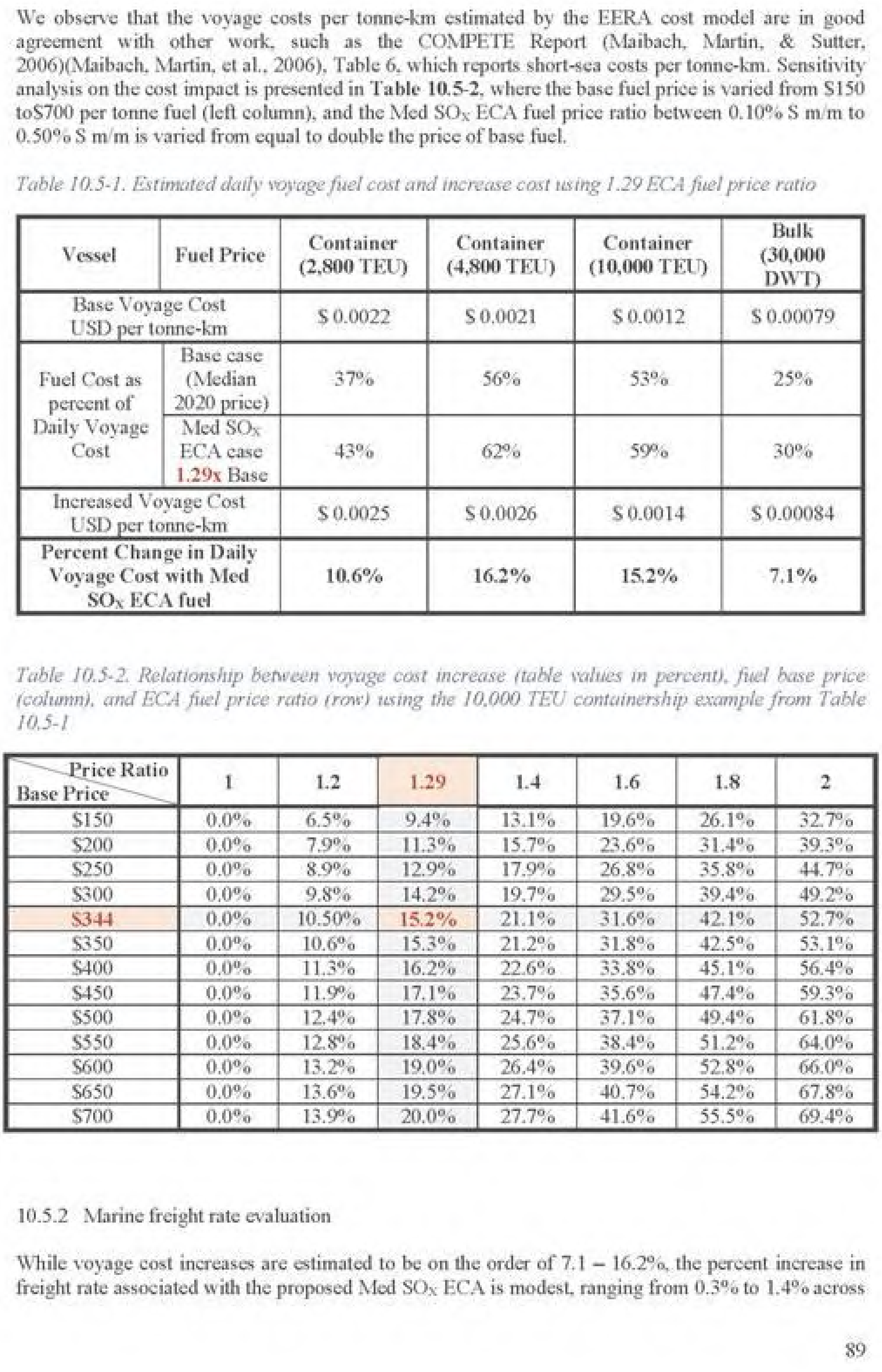
EERA applied its cost model for vessel and alternative mode costs under changing fuel cost scenarios (Winebrake et al., 2010)[43][44]. Evaluating changing fuel costs for marine transport enables comparison with cost statistics for land-based transportation modes including truck and rail transportation.

Fuel consumption and fuel price data are used in the cost model to inform cost-based freight rates. Marine fuels can account for 30-50% of voyage costs depending on vessel capital financing costs. Marine fuels have also shown a large amount of volatility in recent years, largely tied to volatility in crude oil prices. For road freight, fuel accounts for around 20-25% of truck trip costs[45], and for about 40-45% of rail costs[46]. In addition, freight rates based on transportation costs would include per-cargo based allocation of transfer costs related to loading/unloading (cargo handling) and storage; demand-premium freight rates would be higher than cost-based freight rates. Also, freight rates vary by commodity based on cargo densities, utilisation of payload space, perishability, etc. Importantly, including more cost elements reduces the fuel-price effects. Fuel prices reported in **Section 9.2.5** are applied in a *Base Case* (using 0.50% S m/m fuel prices) and the *Med SO_X ECA Case* (using 0.10% S m/m fuel prices). This incremental fuel cost is then added to the estimated voyage costs to estimate new voyage cost under Med SO_X ECA conditions.

Using a fuel price ratio of 1.29 (representing a 29% difference in observed prices between 0.50% S m/m and 0.10% S m/m fuels during the latter months of 2020), typical fuel costs represent about 22% to 38% of daily voyage costs for containerships and less for bulk ships (**Table 10.5-1**).

---

[43] https://www.epa.gov/regulations-emissions-vehicles-and-engines/study-impacts-compliance-eca-fuel-sulfur-limits-us.
[44] https://www.epa.gov/regulations-emissions-vehicles-and-engines/designation-north-american-emission-control-area-marine#Great-lakes.
[45] https://ec.europa.eu/jrc/sites/jrcsh/files/jrc114409.pdf.
[46] https://ec.europa.eu/ten/transport/studies/doc/compete/compete_report_en.pdf and related documents https://ec.europa.eu/transport/themes/infrastructure/studies/ten_t_en.



We observe that the voyage costs per tonne-km estimated by the EERA cost model are in good agreement with other work, such as the COMPETE Report (Maibach, Martin, & Sutter, 2006)(Maibach, Martin, et al., 2006), Table 6, which reports short-sea costs per tonne-km. Sensitivity analysis on the cost impact is presented in **Table 10.5-2**, where the base fuel price is varied from $150 to$700 per tonne fuel (left column), and the Med SO_X ECA fuel price ratio between 0.10% S m/m to 0.50% S m/m is varied from equal to double the price of base fuel.

Table 10.5-1. Estimated daily voyage fuel cost and increase cost using 1.29 ECA fuel price ratio

Vessel	Fuel Price	Container (2,800 TEU)	Container (4,800 TEU)	Container (10,000 TEU)	Bulk (30,000 DWT)
Base Voyage Cost USD per tonne-km		$ 0.0022	$ 0.0021	$ 0.0012	$ 0.00079
Fuel Cost as percent of Daily Voyage Cost	Base case (Median 2020 price)	37%	56%	53%	25%
	Med SO_X ECA case 1.29x Base	43%	62%	59%	30%
Increased Voyage Cost USD per tonne-km		$ 0.0025	$ 0.0026	$ 0.0014	$ 0.00084
Percent Change in Daily Voyage Cost with Med SO_X ECA fuel		**10.6%**	**16.2%**	**15.2%**	**7.1%**

Table 10.5-2. Relationship between voyage cost increase (table values in percent), fuel base price (column), and ECA fuel price ratio (row) using the 10,000 TEU containership example from Table 10.5-1

Price Ratio / Base Price	1	1.2	1.29	1.4	1.6	1.8	2
$150	0.0%	6.5%	9.4%	13.1%	19.6%	26.1%	32.7%
$200	0.0%	7.9%	11.3%	15.7%	23.6%	31.4%	39.3%
$250	0.0%	8.9%	12.9%	17.9%	26.8%	35.8%	44.7%
$300	0.0%	9.8%	14.2%	19.7%	29.5%	39.4%	49.2%
$344	0.0%	10.50%	15.2%	21.1%	31.6%	42.1%	52.7%
$350	0.0%	10.6%	15.3%	21.2%	31.8%	42.5%	53.1%
$400	0.0%	11.3%	16.2%	22.6%	33.8%	45.1%	56.4%
$450	0.0%	11.9%	17.1%	23.7%	35.6%	47.4%	59.3%
$500	0.0%	12.4%	17.8%	24.7%	37.1%	49.4%	61.8%
$550	0.0%	12.8%	18.4%	25.6%	38.4%	51.2%	64.0%
$600	0.0%	13.2%	19.0%	26.4%	39.6%	52.8%	66.0%
$650	0.0%	13.6%	19.5%	27.1%	40.7%	54.2%	67.8%
$700	0.0%	13.9%	20.0%	27.7%	41.6%	55.5%	69.4%

10.5.2 Marine freight rate evaluation

While voyage cost increases are estimated to be on the order of 7.1 – 16.2%, the percent increase in freight rate associated with the proposed Med SO_X ECA is modest, ranging from 0.3% to 1.4% across the median estimates, depending on commodity (**Table 10.5-3**). The effect for specific commodities can vary more widely within the range of prices observed in the commodity group, as illustrated in **Table 10.5-4**.

Table 10.5-3. Percent increase in MTCs from higher fuel costs by commodity group and vessel type

USD per tonne-km	Agriculture			Manufacturing			Raw Material
	Combined	Containers	Clean Bulk	Combined	Containers	Dirty Bulk	
10th percentile	2.5%	2.1%	0.4%	4.9%	1.9%	1.3%	1.4%
25th percentile	2.0%	1.8%	0.4%	1.1%	0.9%	1.3%	0.8%
Median	1.4%	1.4%	0.3%	0.5%	0.5%	0.9%	0.4%
75th percentile	1.1%	1.1%	0.3%	0.4%	0.4%	0.8%	0.3%
90th percentile	0.8%	0.9%	0.1%	0.3%	0.3%	0.6%	0.3%

Table 10.5-4. Fuel cost impact on MTCs by type of vessel for a selected range of commodities

	MTC by type of vessel (average USD per tonne-km)		
Commodity	**Clean bulk**	**Containers**	**Dirty bulk**
General Agriculture	0.1%	0.9%	
07: Edible vegetables and certain roots and tubers		1.0%	
08: Edible fruit, nuts, peel of citrus fruit, melons		0.7%	
09: Coffee, tea, mate, and spices		0.9%	
10: Cereals	0.2%		
12: Oil seed, oleagic fruits, grain, seed, fruit, etc, ne	0.1%		
19: Cereal, flour, starch, milk preparations and products		0.9%	
22: Beverages, spirits, and vinegar		1.2%	
General Manufacturing		0.3%	0.9%
31: Fertilizers			0.9%
47: Pulp of wood, fibrous cellulosic material, waste etc		1.6%	
48: Paper & paperboard, articles of pulp, paper, and board		0.8%	
52: Cotton		0.5%	
61: Articles of apparel, accessories, knit or crochet		0.2%	
62: Articles of apparel, accessories, not knit or crochet		0.2%	
64: Footwear, gaiters and the like, parts thereof		0.2%	
73: Articles of iron or steel		0.7%	
84: Nuclear reactors, boilers, machinery, etc		0.5%	
85: Electrical, electronic equipment		0.4%	
87: Vehicles other than railway, tramway		0.4%	
95: Toys, games, sports requisites		0.3%	
General Raw material			0.4%
25: Salt, sulphur, earth, stone, plaster, lime, and cement			0.5%
72: Iron and steel			0.4%

10.5.3 Potential for freight mode shift

This analysis does not find significant evidence of pressure to mode shift with estimated voyage costs associated with the proposed Med SO_X ECA.

As shown in **Table 10.1-2** and **Table 10.2-1**, MTCs are an order of magnitude lower than land-based costs, by rail or by truck. Ships benefit from significant economies of scale, efficiently moving tens of thousands of containers, or tonnes of cargo along waterborne trade routes. With the proposed Med SO_X ECA, estimated changes in MTCs range from 0.3% to 1.4% per tonne-km cargo. The maximum total cost change estimated, for the full transit of the Mediterranean from entrance to the Suez Canal at Port Said to the Straits of Gibraltar is $1.31 per tonne cargo (**Table 10.5-5**). For shorter route segments within the Mediterranean, the estimated change in costs is correspondingly lower, as changes in cost scale with changes in vessel transit distance in the proposed Med SO_X ECA.

Table 10.5-5. Baseline freight costs between origin and destination pairs (USD/tonne cargo)

Origin	Destination	Agriculture	Manufacturing	Raw material	Cost change with 0.10% S m/m fuel
Port Said	Gibraltar	$90.86	$265.66	$46.11	$1.31
Algeciras	Fos-sur-Mer	$34.58	$101.11	$17.55	$0.50
Algeciras	Koper	$79.10	$231.27	$40.14	$1.14
Genoa	Gioia Tauro	$23.01	$67.27	$11.68	$0.33
Koper	Malta Freeport	$35.99	$105.22	$18.26	$0.52
Koper	Singapore	$298.46	$872.61	$151.46	$0.90
Port Said	Koper	$62.51	$182.77	$31.72	$0.90
Lisbon	Jeddah	$139.37	$407.46	$70.72	$1.31
Piraeus	Limassol	$24.88	$72.75	$12.63	$0.36
Port Said	Beirut	$10.92	$31.92	$5.54	$0.16
Shanghai	Rotterdam	$494.81	$1,446.68	$251.10	$1.31
Shanghai	Fos-sur-Mer	$411.96	$1,204.44	$209.06	$1.05
Port Said	Fos-sur-Mer	$73.24	$214.14	$37.17	$1.05
Singapore	New York	$474.90	$1,388.45	$241.00	$1.31
Tangier	Oran	$12.28	$35.90	$6.23	$0.18
Tangier	Tunis	$38.33	$112.07	$19.45	$0.55
Thessaloniki	Piraeus	$12.65	$36.99	$6.42	$0.18
Xiamen	Beirut	$322.74	$943.58	$163.78	$0.16

Considering these higher vessel costs embedded in the freight rate and compared to the least cost feasible land-side mode, all routes studied show that the water route remains the least-cost option compared to the lowest cost all-land alternative route (**Table 10.5-6**).

Analysis of the marine freight rate increase necessary to break even with the lowest cost all-land alternative, i.e. the point at which mode shift becomes economically feasible, is presented in **Table 10.5-7**. These estimates show that waterborne freight rates would need to increase by 1.6 – 32.3x in order for the all-land alternative to become economically feasible. The ratios are generally lower for manufactured goods, typically transported using containerised modes, ranging from 1.6 to 4.3. As such, containerised transport costs would need to increase by 1.6x to 4.3x before all-land transport modes became feasible. Raw material and agriculture break even ratios are considerably higher, making the potential for mode switch from bulk vessels to all-land alternatives less feasible than for containerised goods.

Given the estimated changes in fuel prices associated with the proposed Med SO_X ECA, this work does not find evidence of potential mode shifting.

Table 10.5-6. Higher freight costs between O-D pairs compared with land-side mode (USD/tonne cargo)

Origin	Destination	Agriculture	Manufacturing	Raw material	Land-side cost	Alternate mode
Port Said	Gibraltar	$92.17	$266.97	$47.42	1,151.81	Road
Algeciras	Fos-sur-Mer	$35.08	$101.61	$18.05	276.06	Road
Algeciras	Koper	$80.24	$232.41	$41.28	466.09	Road
Genoa	Gioia Tauro	$23.34	$67.60	$12.01	197.94	Rail
Koper	Malta Freeport	$36.51	$105.74	$18.78	303.03	Road
Koper	Singapore	$299.36	$873.51	$152.36	2,012.99	Road
Port Said	Koper	$63.41	$183.67	$32.62	542.19	Road
Lisbon	Jeddah	$140.68	$408.77	$72.03	1,333.31	Road
Piraeus	Limassol	$25.24	$73.11	$12.99	408.12	Road
Port Said	Beirut	$11.08	$32.08	$5.70	110.05	Road
Shanghai	Rotterdam	$496.12	$1,447.98	$252.41	2,366.39	Rail
Shanghai	Fos-sur-Mer	$413.02	$1,205.50	$210.11	2,477.37	Rail
Port Said	Fos-sur-Mer	$74.30	$215.20	$38.22	684.02	Road
Singapore	New York	$476.21	$1,389.75	$242.30	NONE	
Tangier	Oran	$12.45	$36.07	$6.41	115.48	Road
Tangier	Tunis	$38.88	$112.63	$20.00	344.26	Road
Thessaloniki	Piraeus	$12.83	$37.17	$6.60	89.90	Road
Xiamen	Beirut	$322.89	$943.74	$163.94	2,164.73	Rail

Table 10.5-7. Break-even freight rate between origin and destination pairs (USD/tonne cargo)

			Route-specific break-even freight rate ratios necessary to equal land-side mode costs		
Origin	Destination	Break-even MTC rate (USD/t-km)	Agriculture	Manufacturing	Raw material
Port Said	Gibraltar	0.3207	12.7	4.3	25.0
Algeciras	Fos-sur-Mer	0.2020	8.0	2.7	15.7
Algeciras	Koper	0.1491	5.9	2.0	11.6
Genoa	Gioia Tauro	0.2177	8.6	2.9	17.0
Koper	Malta Freeport	0.2130	Not applicable		
Koper	Singapore	0.1707	6.7	2.3	13.3
Port Said	Koper	0.2195	8.7	3.0	17.1
Lisbon	Jeddah	0.2421	9.6	3.3	18.9
Piraeus	Limassol	0.4150	Not applicable		
Port Said	Beirut	0.2550	10.1	3.4	19.9
Shanghai	Rotterdam	0.1210	4.8	1.6	9.4
Shanghai	Fos-sur-Mer	0.1522	6.0	2.1	11.9
Port Said	Fos-sur-Mer	0.2363	9.3	3.2	18.4
Singapore	New York	NONE	Not applicable		
Tangier	Oran	0.2380	9.4	3.2	18.5
Tangier	Tunis	0.2272	9.0	3.1	17.7
Thessaloniki	Piraeus	0.1798	7.1	2.4	14.0
Xiamen	Beirut	0.1697	6.7	2.3	13.2

10.6 Commodity and product price effects

10.6.1 Fuel price impact on freight service to remote areas and island communities

Analysis of the impacts of remote areas and island communities revolves around analysis of changes in marine freight costs. Modal shift is not an option for remote or island areas, as intermodal connections do not exist, or are limited. As such, all goods movements must occur either by sea or by air. Additional costs of marine freight transportation are discussed in **Section 10.5.3**, and we do not find evidence supporting the potential for mode shift. The work in **Section 10.6** provides evidence that cargo transport serving islands and remote areas will not be disproportionally affected by the change in costs associated with the Med SO_x ECA.

An example using the commodity coffee transported by containership can demonstrate the cascade effect of embedded fuel price changes. In **Table 10.6-1** and in **Figure 10.6-1**, we follow the change of USD $99 per tonne fuel price (USD $344 for 0.50% S m/m fuel increasing to USD $443 for 0.10% S m/m fuel). The fuel price increases by about 29%, which represents a ~16% increase in the daily at-sea voyage cost (refer to **Table 10.5-1** in **Section 10.5.1**). Adding the increase in the voyage cost to the median freight rate (refer to **Table 10.5-3** in **Section 10.5.2**) increases the freight rate for transporting agriculture cargos like coffee by ~1.4%. Given that coffee by the tonne costs more than $2,700 per tonne (refer to **Table 10.4-1** in **Section 10.4**), the fuel-related price change per tonne of coffee is less than one-tenth of a percent (0.05%).

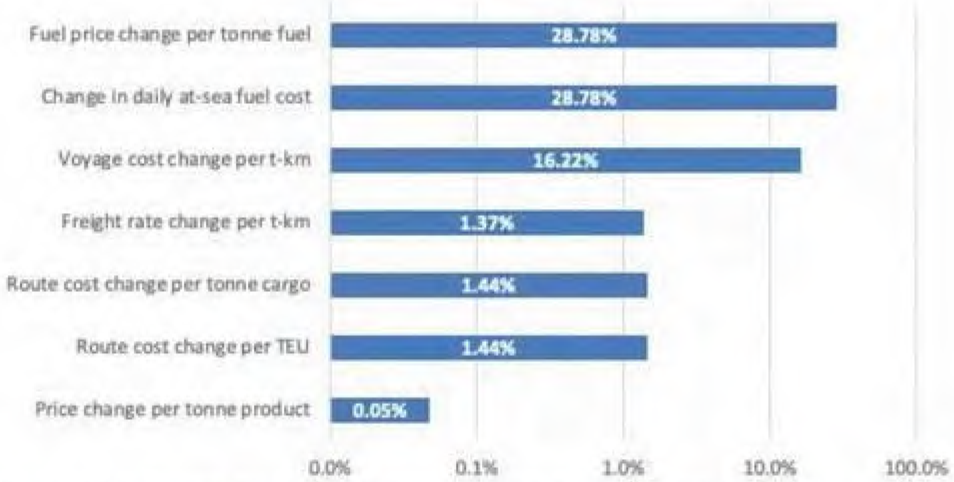


Figure 10.6-1: Example for coffee of fuel price embedded in voyage cost, freight rates, route costs, and product prices

Table 10.6-1. Example for coffee how fuel price changes voyage cost, rates, route cost, and product price

Different contexts for price effect	Price/cost change	Units	Percent of cost
Fuel price change per tonne fuel	$99	USD/tonne	28.78%

Change in daily at-sea fuel cost	$20,356	USD/day	28.78%
Voyage cost change per t-km	$0.00036	USD/t-km	16.22%
Freight rate change per t-km	$0.00036	USD/t-km	1.37%
Route cost change per tonne cargo	$1.31	USD/tonne cargo	1.44%
Route cost change per TEU	$13.08	USD/TEU	1.44%
Price change per tonne product	$1.31	USD/tonne product	0.05%

10.6.2 Fuel price impact on passenger service to remote areas and island communities

Analysis of the impacts of remote areas and island communities revolves around analysis of changes in marine passenger costs. Modal shift is not an option for remote or island areas, as intermodal connections do not exist, or are limited. As such, all passenger movements must occur either by sea or by air. Based on the data developed in **Section 10.1.2**, we evaluate whether passenger transport serving islands and remote areas may be disproportionally affected by the change in costs associated with the Med SO_X ECA.

Passenger ferries, including RoPax vessels, operate along numerous routes in the Mediterranean Sea, as shown in **Figure 10.1-2** and **Figure 10.1-3**. As shown by the intensity of emissions in the two figures, ROPAX vessels are far higher emitters of CO_2, and therefore consume greater quantities of fuel. This work analyses a set of ten ferry routes in the Mediterranean Sea. Ferry routes analysed were selected for routes between the mainland and islands, as well as inter-island routes and a coastwise route. One-way prices for a single adult booking deck passage were retrieved from published fare schedules for each of the routes shown in **Table 10.6-2**.

These estimate show that **ferry prices may rise by between €0.8 and €2.1 per passenger ticket, a ticket** increase of 0.8% to 5.0% per passenger. The literature indicates that the PED for ferry travel is significant and inelastic, with a coefficient of 0.3 (Adler, Dehghani, & Gihring, 2010). As such, using the demand elasticity equation (Equation 1), we can estimate that demand for ferry transport may be affected by between 0.25% on the Marseille -Algiers route, 1.49% on the Naples – Cagliari route, and 1.45% on the Famagusa – Mersin route, all else equal. Interpretation of these coefficients demonstrates the inelastic relationship of ferry transport and ticket prices, with demand changing disproportionally, and less, than estimated price increases.

Table 10.6-2. Ferry routes, distances, prices, and ticket price change with shift to 0.10% S m/m fuel

Ferry Route	Distance (NM)	One-way cost (EUR)	Passengers	Ticket price change (EUR)	% Change
Naples - Cagliari	282	42.41	1,845	2.1	5.0%
Barcelona - Porto Torres	307	35	2,794	1.4	4.0%
Marseille - Algiers	421	198	2,400	1.6	0.8%
Piraeus - Paros	107	33	1,715	0.8	2.5%
Piraeus - Kos	203	52.5	2,000	1.1	2.1%
Piraeus - Rhodes	256	61.5	2,000	1.1	1.8%
Valetta - Pozzallo	53	68	1,120	0.2	0.3%
Mykonos - Naxos	26	14.5	2,400	0.02	0.1%
Famagusa - Mersin	112	42.93	343	0.6	1.5%
Barcelona - Genoa	352	49	2,230	1.7	3.5%

Of the routes studied, the inter-island route between Mykonos and Naxos represents the smallest price change of the routes studied, in absolute terms, and the smallest percent change in price.

While the above table includes estimated changes in price across a set of routes between specific port pairs, the routes were selected to be representative of the possible set of routes transited by ferries in the Mediterranean. The routes in **Table 10.6-2** include both mainland – island routes and inter-island routes, representative of the whole Mediterranean, and may be used for comparison of expected changes in costs across routes with similar parameters.

Coastwise ferry transits, such as the Barcelona – Genoa route, are shown in **Figure 10.1-2**. The economics of land-based transportation costs mean that water transit by ferry typically offers lowest cost route, for equivalent transit distances. The data in **Table 10.2-1** show that transit by coach typically costs around $0.10 per p-km. From **Table 10.6-2** the data show that ferry transit on the Barcelona – Genoa route costs $0.0895 per p-km (assuming $1 = €0.84) with estimated price changes expected to increase the route costs to $0.0926 per p-km. As shown this price differential from the proposed Med SO_X ECA is small in terms of absolute price, and in terms of price per p-km, and is unlikely to induce mode shift to the land-based alternative route.

For islands and remote areas, air travel offers the only mode option other than water for transit of passengers to and from those regions. Air prices are typically more variable than ferry mode prices, responding dynamically to changes in demand by reallocating resources to high demand and priority routes, On the other hand, ferries typically operate transit operations, with fixed schedules and resources allowing for more stable prices.

A review of airfares[47] among the Greek Islands show flight prices from Athens to Paros, Kos and Rhodes were $97, $66, and $57 respectively (€80.6, €54.9, and €47.4). Flights from Athens to Paros and Kos are higher priced than the respective ferry routes, while the Rhodes ferry is higher priced than the corresponding air fare. It is important to consider that mode selection for passengers depends on a set of factors in addition to price, including travel time, route availability, convenience, and capacity (i.e. vehicle transport). Considering transit price, estimated changes in ferry prices as a result of the proposed Med SO_X ECA do not induce modal switchover in any of the routes studied.

10.7 Price Elasticity of Demand for Goods and Commodities

The price elasticity of demand (PED) measures the change in the quantity of a good demanded when the price of that good changes, i.e., it may be thought of as the ratio of the percent change in quantity demand to the percent change in the price of the good. PED is estimated based on the formula in Equation 1, where $e_{(p)}$ is the price elasticity of demand, Q is the quantity of the good demanded, and P is the price of the good.

Equation 1: Price elasticity of demand

$$e_{(p)} = \frac{dQ/Q}{dP/P}$$

Price elasticity of demand is typically negative, i.e. when the price of a good goes up the quantity demanded goes down, following the law of demand. Conventionally, though PED estimates are typically negative, PED coefficients are typically discussed as positive, omitting the negative sign on the coefficient. For goods that show elastic demand, the change in quantity demanded is proportional, or more than proportional, to the change in price, and the elasticity is greater than or equal to 1. For goods that show inelastic demand, the change in quantity demanded changes less than proportionally to the change in price, and the elasticity is less than 1.

The United States Department of Agriculture (USDA) provides access to a set of commodity elasticities through their "Commodity and Food Elasticities" database. These data include elasticities for 115 countries, including for 8 commodity groups in 13 countries that are Contracting Parties to the Barcelona Convention. These commodities and their elasticities are shown in **Table 10.7-1** and **Figure 10.7-1**. The elasticity data from USDA are supplemented with estimates compiled by Fally

---

[47] One-way economy, single passenger, 21-day advance ticket, cheapest flight of day in March 2021.

and Sayre, 2018 for additional commodities (**Table 10.7-2**). For the purposes of this analysis, the upper bound elasticity is assumed as a conservative estimate for the maximum possible effect on demand for goods and commodities based on increased costs associated with the proposed Med SO_X ECA.

Table 10.7-1. Price elasticity of demand for 8 food and beverage commodity groups in available Mediterranean coastal States that are Contracting Parties to the Barcelona Convention from USDA

	Beverage and tobacco	**Bread and cereal**	**Dairy**	**Fish**	**Food other**	**Fruit and vegetable**	**Meat**	**Oil and fat**
count	13.000	13.000	13.000	13.000	13.000	13.000	13.000	13.000
mean	0.594	0.259	0.493	0.512	0.456	0.366	0.457	0.281
std	0.171	0.091	0.126	0.133	0.113	0.094	0.114	0.090
min	0.337	0.129	0.294	0.303	0.274	0.217	0.275	0.150
25%	0.469	0.187	0.407	0.420	0.379	0.300	0.380	0.213
50%	0.660	0.294	0.529	0.552	0.485	0.393	0.487	0.320
75%	0.726	0.332	0.599	0.623	0.552	0.445	0.554	0.354
max	0.831	0.385	0.641	0.671	0.591	0.476	0.593	0.401

Table 10.7-2. Price elasticity of demand for selected consumable and durable commodities (Fally and Sayre, 2018)

Commodity	**Price Elasticity of Demand**
Bananas	-0.566 to -0.738
Cobalt	-0.029 to -0.5
Coffee	-0.07 to -0.54
Cotton	-0.684
Manganese	-0.1
Nickel	-0.038

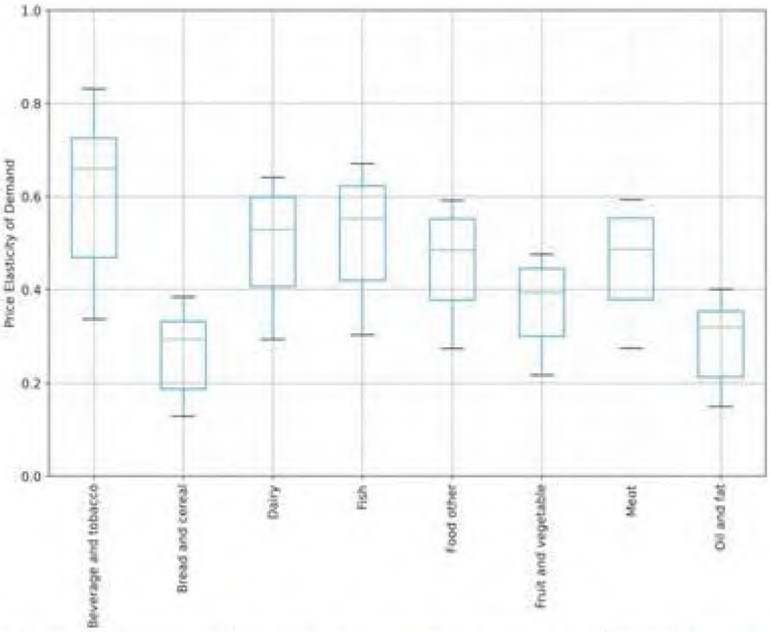


Figure 10.7-1: Price elasticity of demand for 8 commodity groups in available Mediterranean coastal States that are Contracting Parties to the Barcelona Convention

As discussed in **Table 10.5-5** the maximum price increase, along the route from Port Said to Gibraltar, a full transit of the Mediterranean, per ton cargo is \$1.31. Assuming this \$1.31/ton price increase is fully transferred to the end user price of the group of commodities studied, the estimated change in demand is shown in **Table 10.7-3**. Applying the maximum elasticity by commodity group we show that the largest change in demand is for phosphate rock, where demand is estimated to decrease by 0.759%. Phosphate rock, a primary ingredient of fertilisers, is the lowest cost per metric tonne commodity on the list, therefore projected changes in price of transit per ton cargo have the largest effect on the price of the commodity in terms of percent change.

All estimated changes in demand are less than 1%, and less than 0.1% in all cases studied other than phosphate rock and bananas. As discussed above, all elasticities show inelastic demand for the goods and commodities studied. Given inelastic demand, and the relatively small changes in commodity prices estimated with the proposed Med SO_X ECA, the anticipated change in demand for goods and commodities is generally very small.

Table 10.7-3. Estimated change in demand for commodities based on estimated change in price and price elasticity of demand

Commodity	Price ($/MT)	New Price	% Change Price	Max Elasticity	% Change Demand
Salmon, fresh	6,940.0	6,941.31	0.019%	0.671	0.013%
Bananas	1,140.0	1,141.31	0.115%	0.738	0.085%
Coffee	2,767.2	2,768.55	0.047%	0.831	0.039%
Tea	2,200.0	2,201.31	0.060%	0.831	0.049%
Tobacco	4,578.7	4,579.96	0.029%	0.831	0.024%
Phosphate rock	88.0	89.26	1.489%	0.509	0.759%
Zinc	2,736.6	2,737.90	0.048%	0.5	0.024%
Rubber	1,662.2	1,663.48	0.079%	0.91	0.072%
Plywood	1,669.8	1,671.08	0.078%	0.91	0.071%
Fine wool	14,183.2	14,184.54	0.009%	0.684	0.006%

10.8 Total costs discussion

Using the most recently available fuel prices the estimated additional costs of the Med SO_X ECA would be $1.761 billion per year.

Among Mediterranean coastal States, the container throughput in 2019 was 73.892 million TEUs. As a first-order example, if all additional costs of the Med SO_X ECA were borne by container vessels, which make up 35% of the total fuel usage in the Mediterranean, then the additional cost per TEU would be $8.30/TEU or $0.83/MT, assuming 10 MT per TEU. This example demonstrates upper bounds in costs per containerised tonne of freight, and is very consistent with the results in **Table 10.5-5** in **Section 10.5.3**, which report route specific cost increases averaging $7.30/TEU or $0.73/MT.

The estimated changes in transport costs will have both short-term transitional, and long-term effects. In the short term, the price change associated with 0.10% S m/m fuels will affect the market in much the same way that the changes in observed fuel prices have done previously, by adjusting freight rates to accommodate changing fuel prices. Those freight rates are embedded in market prices for products as described in **Section 10.6**. The analysis shows that these costs are not large, but they are computable, and economic theory suggests a range of market responses other than decreasing demand or substitution. Long-run cost changes can be expected to signal an adjustment in the market, that might include cost cutting elsewhere in supply chain, cargo handling efficiency improvements, and innovation in transport, intermodal, and cargo handling procedures and technology.

10.9 Summary of Costs of Reducing Emissions from Ships

In conclusion, the proposed Med SO_X 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.

11 References

These references refer to references from the Technical and Feasibility Study.

1. M. Sofiev *et al.*, Cleaner fuels for ships provide public health benefits with climate tradeoffs. *Nature Communications* **9**, 406 (2018).
2. International Standardisation Organization (ISO), "Petroleum Products - Fuels (Class F) - Specifications of Marine Fuels, ISO 8217:2017," *Sixth Edition* (International Organization for Standardization, Geneva, Switzerland, 2017).
3. Center for International Earth Science Information Network - CIESIN - Columbia University. (NASA Socioeconomic Data and Applications Center (SEDAC), Palisades, NY, 2016).
4. J. J. Corbett *et al.*, Mortality from ship emissions: a global assessment. *Environmental Science and Technology-Columbus* **41**, 8512 (2007).
5. J. J. Winebrake, J. J. Corbett, E. H. Green, A. Lauer, V. Eyring, Mitigating the Health Impacts of Pollution from Oceangoing Shipping: An Assessment of Low-Sulfur Fuel Mandates. *Environmental Science & Technology* **43**, 4776-4782 (2009).
6. B. Ostro, in *Environmental burden of disease series*. (OMS, 2004), vol. 5.
7. D. W. Dockery *et al.*, An Association between Air Pollution and Mortality in Six U.S. Cities. *New England Journal of Medicine* **329**, 1753-1759 (1993).
8. F. Laden, J. Schwartz, F. E. Speizer, D. W. Dockery, Reduction in fine particulate air pollution and mortality: extended follow-up of the Harvard Six Cities study. *American journal of respiratory and critical care medicine* **173**, 667-672 (2006).
9. C. A. Pope, 3rd *et al.*, Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *Jama* **287**, 1132-1141 (2002).
10. J. Lepeule, F. Laden, D. Dockery, J. Schwartz, Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. *Environmental health perspectives* **120**, 965 (2012).
11. X.-y. Zheng *et al.*, Association between air pollutants and asthma emergency room visits and hospital admissions in time series studies: a systematic review and meta-analysis. *PLoS One* **10**, e0138146 (2015).
12. United Nations, World Population Prospects: The 2015 Revision, Key Findings and Advance Tables. New York: United Nations, Department of Economic and Social Affairs PD. *Population Division*, (2015).
13. World Health Organization, W. H. Organization, Ed. (2016).
14. World Health Organization, W. H. Organization, Ed. (2018).
15. Global Asthma Network, *The Global Asthma Report 2014* (Auckland, New Zealand, 2014).
16. H. Liu *et al.*, Health and climate impacts of ocean-going vessels in East Asia. *Nature climate change* **6**, 1037 (2016).
17. J. Lepeule, F. Laden, D. Dockery, J. Schwartz, Chronic exposure to fine particles and mortality: an extended follow-up of the Harvard Six Cities study from 1974 to 2009. *Environ Health Perspect* **120**, 965-970 (2012).
18. R. T. Burnett *et al.*, An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environ Health Perspect* **122**, 397-403 (2014).
19. World Health Organization, *Ambient air pollution: a global assessment of exposure and burden of disease.*, (World Health Organization, 2016).
20. Bunker Index. (Bunker Index, United Kingdom, 2018), vol. 2018.
21. International Monetary Fund. (retrieved from FRED, Federal Reserve Bank of St. Louis,, 2018), vol. 2018.
22. U.S. Bureau of Labor Statistics. (retrieved from FRED, Federal Reserve Bank of St. Louis,, 2018), vol. 2018.
23. E. W. Carr, J. J. Corbett, Ship Compliance in Emission Control Areas: Technology Costs and Policy Instruments. *Environmental Science & Technology* **49**, 9584-9591 (2015).
24. S. De Bruyn *et al.*, Shadow prices handbook: valuation and weighting of emissions and

environmental impacts. *CE Delft, Delft, the Nethelands.[online] URL: http://www.cedelft.eu/publicatie/shadow_prices_handbook_% 3A_valuation_and_weighting_of_emissions_and_environmenta l_impacts/1032 Ecology and Society* **21**, 10 (2010).

25. P. Hammingh *et al., Effectiveness of international emission control measures for North Sea shipping on Dutch air quality*. (2019).
26. W. K. Viscusi, C. J. Masterman, Income elasticities and global values of a statistical life. *Journal of Benefit-Cost Analysis* **8**, 226-250 (2017).

These references refer to references other than those from the Technical and Feasibility Study.

Abbass, Rana Alaa, Prashant Kumar, and Ahmed El-Gendy. 2018. "An Overview of Monitoring and Reduction Strategies for Health and Climate Change Related Emissions in the Middle East and North Africa Region." Atmospheric Environment 175 (November 2017): 33–43. https://doi.org/10.1016/j.atmosenv.2017.11.061.

Adler, T., Dehghani, Y., & Gihring, C. (2010). Estimating price elasticities of ferry demand. Transportation Research Record, (2176), 59–66. https://doi.org/10.3141/2176-07

Arvis, J.-F., Vesin, V., Carruthers, R., Ducruet, C., & de Langen, P. (2019). Maritime Networks, Port Efficiency, and Hinterland Connectivity in the Mediterranean. Maritime Networks, Port Efficiency, and Hinterland Connectivity in the Mediterranean. Washington, D.C: World Bank Group. https://doi.org/10.1596/978-1-4648-1274-3

Boyd, Gale, J Molburg, and Raymond Prince. 1996. "Alternative Methods of Marginal Abatement Cost Estimation: Non-Parametric Distance Functions." Argonne National Lab., IL (United States). Decision and Information Sciences ….

CE Delft. 2010. "Shadow Prices Handbook Valuation and Weighting of Emissions and Environmental Impacts," no. March: 1–140. http://www.ce.nl/?go=home.downloadPub&id=1032&file=7788_defMainReportMaKMV_1271765427.pdf.

———. 2018. "Environmental Prices Handbook EU28 Version - Methods and Numbers for Valuation of Environmental Impacts." CE Delft, 175. https://cedelft.eu/wp-content/uploads/sites/2/2021/04/CE_Delft_7N54_Environmental_Prices_Handbook_EU28_version_Def_VS2020.pdf.

Ceuster, G. De, Herbruggen, B. van, & Logghe, S. (2006). TREMOVE: Description of model and baseline version 2.41, Draft Report. (TRANSPORT & MOBILITY LEUVEN, Ed.). Brussels, Belgium: European Commission. Retrieved from http://www.tremove.org/

Cofala, Janusz, Markus Amann, Jens Borken-Kleefeld, Adriana Gomez-Sanabria, Chris Heyes, Gregor Kiesewetter, Robert Sander, et al. 2018. "Final Report The Potential for Cost-Effective Air Emission Reductions from International Shipping through Designation of Further Emission Control Areas in EU Waters with Focus on the Mediterranean Sea." IIASA - Air Quality and Greenhouse Gases (AIR).

Coggins, Jay S, and John R Swinton. 1996. "The Price of Pollution: A Dual Approach to Valuing SO_2 allowances." Journal of Environmental Economics and Management 30 (1): 58–72.

Corbett, James J., James J. Winebrake, Erin H. Green, Prasad Kasibhatla, Veronika Eyring, and Axel Lauer. 2007. "Mortality from Ship Emissions: A Global Assessment." Environmental Science and Technology 41 (24): 8512–18. https://doi.org/10.1021/es071686z.

Corbett, J. J., & Carr, E. W. (2019). REMPEC WG.45/INF9 Technical and feasibility study to examine the possibility of designating the Mediterranean Sea, or parts thereof, as SO_X ECA(s) under MARPOL Annex VI. Valletta, Malta. Retrieved from https://www.rempec.org/en/knowledge-centre/online-catalogue/2019/rempec-wg-45-inf-9-technical-and-feasibility-study-to-examine-the-possibility-of-designating-the-mediterranean-sea-or-parts-thereof-as-sox-eca-s-under-marpol-annex-vi-english-only

Crippa, Monica, Efisio Solazzo, Ganlin Huang, Diego Guizzardi, Ernest Koffi, Marilena Muntean, Christian Schieberle, Rainer Friedrich, and Greet Janssens-Maenhout. 2020. "High Resolution Temporal Profiles in the Emissions Database for Global Atmospheric Research." Scientific

Data. https://doi.org/10.1038/s41597-020-0462-2.

Dang, T, and A Mourougane. 2014. "Estimating Shadow Prices of Pollution in Selected OECD Countries." OECD Green Growth Papers 2014–02 (August).

Dulière, V., Baetens, K., & Lacroix, G. (2020). Potential impact of wash water effluents from scrubbers on water acidification in the southern North Sea. RBINS. Retrieved from http://biblio.naturalsciences.be/library-1/rbins-staff-publications-2020/Scrubber_report.2020

EEA. 2020a. "Air Quality E-Reporting (AQ e-Reporting)." 2020. https://www.eea.europa.eu/data-and-maps/data/aqereporting-8.

———. 2020b. "The European Environment - State and Outlook 2020. Knowledge for Transition to a Sustainable Europe." https://doi.org/10.15196/TS600305.

EPA. 2009. "Proposal to Designate an Emission Control Area for Nitrogen Oxides, Sulfur Oxides and Particulate Matter: Technical Support Document." U.S. Environmental Protection Agency.

EU. 2016. "National Emissions Ceilings (NEC) Directive (2016/2284/EU)."

EU. (2020). Commodity Price Dashboard, (100). Retrieved from https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/commodity-price-dashboard_092020_en.pdf

European Commission. 1999. "Economic Evaluation of a Directive on National Emission Ceilings for Certain Atmospheric Pollutants."

———. 2020. "National Emission Reduction Commitments Directive Reporting Status 2020 Key Messages," 1–16.

European Commission. (2017). Study on Mediterranean TEN-T Core Network Corridor, 2nd Phase, Final Report. Brussels, Belgium.

European Commission. (2018). In-depth analysis in support on the COM(2018) 773: A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. Brussels, Belgium. Retrieved from https://ec.europa.eu/knowledge4policy/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en

European Commission. (2020). COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, Stepping up Europe's 2030 climate ambition, Investing in a climate-neutral future for the benefit of our people. Brussels, Belgium. Retrieved from https://ec.europa.eu/knowledge4policy/publication/communication-com2020562-stepping-europe's-2030-climate-ambition-investing-climate_en

Faber, J., Hanayama, S., Yuan., S., P., Z., H., P., Comer, B., … Yuan, H. (2020). MEPC 75/7/15 Fourth IMO GHG Study 2020 - Final Report. London, UK. Retrieved from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Reducing-greenhouse-gas-emissions-from-ships.aspx

Fãre, Rolf, Shawna Grosskopf, Dong-Woon Noh, and William Weber. 2005. "Characteristics of a Polluting Technology: Theory and Practice." Journal of Econometrics 126 (2): 469–92.

Hassellöv, Ida Maja, David R. Turner, Axel Lauer, and James J. Corbett. 2013. "Shipping Contributes to Ocean Acidification." Geophysical Research Letters. https://doi.org/10.1002/grl.50521.

Hassellöv, I.-M., Koski, M., Broeg, K., Marin-Enriquez, O., Tronczyński, J., Dulière, V., … Parmentier, K. (2020). *ICES VIEWPOINT BACKGROUND DOCUMENT: IMPACT FROM EXHAUST GAS CLEANING SYSTEMS (SCRUBBERS) ON THE MARINE ENVIRONMENT (AD HOC)*. Copenhage, Denmark: International Council for the Exploration of the Sea. https://doi.org/10.17895/ices.pub.7487

International Transport Forum, Kirstein, L., Halim, R., & Merk, O. (2018). Decarbonising Maritime Transport. Paris, France. https://doi.org/10.1787/b1a7632c-en

Korinek, J. (2008). Clarifying trade costs in maritime transport. Organization for Economic Co-Operation and Development, (2011), 1–41. Retrieved from https://www.oecd-ilibrary.org/trade/clarifying-trade-costs_220157847513

He, Ling Yun, and Jia Ou. 2017. "Pollution Emissions, Environmental Policy, and Marginal Abatement Costs." International Journal of Environmental Research and Public Health 14 (12). https://doi.org/10.3390/ijerph14121509.

Lee, Jeong-Dong, Jong-Bok Park, and Tai-Yoo Kim. 2002. "Estimation of the Shadow Prices of Pollutants with Production/Environment Inefficiency Taken into Account: A Nonparametric Directional Distance Function Approach." Journal of Environmental Management 64 (4): 365–75.

Maibach, M., Martin, P., & Sutter, D. (2006). Annex 1 to COMPETE Final Report: Analysis of operating cost in the EU and the US. Karlsruhe, Germany.

Mekaroonreung, Maethee, and Andrew L Johnson. 2012. "Estimating the Shadow Prices of SO_2 and NO_X for U.S. Coal Power Plants: A Convex Nonparametric Least Squares Approach." Energy Economics 34 (3): 723–32.

Ministry of Environmental Protection. 2019. "Clean Air Law, 2008." 2019.

MoE. 2017. "Lebanon's National Strategy for Air Quality Management 2015 - 2030."

Negev, Maya. 2020. "Air Pollution Policy in Israel." *Atmosphere* 11 (10). https://doi.org/10.3390/atmos11101065.

Pope, C Arden, Richard T Burnett, Michael J Thun, Eugenia E Calle, Daniel Krewski, Kazuhiko Ito, and George D Thurston. 2002. "Lung Cancer, Cardiopulmonary Mortality, and Long-Term Exposure to Fine Particulate Air Pollution." Jama 287 (9): 1132–41.

Principaute de Monaco. 2019. "L'Environement in the Principality of Monaco."

Rouïl, Laurence, Catherine Ratsivalaka, Jean-Marc André, and Nadine Allemand. 2019. "ECAMED: A Technical Feasibility Study for the Implementation of an Emission Control Area (ECA) in the Mediterranean Sea," 94. https://www.ineris.fr/en/ineris/news/ecamed-conclusions-technical-feasibility-study-implementing-emissions-control-area-eca.

Schmolke, S., Ewert, K., Kaste, M., Schöngaßner, T., Kirchgeorg, T., & Marin-Enriquez, O. (2020). *Environmental Protection in Maritime Traffic –Scrubber Wash Water Survey*. Hamburg, Germany. https://doi.org/ISSN 1862-4804

Sofiev, Mikhail, James J Winebrake, Lasse Johansson, Edward W Carr, Marje Prank, Joana Soares, Julius Vira, Rostislav Kouznetsov, Jukka-Pekka Jalkanen, and James J Corbett. 2018. "Cleaner Fuels for Ships Provide Public Health Benefits with Climate Tradeoffs." Nature Communications 9 (1): 406. https://doi.org/10.1038/s41467-017-02774-9.

Swinton, John R. 1998. "At What Cost Do We Reduce Pollution? Shadow Prices of SO_2 Emissions." The Energy Journal 19 (4).

Syrian Arab Republic. 2018. "Nationally Determined Contributions Under Paris Agreement on Climate."

Teuchies, J., Cox, T. J. S., Van Itterbeeck, K., Meysman, F. J. R., & Blust, R. (2020). The impact of scrubber discharge on the water quality in estuaries and ports. *Environmental Sciences Europe*, *32*(1), 103. https://doi.org/10.1186/s12302-020-00380-z

Tu, Z G. 2009. "The Shadow Price of Industrial SO_2 Emission: A New Analytic Framework." China Econ Quart 9 (1): 259–82.

Turner, Judi A. 1995. "Measuring the Cost of Pollution Abatement in the U.S. Electric Utility Industry: A Production Frontier Approach." University of North Carolina at Chapel Hill.

UMAS, L. R. and. (2020). Techno-economic assessment of zero-carbon fuels. London, UK. Retrieved from https://www.lr.org/en/insights/global-marine-trends-2030/techno-economic-assessment-of-zero-carbon-fuels/

UN. 2017. "Factsheet on Air Quality in Bosnia and Herzegovina," 1–8.

UNECE. 2015. Environmental Performance Reviews: Montenegro. Third Review. Environmental Performance Reviews Series No. 41.

———. 2019. "'Protocols', United Nations Economic Commission for Europe." 2019.

UNEP. 2015a. "Libyan Arab Jamahiriya Air Quality Overview." https://wedocs.unep.org/bitstream/handle/20.500.11822/17040/Libya.pdf?sequence=1&isAllowed=y.

———. 2015b. "Syrian Arab Republic Air Quality Overview." https://www.unenvironment.org/resources/policy-and-strategy/air-quality-policies-syria.

———. 2015c. "Turkey Air Quality Overview." https://www.unenvironment.org/resources/policy-and-strategy/air-quality-policies-turkey.

Viana, M, N Fann, A Tobias, X Querol, D Rojas-Rueda, A Plaza, G Aynos, J A Conde, L Fernández, and C Fernández. 2015. "Environmental and Health Benefits from Designating the Marmara

Sea and the Turkish Straits as an Emission Control Area (ECA)." Environmental Science & Technology 49 (6): 3304–13. https://doi.org/10.1021/es5049946.

Winebrake, J. J., J. J. Corbett, E. H. Green, A. Lauer, and V. Eyring. 2009. "Mitigating the Health Impacts of Pollution from Oceangoing Shipping: An Assessment of Low-Sulfur Fuel Mandates." Environmental Science and Technology 43 (13): 4776–82. https://doi.org/10.1021/es803224q.

Winebrake, J. J., Corbett, J. J., Comer, B., Green, E., Silberman, J. A., & Korfmacher, K. (2010). *Analysis of Impacts of Category 3 Marine Rule on Great Lakes Shipping*. Pittsford, NY: Energy and Environmental Research Associates.

World Bank. 2013. "The Arab Republic of Egypt For Better or for Worse: Air Pollution in Greater Cairo" Report No. (April 2013): 150.

Zeebroeck, B. Van, Ceuster, G. De, & Herbruggen, B. Van. (2006). TREMOVE 2: Maritime model and runs. (TRANSPORT & MOBILITY LEUVEN, Ed.). Brussels, Belgium: European Commission. Retrieved from http://www.tmleuven.be/methode/tremove/home.htm

Zhang, Fenfen, Jia Xing, Yang Zhou, Shuxiao Wang, Bin Zhao, Haotian Zheng, Xiao Zhao, et al. 2020. "Estimation of Abatement Potentials and Costs of Air Pollution Emissions in China." Journal of Environmental Management 260 (January): 110069. https://doi.org/10.1016/j.jenvman.2020.110069.