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

Regional Expert Meeting on the Possible Designation of the Mediterranean, as a whole, as a Nitrogen Oxides Emission Control Area (Med NO_X ECA), pursuant to MARPOL Annex VI

Lija, Malta, 18-19 November 2025

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Agenda Item 6: Examining the Possibility of Designating the Mediterranean Sea, as a whole, as NOx ECA under MARPOL Annex VI

Final draft Detailed Technical and Feasibility Study to Assess the Relevant Existing and On-going Studies as well as to Examine the Possible Designation of the Mediterranean Sea, as a whole, as an Emission Control Area for Nitrogen Oxides (Med NOx ECA) pursuant to MARPOL Annex VI, including Health and Socio-economic Impacts on the Mediterranean Region and the Individual Contracting Parties to the Barcelona Convention

REMPEC
Malta, 2025

Note by the Secretariat

This document presents the Final draft Detailed Technical and Feasibility Study to Assess the Relevant Existing and On-going Studies as well as to Examine the Possible Designation of the Mediterranean Sea, as a whole, as an Emission Control Area for Nitrogen Oxides (Med NOx ECA) pursuant to MARPOL Annex VI, including Health and Socio-economic Impacts on the Mediterranean Region and the Individual Contracting Parties to the Barcelona Convention.

Background

1 The Secretariat, in consultation with the MAP NO_X ECA Technical Committee of Experts (NECA TCE) prepared the Final draft Detailed Technical and Feasibility Study to Assess the Relevant Existing and On-going Studies as well as to Examine the Possible Designation of the Mediterranean Sea, as a whole, as an Emission Control Area for Nitrogen Oxides (Med NOx ECA) pursuant to MARPOL Annex VI, including Health and Socio-economic Impacts on the Mediterranean Region and the Individual Contracting Parties to the Barcelona Convention, hereinafter referred to as “the Final draft Technical and Feasibility Study”.

2 The NECA TCE undertook four main phases of work, with Phases 2 and 3 split into three. For each phase, the Secretariat issued guidance on the tasks to be undertaken, as set out above, and circulated documents to be commented upon, with a view to facilitating its work.

3 In July 2025, under Phase 4, the Secretariat, requested the NECA TCE for validation of the Final draft Technical and Feasibility Study.

4 The Final draft Technical and Feasibility Study is presented in the **Appendix** to the present document.

Action requested by the Meeting

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

Appendix

Final draft Detailed Technical and Feasibility Study to Assess the Relevant Existing and On-going Studies as well as to Examine the Possible Designation of the Mediterranean Sea, as a whole, as an Emission Control Area for Nitrogen Oxides (Med NO_X ECA) pursuant to MARPOL Annex VI, including Health and Socio-economic Impacts on the Mediterranean Region and the Individual Contracting Parties to the Barcelona Convention

MEDITERRANEAN ACTION PLAN (MAP)

REGIONAL MARINE POLLUTION EMERGENCY RESPONSE CENTRE FOR THE MEDITERRANEAN SEA (REMPEC)

Preparation of a Detailed Technical and Feasibility Study to Assess the Relevant Existing and On-going Studies as well as to Examine the Possible Designation of the Mediterranean Sea, as a whole, as an Emission Control Area for Nitrogen Oxides (Med NOx ECA) pursuant to MARPOL Annex VI, including Health and Socio-economic Impacts on the Mediterranean Region and the Individual Contracting Parties to the Barcelona Convention

Draft Final Technical and Feasibility Study (D4)

Prepared by Ricardo

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Table of contents

1. Introduction 11
  1.1 Overall objective of the contract 11
  1.2 Criteria for designation of an ECA 12
2. Review of current policy landscape 14
  2.1 Summary of existing ECAs 14
  2.2 Review of NO_x emission control policies and technologies 18
3. Possible designation of the Med NOx ECA 20
  3.1 Area of application 20
  3.2 Possible entry into force dates 20
  3.3 Emissions proposed for control 22
  3.4 Population and environment at risk from exposure to ship emissions 23
  3.5 Local conditions influencing air pollution 25
4. Contribution of shipping to NO_x emissions 27
  4.1 Methodology 27
    4.1.1 AIS-based traffic and emissions modelling 27
    4.1.2 Scope 27
    4.1.3 Emission factors 28
  4.2 Ship traffic in the Mediterranean Sea 31
  4.3 Fleet operating in the Mediterranean Sea 32
  4.4 Estimation of current NO_x emissions from shipping 34
5. Impact assessement 36
  5.1 Methodology 36
    5.1.1 Fleet projection model 37
    5.1.2 Fuel and technology mix scenarios 39
    5.1.3 Alternative methods for NOx ECA compliance 41
  5.2 Air quality impacts 41
    5.2.1 Approach and assumptions for modelling air quality impacts 42
    5.2.2 Projections in the baseline 43
    5.2.3 Projections in NO_x ECA scenarios 43
    5.2.4 Health impacts 45
    5.2.5 Air quality impact results 46
  5.3 Economic impacts 47
    5.3.1 Approach and assumptions for modelling compliance costs 47

5.3.2 Costs and availability of NO_x emission abatement technology..........47
5.3.3 Presentation of results on fleet-wide compliance costs 50
5.3.4 Comparison to NGMT scenario 54
5.4 Impacts on the maritime sector 55
5.4.1 Impacts on shipping costs 55
5.4.2 Impacts on short sea shipping 55
5.4.3 Impacts on modal shift 59
5.4.4 Impacts on port competition and re-routing risks 59
5.4.5 Other impacts on ports 61
5.5 Other impacts on economies, citizens and authorities 62
5.5.1 Impact on prices 63
5.5.2 Impact on gross domestic product and total employment 65
5.5.3 Impact on environmental biodiversity 67
5.5.4 Impact on Cultural Heritage 68
5.5.5 Impact on authorities 69
6. Alternative Measures for Land-Based Sources 70
6.1 Land-based NO_x emissions data 70
6.1.1 Projections 72
6.1.2 Recommendations 73
6.2 Assessment of land-based measures and their implementation 74
6.2.1 EU Member States 74
6.2.2 Non-EU Mediterranean Coastal States 75
6.3 Cost assessment of land-based control measures 76
6.3.1 Limitations and implications for cost-effectiveness assessment 77
6.3.2 Cost effectives of land-based measures from countries not bordering the Mediterranean 77
7. Cost-effectiveness of NO_x ECA introduction 79
8. Recommendations and Roadmap for Med NOx ECA Designation 82
8.1 Draft recommendation for the decision-making process for the Med NO_x ECA designation 82
8.2 Roadmap towards the Med NO_x ECA designation 84
9. References 90

List of tables and figures

Table 1-1 Criteria for the designation of an ECA under MARPOL Annex VI 13

Table 2-1 Summary of existing ECAs 14

Table 4-1 Scope of NO_x emissions modelling 27

Table 4-2 NO_x emission limits in gNO_x/kWh for Tier II and Tier III compliance for a range of engine speeds in RPM, as well as the relative reduction between Tier II and Tier III NO_x emissions. 29

Table 4-3 Relative NO_x emissions for alternative maritime fuels included in the NMGMT/GMTM scenarios, relative to the baseline fuels of HFO + scrubber and VLSFO/MGO/HVO.............30

Table 5-1 Share of energy use per fuel type in Scenario with no global mid-term measures (NGMT) 40

Table 5-2 Share of energy use per fuel type in Scenario with global mid-term measures (GMT) 40

Table 5-3 Health benefits for the period 2031-2050 in for both the NGMT and GMT scenario 45

Table 5-4 Designation of MCP, main engine type and NO_x abatement technology for each vessel type in study scope 49

Table 5-5 CAPEX and OPEX for NO_x abatement technologies, in EUR/kW main engine power. 50

Table 5-6 Additional cumulative (average annual for period) costs in million € 51

Table 5-7 Percentage cumulative cost (OPEX only) increase due to NO_x ECA compliance for freight vessels only, by introduction date and interval period. 51

Table 5-8 Annual share of Tier III compliant new build vessels under the main and CAPEX sensitivity analyses, 2025-2040. 53

Table 5-9 Additional cumulative CAPEX investment (average annual for period) costs between the main and CAPEX sensitivity analysis, in million €. 53

Table 5-10 Barcelona-Civitavecchia ferry connection route characteristics...........................56

Table 5-11 Ticket price increases for the Barcelona-Civitavecchia route in each 10-year period, as a percentage increase in 2025 prices (%). 57

Table 5-12 Ratification status of MARPOL Annex VI among Contracting Parties 60

Table 5-13 Main container ports in Contracting Parties that have not ratified MARPOL Annex VI (main transhipment hubs in bold) 60

Table 5-14 Countries available in the GTAP database 64

Table 6-1 Comparison of land-based sector NO_x emission totals for 2km and 5km buffer zones, ranked by total emissions 71

Table 6-2 Scaled projected NO_x emissions (Mg) by sector for 2030 within the 2km buffer zone, ranked from highest to lowest emissions 73

Table 6-3 Projected total NO_x emission reduction from PaMs considered for adoption (kt/year) 75
Table 6-4 Reported cost of measures from NAPCPs..........76
Table 6-5 Reported cost of measures from NECPs..........77
Table 6-6 Cost effectiveness of land-based measures..........78
Table 7-1 Net Present Value (NPV) for each introduction year and fuel technology sensitivity under the NO_x ECA scenario, in million Euro. Source: Ricardo analysis for this Study..........80
Table 7-2 NO_x abatement cost ranges from this Study and previous NO_x ECA proposals, Euro per tonne NO_x reduced in 2025 prices. Note: to compare, currency and price level corrections have been made. Source: Ricardo analysis for this Study, various studies below...............81
Table 8-1 Roadmap towards the designation of a Med NO_x ECA..........85

Figure 2-1 Map of the geographical coverage of existing and recently approved ECAs........15

Figure 3-1 Area covered by proposed Med NO_x ECA..20

Figure 3-2 Population density in the Mediterranean Sea 25

Figure 4-1 Map of maritime traffic – the green lines indicate vessel traffic density (2021) and the red lines illustrate regular ferry routes (European Commission, 2025c) 32

Figure 4-2 Number of vessels per Tier and year...33

Figure 4-3 Number of vessels in 2023 by Tier and type...34

Figure 4-4 NO_x emissions from shipping within the scope of a potential NO_x ECA in the Mediterranean Sea over the period 2021-2024, based on real-world and regulatory emission factors 35

Figure 4-5 NO_x emissions from shipping within the scope of a potential NO_x ECA in the Mediterranean Sea over the period 2021-2024 by vessel category, based on real-world and regulatory emission factors...35

Figure 5-1 Process diagram for the impact assessment of Med NO_x ECA introduction.........36

Figure 5-2 Mediterranean fleet stock projections, 2025-2050 38

Figure 5-3 Projected NOx emissions from shipping in the baseline, under global mid-term measures (GMT) and no global mid-term measures (NGMT) scenarios. 43

Figure 5-4 Projected NO_x emissions from shipping under the NGMT scenario for different NO_x ECA implementation dates. Source: Ricardo modelling for this Study 44

Figure 5-5 Projected NO_x emissions from shipping in the Mediterranean under the GMT scenario for different NO_x ECA implementation dates..44

Figure 5-6 Cumulative air quality benefits for each NO_x ECA implementation start date in both the NGMT and GMT scenarios (billion EUR)..46

Figure 5-7 Diagrams showing NOx emission abatement processes using an EGR system (left) and SCR system (right). 48

Figure 5-8 Annual fleet-wide compliance costs (OPEX only) for NO_x ECA introduction in 2032 under the GMTM and NGMTM decarbonisation scenarios 54

Figure 5-9 Change in price of agriculture goods under NOx ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model...64

Figure 5-10 Change in price of fuels under NOx ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model 65

Figure 5-11 Change in price of consumer goods under NOx ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model..65

Figure 5-12 Gross domestic product (GDP) change under NOx ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model...66

Figure 5-13 Employment change under NO_x ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model 67

Figure 6-1 NO_x emissions in the Mediterranean Sea (2022)..70

Figure 6-2 Total national NO_x emissions (Mg) per sector from 2012-2022 for land-based sources 71

Abbreviations and definitions

Term	Definition
AIS	Automatic Identification System
AQ	Air quality
BAU	Business-as-usual
BCR	Benefit-cost-ratio
CAPEX	Capital expenditure
CBR	Cost benefit ratio
COPD	Chronic obstructive pulmonary disease
CPs	Contracting Parties to the Barcelona Convention
CRF	Concentration-response functions
ECA	Emission Control Area
EEZ	Exclusive economic zone
EGR	Exhaust Gas Recirculation
EMEP	European Monitoring and Evaluation Programme
EU	European Union
EUR	Euros
EUR/MWh	Euros per Megawatt-hour
EUR/kW	Euros per kilowatt
EU ETS	EU Emissions Trading System
gNO_x/kWh	Mass of NO_x emissions in grams per kilowatt-hour of engine power output
GDP	Gross Domestic Product
GHG	Greenhouse gas
GMT	Global mid-term measure
GNFR	Gridded Nomenclature for Reporting
GT	Gross tonnage
HFO	Heavy fuel oil
HVO	Hydrotreated Vegetable Oil
IHO	International Hydrographic Organization
IMO	International Maritime Organization
km	Kilometres
$ktNO_x$	Kilotonnes of NO_x
ktonnes	Kilotonnes
kW	Kilowatt

kWh	Kilwatt-hour
LNG	Liquefied Natural Gas
MARPOL	International Convention for the Prevention of Pollution from Ships
MARPOL VI	MARPOL Annex VI
Med NO_x ECA	Mediterranean sea nitrogen oxides emission control area
MB	Marine Benchmark
MCP	Maximum Continuous Power
Mg	Megagram
MGO	Marine Gas Oil
MMSIs	Maritime Mobile Service Identities
MRAD	Minor Restricted Activity Days
NAPCPs	National Air Pollution Control Programmes
NECP	National Energy and Climate Plan
NGMT	No global mid-term measures
NRMM	Non-Road Mobile Machinery
NO	Nitric oxide
NO_x	Nitrogen oxides
NO_2	Nitrogen dioxide
NO_x regulation	Regulation 13 of the MARPOL Annex VI
NPV	Net present value
OPEX	Operational expenditure
PaM	Policies and Measures
PM	Particulate matter
$PM_{2.5}$	Particulate matter with a diameter of 2.5 micrometres or smaller
PPM	Parts per million
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea
RoRo	Roll-on/Roll-off
RoPax	Roll-on/Roll-off passenger
RPM	Engine speed
SCR	Selective Catalytic Reduction
SO_x	Sulphur oxides
TCO	Total cost of ownership
VLSFO	Very Low Sulphur Fuel Oil
VSR	Ship speed reduction
$\mu g/m^3$	micrograms per cubic meter

Executive summary

[Placeholder – to be included in the final version of the report]

1. INTRODUCTION

This Draft Final Technical and Feasibility Study aims to present the results on the review of the relevant existing and on-going studies, as well as to examine the possible designation of the Mediterranean Sea as an Emission Control Area (ECA) for nitrogen oxides (NO_x), hereinafter referred to as the Med NO_x ECA, in accordance with Annex VI of MARPOL.

This report provides a review of relevant literature in this area and an analysis of NO_x emissions from shipping and ship traffic in the Mediterranean Sea based on AIS data. It also includes an environmental and economic impacts assessment of a possible designation of the Med NO_x ECA, along with an analysis of the cost-effectiveness of the Med NO_x ECA, compared to previous ECA proposals, and abatement measures for land-based sources. The report concludes with a roadmap and recommendations for the Med NO_x ECA designation.

1.1 Overall objective of the contract

Regulation 13 of the MARPOL Annex VI (hereafter NO_x Regulation) intends to control emissions of nitrogen oxides (NO_x) from applicable marine diesel. The NO_x Regulation applies to marine diesel engines with a power output of more than 130 kW installed on a ship, including those that are converted (not directly replaced) from 2000 onwards. However, the regulation excludes marine diesel engines intended to be used solely for emergencies; and ships only used in waters of its flag (domestic).

According to MARPOL Annex VI, Appendix III, ECAs are defined as sea and port areas where special mandatory measures are required to control emissions from ships to prevent, reduce, and control air pollution from nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter (PM), or all three. Specifically for NO_x ECAs, emissions by vessels sailing on marine diesel engines above 130 kW and constructed on or after the date of adoption of the NO_x ECA, need to be below Tier III limits[1] as defined in the NO_x Regulation.

There are currently four NO_x ECAs adopted globally, namely the North American, the US Caribbean Sea (which entered into effect in 2016), the Baltic Sea and the North Sea (which entered into effect in 2021), with the first two defined in Appendix VII of Annex VI, and the last two in Annexes I and V of MARPOL, respectively.

Following these, discussions have continued or are currently ongoing at IMO level regarding the potential expansion of NO_x ECA coverage. During MEPC 80 and 81, several submissions have been discussing the inclusion of Canadian Arctic waters, the Norwegian Sea, which led to the adoption of their designation but have not yet entered into effect, and the North-East Atlantic Ocean as ECAs for all three pollutants in scope. A proposal for the designation of a North-East Atlantic ECA was approved during the 83rd session of the MEPC in April 2025, covering the Faroe Islands, France, Greenland, Iceland, Ireland, Portugal, Spain, and the United Kingdom in view of its adoption in fall 2025.

Certification, testing and measurements of vessels' engines sailing in ECAs are conducted according to the revised NO_x Technical Code 2008, which also provides guidelines for approval of emission reduction technologies as well as compliance and enforcement. In this regard, it is important to note that MEPC 83 adopted amendments to the mentioned Code concerning the

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[1] See Table 4-2.

use of multiple engine operational profiles, including clarifying engine test cycles as well as the certification of an engine subject to substantial modification or being certified to a tier to which the engine was not certified at the time of its installation.

Regarding SO_x and PM control in the Mediterranean basin, the Mediterranean Sea (Med) has been designated, as a whole, as a SO_x ECA by the 80th MEPC session, under MARPOL Annex VI, with relevant legal amendments entering into force on 1 May 2024, and with the new SO_x and PM emission controls taking effect from 1 May 2025.

Through Decision IG.25/16 on the Mediterranean Strategy for the Prevention of, Preparedness, and Response to Marine Pollution from Ships (2022-2031), the Contracting Parties to the Barcelona Convention (CPs) agreed to explore the possible designation of the Mediterranean Sea, as a whole, as an Emission Control Area (ECA) for Nitrogen Oxides (NO_x) (the "Med NOx ECA").

The Fifteenth Meeting of the Focal Points of Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC) also requested the Secretariat to prepare the Technical and Feasibility Study to examine the possibility of designating the Med NOx ECA for consideration by the Sixteenth Meeting of the Focal Points of REMPEC.

Overall objective of the technical and feasibility study

The objective of this Study is to enable REMPEC to assist the Mediterranean coastal States to prepare a submission to IMO proposing the designation of the Med NO_x Emission Control Area (Med NO_x ECA). The study aims to provide evidence needed to address criteria set out in Appendix III of MARPOL Annex VI, relating to the designation of Emission Control Areas (ECAs).

The final outputs of the technical and feasibility study will include the following:

- **Final technical and feasibility study report**, of which this document serves as the preliminary draft.
- A **comprehensive set of recommendations** including a discussion of existing gaps in information, outlining the necessary steps for further studies or requirements to meet the criteria for ECA designation, and detailing required changes in regulatory frameworks tailored to regional needs. It will also include a proposal of incentive mechanisms to encourage industry participation and an evaluation of strategies to ensure the effectiveness of the ECA.
- A **strategic roadmap** detailing the path towards Med NO_x ECA designations, including information on milestones, timeline and stakeholder engagement necessary for its successful implementation.

1.2 Criteria for designation of an ECA

Under MARPOL Annex VI, the adoption of an ECA may be considered by the Organisation if there is a demonstrated need to prevent or reduce air pollution from ships. The criteria for the designation of an ECA are outlined in Section 3 of Appendix III to MARPOL Annex VI.

The proposal shall include the elements described in Table 1-1.

Table 1-1 Criteria for the designation of an ECA under MARPOL Annex VI

Ref.	Criteria	Section of the report
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
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);	3.3
3.1.3	a description of the human populations and environmental areas at risk from the impacts of ship emissions;	3.4
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 on 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;	Emissions from ships: 4.4 Air quality impacts: 5.1.3
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;	3.5
3.1.6	the nature of the ship traffic in the proposed emission control area, including the patterns and density of such traffic;	4.2
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 concurrently with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI;	5.3
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.	7

2. REVIEW OF CURRENT POLICY LANDSCAPE

2.1 Summary of existing ECAs

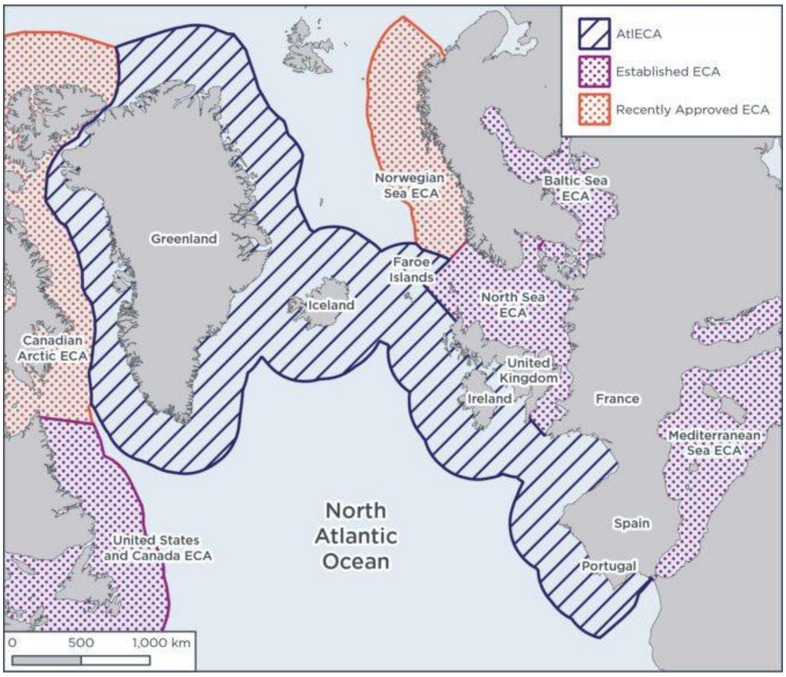
Currently there are five ECAs designated by the IMO under MARPOL Annex VI, which are presented in Table 2-1 and in Figure 2-1 below. The entry into force date represents the date the first restriction for the relevant pollutant entered into force. Similarly, the proposal date presents the date the emission control area was first proposed for any pollutant.

Table 2-1 Summary of existing ECAs

Name of ECA	Proposal date	Pollutants	Entry into force date	Proposal reference
North American	2009	SO_x, PM	1st August 2011	(United States Environment Protection Agency , 2009) (United States Environment Protection Agency , 2009)
		NO_x	1 January 2016	(IMO, 2010)
United States Caribbean Sea	2010	SO_x, PM	1st January 2014	(IMO , 2010)
		NO_x	1st January 2016	(United States Environmental Protection Agency, 2011)
Baltic Sea	1997	SO_x, PM	19 May 2006	(IMO, 2016)
	2016	NO_x	1st January 2021	
North Sea	2005	SO_x, PM	22 November 2006	(Marine Link, 2006)
	2016	NO_x	1st January 2021	(IMO, 2016b)
Mediterranean	2022	SO_x, PM	1st May 2025	(IMO, 2022)
Canadian Arctic Waters	2023	SO_x, PM	1st March 2026	(DNV, 2025)
		NO_x	1 January 2025	(IMO, 2023c)
Norwegian Sea	2023	NO_x, SO_x, PM	1st March 2026[2]	(IMO, 2023b)
North East Atlantic	2025	NO_x, SO_x, PM	1st January 2027	(IMO, 2024b)

[2] For the NO_x ECA, ships with building contracts placed on or after 1 March 2026, or without a building contract, but with keels laid on or after 1 September 2026, or are delivered on or after 1 March 2030, must operate Tier III-certified marine diesel engines within the Norwegian Sea ECA.

Figure 2-1 Map of the geographical coverage of existing and recently approved ECAs



Source: Adapted from (ICCT, 2025).

This review focuses primarily on the recent implementation of ECAs within European shipping lanes, namely the Mediterranean SO_x ECA, North-East Atlantic ECA, and North Sea and Baltic Sea ECAs, due to their geographical and techno-economic relevance to the designation of a Mediterranean NO_x ECA (Med NO_x ECA).

Baltic Sea and North Sea NO_x ECAs

Both the Baltic Sea and North Sea NO_x ECAs took effect from 1st January 2021 (IMO, 2016a); (IMO, 2016b). The extent of the Baltic Sea NO_x ECA comprises the Baltic Sea including the Gulf of Bothania, the Gulf of Finland and the entrance to the Baltic Sea and is bounded by the parallel of the Skaw in the Skaggerak. The North Sea NO_x ECA includes the geographical area generally referred to as the North Sea and the English Channel.

Costs

For the costs of implementing the Baltic Sea NO_x ECA, Selective Catalytic Reduction (SCR) technology was deemed the only mass-market option available from 2016 to reduce NO_x emissions and thus the only technology/fuel considered in the cost assessment (IMO, 2016a). For the Baltic Sea NO_x ECA NO_x abatement costs from SCR technology were estimated to range from around €787-4,699 per ton NO_x reduced, averaging around €1,316-1,844 per ton NO_x.

For the costs of implementing the North Sea NO_x ECA, the proposal made assumptions on the fleet size impacted by the proposed NO_x ECA. The North Sea fleet was reduced by 15% based on the assumption that a specialisation of the fleet will take place, where ships already equipped with Tier III compliance technology are assumed to take over and be limited to operations in the North Sea (IMO, 2016b). A third of all ships operate strictly in the North Sea, and a sixth of ships operates both inside and outside the North Sea NO_x ECA – this share will need to invest in new technology for North Sea NO_x ECA compliance upon vessel replacement (IMO, 2016b). The most cost-efficient applications of the technologies are SCR for 4-stroke main or auxiliary engines, and Exhaust Gas Recirculation (EGR) for 2-stroke main engines (IMO, 2016b).

Environmental impacts

Scenario simulations projected that the Baltic Sea NO_x ECA could reduce NO_x emissions by up to 40% in the Baltic Sea area compared to the 2007 baseline. Eutrophication in several Baltic Sea areas is expected to be reduced under the Tier III scenario by up to 20-30%. The scenario stimulations also show that there is a pronounced decrease in algae growth as a result of the decrease in emissions, improving water quality.

Health impacts

Both the Baltic Sea and North Sea NO_x ECAs bring health benefits, which are concentrated on higher density populations close to the area of NO_x ECA designation. The Baltic Sea NO_x ECA is expected to reduce human exposure to NO_x by 50-60% along the northern Baltic coastline. Additionally, 85% of all health impacts due to the North Sea NO_x ECA are seen in the North Sea coastal countries and 15% in other European countries (Hammingh, et al., 2012).

Cost-benefit analysis

For the North Sea NO_x ECA, compliance costs of the NO_x ECA increase between 2016-2030 as old ships are retired and replaced with NO_x ECA-compliant vessels, resulting in average annual cost increases of €19 million (IMO, 2016b). Additionally, the average NO_x abatement cost from establishing a NO_x ECA is estimated to be €1,878 per tonne NO_x (IMO, 2016b). Consequently, a cost-benefit analysis for the North Sea NO_x ECA estimated that the cumulative total compliance cost of establishing a NO_x ECA will be €282 million in 2030, with a total benefit to society estimated to at between €443-1,928 million (IMO, 2016b). This results in a cost benefit ratio (CBR) between 1.6 - 6.8, such that the benefits of the North Sea ECA are between 1.6 and 6.8 times as large as the costs (IMO, 2016b). Therefore, the relative costs of reducing NO_x emissions from ships are low.

Similarly, for the Baltic Sea NO_x ECA, the cost-benefit analysis concluded that the benefits justify the costs (IMO, 2016a). Nitrogen removal costs are similar to agriculture treatment (it is estimated that removing nitrogen from agriculture costs 3,500 EUR per tonne and 16.9 million EUR annually) and wastewater treatment (estimated to cost 12.6 million EUR/year) (IMO, 2016a) Furthermore, nitrogen abatement from RoRo, RoPax and container ships is cost-efficient with a unit cost being €3,000 per ton of NO_x (IMO, 2016a).

Mediterranean Sea SO_x ECA

The Mediterranean SO_x ECA was introduced on 1st January 2024 as an emission control area for SO_x. The Mediterranean SO_x ECA covers the waters internal to the Mediterranean Sea, with the exception of the Northern entrance to the Suez Canal (IMO, 2022).

Health impacts of the Mediterranean SO_x ECA

The reduction of SO_x emissions from the Mediterranean SO_x ECA brings significant health benefits to the Mediterranean region. The Health Impact Assessment found that the Mediterranean ECA is expected to prevent 1,000 annual premature deaths and 2,300 cases of childhood asthma (IMO, 2022). The premature death modelling results comprise a reduction in cardiovascular disease mortality of around 969 deaths per year and a reduction in lung cancer mortality of 150 deaths per year. In addition, a technical and feasibility study by REMPEC found that introduction of the Mediterranean SO_x ECA would result in a combined avoided mortality of 1,118 people for the assessment year of 2020, along with 2,314 avoided childhood asthma cases (REMPEC, 2019).

Cost-benefit analysis for NO_x emission control in the Mediterranean

With relevance to the current study, a MEDECA technical feasibility study was prepared as part of the proposal for the Mediterranean SO_x ECA which also evaluated the impact of introducing a NO_x ECA in the Mediterranean Sea (Ineris, 2019). The MEDECA study estimated through a modelling scenario that the implementation of a Med NO_x ECA will reduce NO_x emissions by 38% (compared to the 2015/16 baseline) when 50% of ships will be Tier III and by 77% when 100% of ships will be Tier III.

The study assessed the impact of an ECA for SO_x, NO_x and $PM_{2.5}$. Subsequently, the study projected a monetarised health gain of €8-14 billion per year for the entire Mediterranean from the reduction of all pollutants (NO_x, SO_x and PM) considered and the monetarised value of benefits doubled compared to 2020 if a Mediterranean NO_x ECA is introduced. Costs were estimated at between €1.4-2.7 billion, resulting in a BCR of around 5.2-5.7 (Ineris, 2019) (IMO, 2023a).

North-East Atlantic ECA

The North-East Atlantic ECA will be entered into force on the 1st January 2027 and will be the largest ECA to date globally, comprising of the exclusive economic zones and territorial seas of Portugal, Spain, France, UK, Ireland, Iceland, Faroe Islands and Denmark (Greenland) (IMO, 2024b). An advantage of this ECA is that it will connect to existing ECAs in the North and Baltic Sea and the Mediterranean. Thus, almost 90% of ships that will be sailing across the North-East Atlantic ECA will also navigate across other ECAs (IMO, 2024b). The North-East Atlantic ECA will reduce emissions of SO_x, NO_x and particulate matter.

Environmental impacts

The ECA is expected to reduce SO_x emissions by up to 82%, particulate matter by 64% and black carbon by 36%. It is also predicted that NO_x emissions will decrease by up to 71% over time with fleet renewal (ICCT, 2025). The ECA covers over 1,500 marine protected areas and 17 important marine mammal habitats so the reduction in shipping emissions will protect these ecosystems from further pollution and ocean acidification (ICCT, 2025) .

Health impacts

The reduction in SO_x and NO_x emissions is predicted to prevent 188 to 176 premature deaths in 2030 with a cumulative reduction of 2,900 to 4,300 premature deaths from 2030 to 2050 (IMO, 2024b). It will also benefit coastal communities including Indigenous groups in the Arctic who are vulnerable to the harmful effects of air pollution (ICCT, 2025).

Cost-benefit analysis

The proposal study estimates that implementing a SO_x, NO_x and particulate matter ECA the economic value of the health benefits is estimated at €0.82 to €1.23 billion in 2030 and €19 to €29 billion between 2030 and 2050 (IMO, 2024b).

The expected operation costs partly due to fuel switching and Tier III engine standard compliance are estimated at a total of €472 million for NO_x, SO_x and PM in 2030 (IMO, 2024b). This is calculated by the abatement costs for SO_x and PM emission reductions (fuel switching) for when vessels switch to Marine Gas Oil (MGO) is €437 million (SO_x - €5,845/tonne, PM2.5 - €17,872/tonne, PM10 - €16,442/tonne). Additionally, the costs of NO_x emission reductions (Tier III compliance) for new ships built between 2027 and 2030 is €35 million - €2,566/tonne. Therefore, the cost-benefit analysis indicates that the economic health benefits derived from reducing pollution significantly outweigh these abatement costs (IMO, 2024b).

2.2 Review of NO_x emission control policies and technologies

With a number of NO_x ECAs now in force across multiple locations and pollutants (Section 2.1), ex-post evaluations have begun to highlight shortcomings of existing technologies and processes for NO_x ECA compliance, as well as potential solutions for future NO_x ECA proposals.

Text Box 2-1 Tier Criteria under MARPOL Annex VI regulations

MARPOL Annex VI Regulation 13 states that applicable engines are required to meet (IMO , 2021):

1. Tier 1 if installed between 2000 and 2011 and prior to 2000.
2. Tier 2 if installed after 2011.
3. Tier 3 if installed after the introduction of a NO_x ECA and operating in the NO_x ECA, i.e. currently 2016 (for North American and US Caribbean) or 2021 (for Baltic Sea and North Sea). Recreational purposes as sole vehicle use or shipbuilding activities is excluded from Tier 3 requirements.

2.2.2 Three-dates criteria for NO_x ECA introduction

A delay in the keel-laying dates and ship delivery dates prior to the introduction date of existing NO_x ECAs has been identified, resulting in lower NO_x emission reductions than expected due to the delayed implementation of the Tier III regime (IMO, 2023a).Thus this loophole in the regulations reduced the effectiveness of the NO_x ECA.

In particular, for ships calling at the four Canadian ports covered by the North American NO_x ECA since 2016, only 0.5% of total vessels were Tier III compliant in 2019 (Starcrest Consulting Group LLC, 2020). Analysis of ship-building activity showed that a total of 4,736 keels were laid in the year 2015 prior to the NO_x ECA introduction (18% of all keels laid in the 10-year period 2005-2019), whilst the average time between keel-laying and in-service dates increased from 1.4 years before 2015 to 2 years on or after 2015 (39% increase). Additionally, since 2005, more than 1,000 keels laid have still not been built, and roughly 70% of these ships will not meet the Tier III standard. This backlog of pre-Tier III ships delayed the deployment of the cleanest Tier III ships. Consequently, in the Canadian Arctic waters, Tier III ships are not expected to comprise a substantial part of the fleet until the mid-to-late 2040s with the earliest dates in the mid-2030s for only a few ship types. As such, analysis of data from the introduction of existing ECAs has demonstrated that the application of Regulation 13 to only new-build vessels allows keels laid before the introduction date to be permanently exempt from stricter NO_x emission limits, significantly impacting the uptake and impact of Tier III-compliant vessels.

To resolve the issue of the high keel rate before NO_x ECA introduction dates, the Norwegian Sea Proposal proposed the application of the 'Three Dates Criteria', as introduced by the IMO *Guidance on drafting of amendments to the 1974 SOLAS Convention and related mandatory instruments* (IMO, 2022). This approach differentiates between building contract and/or keel-laying dates, and ship delivery dates (IMO, 2023b), as presented in Text Box 2-2Text Box 2-2.

Text Box 2-2 The Three Dates Criteria under IMO SCIPER and MARPOL regulations

The Three Dates Criteria states that the application of regulation to a ship is governed by the dates (IMO, 2023b):

1. For which the building contract is placed on or after dd/mm/yyyy; or
2. In the absence of a building contract, the keel of which is laid or which is at a similar stage of construction on or after dd/mm/yyyy; or
3. The delivery of which is on or after dd/mm/yyyy.

Following the Three-Dates Criteria, the proposal for the Norwegian ECA provided concrete requirements for ships to strictly comply with Tier III thresholds if the delivery date (rather than keel-laying date) is on or after the introduction of the ECA (2030) or when the keel-laying or order is received on after 2026 (IMO, 2023b).

Development of NO_x emissions control technology

SCR and EGR methods are two key examples of NO_x emissions technologies that are being used, developed and refined to meet ECA Regulatory standards. SCR operate better at higher exhaust temperatures not typically seen at loads below 25% maximum continuous power (MCP). EGR systems are an alternative method for engines to reach Tier III NO_x and are most suitable for large 2-stroke slow speed engines where the exhaust temperature is low for SCR (EGCSA, 2014). SCR technology can be used on any diesel ship engine to achieve Tier III NO_x compliance (Mathur, 2020).

However, there is concern that real-world emissions are not complying with Tier III standards even if the engine has the relevant certification (Starcrest Consulting Group LLC, 2023). This is because actual NO_x emission levels may exceed Tier III standards when ships with IMO NO_x Tier III propulsion engine are operating within ECAs at low loads (below 25% MCR), such as in ports, coastal and inland areas, and ship speed reduction (VSR) zones. These low-load operations occur close to land where populated communities are located and where it is most important to ensure emission reductions.

The techno-economic characteristics of SCR and EGR for NO_x emission abatement are discussed in further detail in Section 5.3. To lower Tier III compliance for ship operators in the future, advancing technologies in SCR and EGR are crucial, as well as greater adoption of alternative fuels such as Liquefied Natural Gas (LNG) and engine optimisation.

3. POSSIBLE DESIGNATION OF THE MED NOX ECA

3.1 Area of application

The area of application of the potential Med NO_x ECA would align with the existing Med SECA. Following the International Hydrographic Organization (IHO) definition of the Mediterranean Sea (IHO, 1953), it is bounded on the southeast by the entrance to the Suez Canal, with the exception of the waiting area of the Suez Canal, on the northeast by the entrance to the Dardanelles, delineated as a line joining Mehmetcik and Kumkale lighthouses, and to the west by the meridian passing through Cap Spartel lighthouse, also defining the western boundary of the Straits of Gibraltar.

The geographical scope of the Mediterranean Sea, which is also outlined in Article 1.1 *Geographical scope* of the Barcelona Convention (UNEP, n.d.), includes 22 Contracting Parties. These Parties are Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syrian Arab Republic, Tunisia, Türkiye, and the European Union.

The proposed area of application for the designation of the proposed Med NO_x ECA, and subsequently modelled in this Study, is illustrated in Figure 3-1.

Figure 3-1 Area covered by proposed Med NO_x ECA

3.2 Possible entry into force dates

Considering feedback from the introduction of existing NO_x ECAs (see Section 2.2), the proposed Med NO_x ECA uses the "**three dates criteria**" approach introduced by the IMO Guidance (IMO, 2022) and adopted by the introduction of the Norwegian NO_x ECA. This would involve individual deadlines for the building contract, keel-laying, and ship delivery of ship orders to meet Tier III compliance requirements. This combined approach could prevent an increase in keel-laying activity prior to entry-into-force of a potential Med NO_x ECA in an effort to circumvent emission requirements, as seen in the implementation of the NO_x ECAs in the Baltic Sea, North Sea and the North American NO_x ECAs.

Guidance on the application of the 'three dates criteria' is presented in Text Box 3-1.

Text Box 3-1 Guidance on format application dates (IMO, 2022)

Guidance on drafting of amendments to the 1974 Solas Convention and related mandatory instruments (MSC.1/Circ.1500/Rev.2, 30 November 2022)

Specific details on format application dates (section 4.2.1)

In case the 'three dates criteria' is used, the following definition should be inserted: "The expression ship constructed on or after DDMMYYYY means:

1. For which the building contract is placed on or after (date 1); or
2. In the absence of a building contract, the keel of which is laid, or which is at a similar stage of construction on or after (date 2); or
3. The delivery of which is on or after (date 3)".

As guidance, date 1 is DDMMYYYY, date 2 is 6 months after date 1, and date 3 is 48 months after date 1.

This phased compliance mechanism provides legal clarity and implementation flexibility, while preventing circumvention of the regulation through early shipbuilding. It also ensures adequate lead time for shipyards and operators to incorporate Tier III-compliant technologies.

Earliest entry-into-force dates: 2029

According to the roadmap on the process for the designation of a Med NO_x ECA presented in Section 8.2, the earliest entry-into-force date considered is 2029.

Based on this timeline, new-build ships will be required to comply with Tier III NO_x standards as defined under Regulation 13 of MARPOL Annex VI when operating within the Mediterranean NO_x ECA if they meet the following criteria:

- **Build contract date**: on or after entry into force date (date 1: 2029)
- **Keel laying date**: on or after six months after date 1 (date 2: late 2029 – early 2030)
- **Delivery date of the ship**: on or after three years after date 1 (date 3: 2032)

Accordingly, the cost and impact modelling assumes 2032 as the first year in which the effects of the implementation will be observable (referred to in this Study as the 'introduction date'). This corresponds to the expected delivery date of ships contracted after the regulation enters into force (date 3).

While a four-year window between contract signing and delivery has been recommended in some cases, this Study uses a three-year period for the following reasons: (i) it reflects typical commercial shipbuilding lead times for standard vessel types, which generally range between 24 and 36 months, depending on the availability of shipyards (AXS Marine, 2024); and (ii) it facilitates a more timely realisation of the regulation's impacts following its entry into force, which is important for ensuring the effectiveness of the proposed measures.

Second possible entry into force date: 2032

A second possible entry-into-force date considered in this study is 2032, should the preparatory process and decision-making at the regional (Barcelona Convention) and global (IMO) levels require more time. Under this scenario, the compliance criteria for new-build ships would shift accordingly:

- **Build contract date**: on or after entry into force date (date 1: 2032)
- **Keel laying date**: on or after six months after date 1 (date 2: late 2032 – early 2033)
- **Delivery date of the ship**: on or after three years after date 1 (date 3: 2035)

In this case, 2035 would be considered the 'introduction date' for modelling purposes, as it represents the earliest year in which newly built ships subject to the Tier III requirement would be expected to enter into service.

Third possible entry into force date: 2035

A third possible entry-into-force date considered in this study is 2035, should the preparatory process and decision-making at the regional (Barcelona Convention) and global (IMO) levels require more time. Under this scenario, the compliance criteria for new-build ships would shift accordingly:

- **Build contract date**: on or after entry into force date (date 1: 2035)
- **Keel laying date**: on or after six months after date 1 (date 2: late 2035 – early 2036)
- **Delivery date of the ship**: on or after three years after date 1 (date 3: 2038)

In this case, 2038 would be considered the 'introduction date' for modelling purposes, as it represents the earliest year in which newly built ships subject to the Tier III requirement would be expected to enter into service.

3.3 Emissions proposed for control

This technical and feasibility study assesses the impact of the possible designation of an ECA to control NO_x emissions from ships in the Mediterranean Sea (as defined in Section 3.3). This would be introduced alongside the existing Med SO_x ECA already in place to control SO_x and PM emissions from ships in the Mediterranean Sea (IMO, 2022).

Nitrogen oxides (NO_x) is a collective term for a group of highly reactive gases composed of varying proportions of nitrogen and oxygen. The term typically refers to two specific gases: nitric oxide (NO), a colourless and odourless gas, and nitrogen dioxide (NO_2), a reddish-brown gas with a pungent odour. However, most nitrogen oxides are colourless and odourless, making them difficult to detect without specialised equipment (EEA, 2025).

In Europe, NO_x emissions from human activities are the predominant source of total emissions. The primary contributors include electricity generation in power stations, road transport, and various industrial and domestic combustion processes. NO_x emissions from diesel engines are separated into NO and NO_2, with NO typically accounting for 95% of total NO_x. NO_x emissions from ships are generated mainly from air-derived nitrogen during the combustion process in ship engines and to a smaller extent from the small share of nitrogen in the fuel itself. The amount of NO_x formed depends on the operation of the ship (engine load, engine speed (RPM), engine temperature, etc.). The most significant environmental and health impacts of NO_x occur through PM formation through contribution to secondary PM, contribution to NO_2 concentrations, contribution to ozone formation, nitrogen deposition, and eutrophication and nitrogen contribution to acidification.

NO_x and other air pollutants like volatile organic compounds also act as ozone precursor, which are a secondary source of ozone pollution when subject to photochemical reactions sensitive to temperature and sunlight. Extended high ambient temperatures and sunlight levels for multiple days can create a relatively stagnant atmosphere that allow ozone and its precursors to build up. Ozone can be transported hundreds of kilometres downwind of precursor emissions sources, resulting in elevated ozone levels even in areas with low local precursor emissions. Therefore, control of precursor formation is critical to reduce ozone levels and the associated health impacts from ozone exposure, including chest pain, coughing, throat irritation, and congestion. For people with pre-existing heart and lung problems, ozone exposure can worsen bronchitis, emphysema, and asthma.

Based on this, the designation of a Med NO_x ECA would complement the existing SO_x ECA by addressing NO_x emissions alongside the SO_x and PM already regulated, thereby broadening the scope of air pollutant controls from maritime sources. Furthermore, it would establish a harmonised regulatory framework and a comprehensive strategy for mitigating air pollution from ships. The combined implementation of the two ECAs would be expected to deliver enhanced environmental and public health benefits through the combined reduction of these key pollutants.

A harmonised regulatory framework would further support effective compliance and enforcement. Enforcement procedures could be integrated and streamlined, allowing competent authorities to address the requirements of both ECAs through coordinated inspections, standardised verification processes, and targeted training programmes. In particular, the potential for a unified regulatory framework for both NO_x and SO_x emissions would simplify compliance for the shipping industry, reduce administrative burdens, and promote the adoption of cleaner technology solutions, such as LNG fuel and the Selective Catalyst Reduction (SCR) system, that simultaneously reduce NO_x, SO_x and PM pollutants.

Existing capacity-building and awareness-raising efforts under the Med SO_x ECA provide a solid foundation that can be leveraged and adapted to support the effective and harmonised implementation of a potential NO_x ECA, promoting efficiency, consistency, and the dissemination of best practices across the region.

3.4 Population and environment at risk from exposure to ship emissions

The Mediterranean Sea is a geographically enclosed area, bordered by land on all sides, and is home to significant coastal populations, critical shipping routes, and valuable cultural and natural heritage.

<u>Coastal populations</u>: In 2018, the Mediterranean coastal States were home to approximately 512 million people, which constitutes around 6.7% of the global population. Of this population, nearly one-third resides in coastal areas[3], with over 70% living in urban environments (PlanBleu, 2021). By 2025, the population living in Mediterranean coastal zones is projected to reach 529 million.

<u>Environmental areas at risk</u>: The Mediterranean region is home to a high concentration of population centres, as well as numerous culturally and environmentally significant sites. These include UNESCO World Heritage sites, archaeological landmarks, and ecologically sensitive marine and coastal ecosystems.

[3] Coastal areas are local administrative units (LAUs) that are bordering or close to a coastline. A coastline is defined as the line where land and water surfaces meet (border each other). Available at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Coastal_area

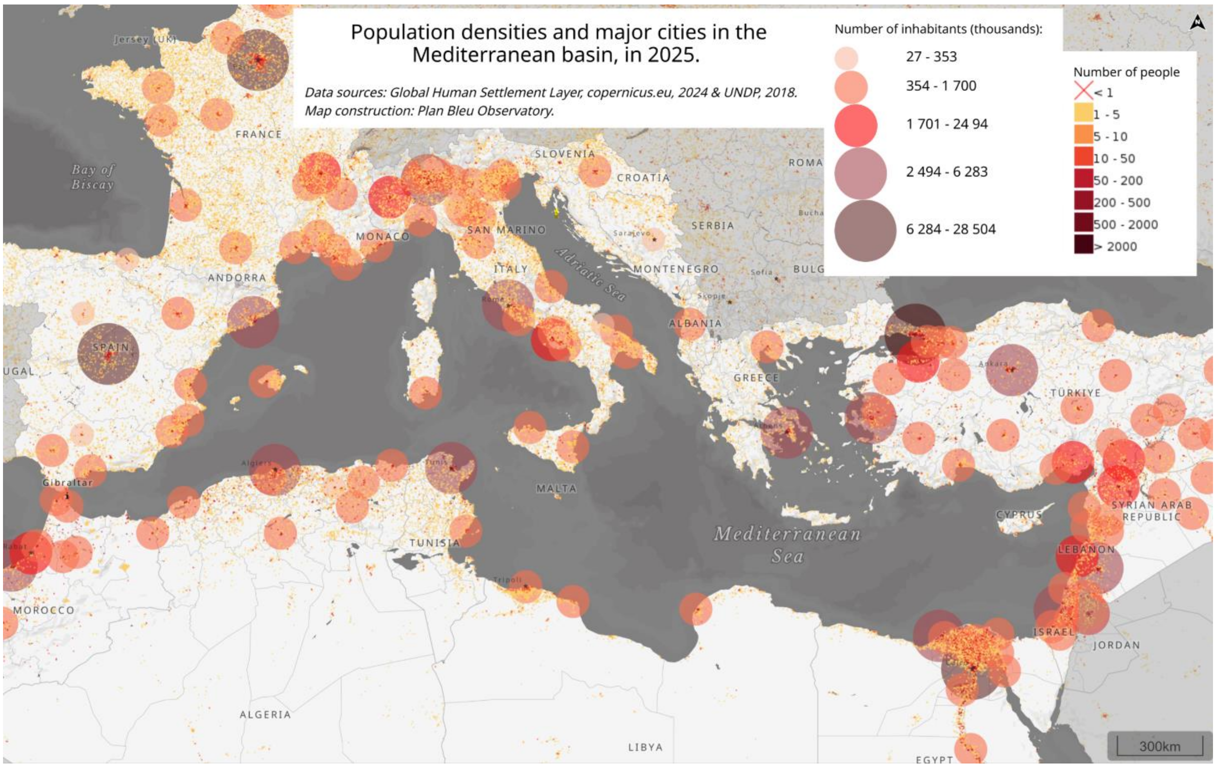
The coastal waters of the Mediterranean Sea are considered 'highly vulnerable to climate change' (UNCTAD, 2018), as the area is heavily impacted by various pollutants, including high nutrient fluxes that contribute to eutrophication, leading to hypoxia, anoxia, harmful algal blooms, and mucilage formation. These phenomena negatively affect marine ecosystems, fisheries, aquaculture, and tourism, contributing as well to air and water quality degradation. Reports indicate that the Mediterranean basin is already experiencing the effects of climate change at a rate exceeding the global average (PlanBleu, 2021). As anthropogenic pressures in coastal zones continue to rise, compounded by climate change, the risks of these cumulative impacts are expected to increase, affecting both ecological systems and the economy.

Such areas are particularly susceptible to air pollution arising from maritime traffic[4], notably emissions of nitrogen oxides (NO_x), which contribute to the formation of ground-level ozone and secondary particulate matter. However, the impact of ship emissions is not limited to coastal zones. Atmospheric transport mechanisms enable pollutants to travel considerable distances inland, thereby affecting air quality well beyond the immediate vicinity of ports and shipping routes. As a result, both coastal and inland populations are exposed to elevated levels of air pollution, with associated risks to human health, including respiratory and cardiovascular conditions. Furthermore, NO_x emissions contribute to environmental degradation through processes such as soil acidification and eutrophication, which can have detrimental effects on biodiversity.

Therefore, the establishment of a NO_x ECA in the Mediterranean is expected to yield public health and environmental benefits across the region. In addition to improving air quality in urban and rural areas alike, a NO_x ECA would support the protection of vulnerable ecosystems and help to preserve cultural heritage sites that are at risk from the corrosive effects of air pollutants.

[4] Mediterranean fleet stock projections (2025-2050) are presented in Figure 5-2 (Section 5.1.1 of this report).

Figure 3-2 Population density in the Mediterranean Sea



Source: REMPEC: Data sources: Global Human Settlement Layer, Copernicus.eu, 2024 & UNDP, 2018. Map construction: Plan Bleu Observatory.

3.5 Local conditions influencing air pollution

Meteorological conditions in the Mediterranean, particularly prevailing onshore winds, are key drivers to the dispersion of NO_x emissions from shipping, carrying pollutants far from their source and inland. These conditions also influence the deposition of emissions, determining how and where they are removed from the atmosphere, with significant implications for both marine and terrestrial ecosystems across the region (IMO, 2022). Once emitted, these pollutants can travel significant distances due to atmospheric processes. It is estimated that approximately 70% of shipping emissions occur within 400 km of the coast, underscoring the close proximity of maritime pollution to coastal populations (Fink, et al., 2023).

Analysis indicates that winds frequently blow onshore throughout the Mediterranean Sea (IMO, 2022). This prevailing wind pattern is vital as it transports emissions from ships at sea, along with pollutants formed in the atmosphere, over land and potentially hundreds of kilometres inland. Consequently, NO_x emissions and their derivatives, such as particulate matter (PM), can be dispersed far beyond their point of origin.

NO_x emissions from ships, along with their secondary pollutants, can remain airborne for five to ten days before being removed from the atmosphere through processes such as deposition or chemical transformation. During this period, prevailing winds facilitate the movement of these pollutants across both water and land adversely affecting large portions of Mediterranean coastal States.

Furthermore, meteorological conditions influence the deposition of NO_x and related compounds. Deposition can occur via both wet and dry processes: wet deposition, where pollutants are incorporated into rain, and dry deposition, where particles settle through gravitational processes. Coastal areas are particularly susceptible to the deposition of oxidised sulphur from ships, which can account for between 5% and 70% of total sulphur deposition in Mediterranean coastal States, depending on proximity to shipping lanes. Additionally, elevated NO_2 deposition over water can contribute to eutrophication, affecting marine ecosystems (Fink, et al., 2023)).

4. CONTRIBUTION OF SHIPPING TO NO_X EMISSIONS

This section presents an estimate of current (2021-2024) traffic and NO_x emissions from shipping within the scope of a possible designation of an NO_x ECA in the Mediterranean Sea. Data on the current fleet and emissions levels are used as input to the scenario analysis in Section 5.

The section is structured as follows:

- Section 4.1 Methodology
- Section 4.2 Current ship traffic in the Mediterranean Sea
- Section 4.3 Estimation of current NO_x emissions

4.1 Methodology

4.1.1 AIS-based traffic and emissions modelling

For this Study, an in-house model provided by Marine Benchmark (MB) was used to estimate number of vessels, energy use and NO_x emissions data in scope for years 2021 - 2024. This model combines AIS data[5] with ship register data. The ships data is primarily provided by S&P Global, the formal UN supported IMO ship register operating the IMO number scheme.

The movements of ships come from AIS signals. The model includes a detailed mapping of IMO vessel numbers to the MMSI[6] number of the AIS transponders, which is verified both by MB and S&P Global. This significantly reduces the risk of double counting vessels as it uses unique IMO numbers to identify vessels rather than MMSI numbers from AIS signals. The MB ship database covers more than 99% of vessels in the global fleet. From the AIS signals, latitude/longitude and draft data is extracted and distance, speed and intake between points are calculated. Weather and other parameters are added.

The model combines ship specific characteristics (fuel coefficient for each vessel's engine and primary fuel type) with environmental/operational data to estimate fuel consumption from the primary fuel along with auxiliary and boiler consumption.

The emission module consists of different types and emission factors according to different standards. For NO_x, different sets of emission factors are being used (Section 4.1.3).

4.1.2 Scope

The AIS-based model described above is applied to the following scope (Table 4-1).

Table 4-1 Scope of NO_x emissions modelling

Element	Description
Source of NO_x emissions	NO_x emissions in scope for shipping are those arising from the combustion of marine diesel engines (both main engines and

[5] Data from Automatic Identification System (AIS) is used to determine the location of vessels along with operational characteristics at any given point in time.

[6] Maritime Mobile Service Identities (MMSIs) are nine-digit numbers used by maritime digital selective calling (DSC), automatic identification systems (AIS) and certain other equipment to uniquely identify a ship or a coast radio station.

Element	Description
	auxiliary engines). Emissions from slippage are excluded from the analysis, as they are not subject to NO_x Regulations.
Period	The base year for estimating current emissions is 2023. However, emissions for years 2021, 2022 and 2024 are also presented. 2024 was not considered for the base year because traffic in the Mediterranean Sea is severely affected by the Red Sea crisis.
Geographical scope	Area of application of the possible NO_x ECA as defined in section 3.1.
Vessels in scope	The modelling includes vessels operating in the Mediterranean Sea in a given year and within the scope of NO_x Regulations. Vessels in scope include those across all gross tonnage (GT) categories and vessel types, with engine power exceeding 130 kW. Vessels with an operational time of over 95% within the exclusive economic zone (EEZ) of the own flag are assumed to operate only within their own flag State waters. This 95% threshold was applied to avoid disturbances. These vessels have been reported separately as they could be subject to a different regulatory treatment.

4.1.3 Emission factors

Emission factors for conventional engines/fuels

Two sets of NO_x emission factors per energy consumed have been used to estimate NO_x emissions from shipping:

- *Regulatory values*: The emission factors are based on maximum permissible values in NO_x Regulation for Tier I-III engines, classified by engine group (as outlined in Annex VI, including Tier 0, 1, 2, 3 and RPM settings: low, medium, and high).
- *Real-world values*: Modelled real world emission factors based on sniffer measurements defined in terms of a NO_x curve per engine load and engine group.

Regulatory values are meant to represent an upper bound of NO_x emissions for a given engine type and Tier category. Emission factors used in the analysis are summarised in Table 4-2 below. It is assumed that in the absence of a NO_x ECA, vessels certified as Tier III can emit up to Tier II NO_x levels.

Table 4-2 NO_x emission limits in gNO_x/kWh for Tier II and Tier III compliance for a range of engine speeds in RPM, as well as the relative reduction between Tier II and Tier III NO_x emissions.

RPM	Tier I (gNO_x/kWh)	Tier II (gNO_x/kWh)	Tier III (gNO_x/kWh)	Tier III reduction (%Tier II)
100	17.00	14.40	3.40	76%
300	14.38	11.85	2.88	76%
600	12.52	10.10	2.50	75%
1000	11.30	8.98	2.26	75%

Source: IMO (2008)

Emission factors representing real-world conditions are based on a new more advanced (nonlinear) model which considers specific NO_x curves by engine type and load. This is based on a large amount of data from sniffer measurements and review of existing literature in the context of Swedish/Danish public and academic research project (NESA)[7].

The model to derive real-world emission factors applied a similar grouping of vessels as in previous approach based on regulatory values and considered a load related NO_x curve for every Tier class and engine speed. Twelve load related curves were established and applied vessels individual load measured every 10 minutes for the calculation. This calculation was made for 35,630 vessels, active in the Mediterranean Sea in the period 2021-2024 and within the scope of this analysis.

This preliminary methodology does not take into consideration non-compliance to the NO_x Regulation (i.e. potentially fraudulent practices). This will be the result of the remaining part of the NESA project, between March 2025 and December 2025. Final result of NO_x emissions can assumably not be lower but realistically slightly higher, depending on the level of non-compliance.

Adjustment for alternative fuels

Marine fuels emit varying levels of NO_x emissions depending on their unique chemical reactions and engine combustion temperatures. As such, it is necessary to consider the implications of different fuel shares on fleet-wide NO_x emissions.

Alternative marine fuels[8] typically have lower NO_x emission factors compared to the conventional fuel baseline. As such, a fleet-average scale factor using the fuel-specific scale factors in Table 4-3 is applied to adjust for the use of alternative fuels. The scale factors were derived by obtaining the NO_x emission reductions from a number of sources, determining a range and then using the intermediate value.

[7] The project is financed by the Swedish Government via Swedish Trafikverket. Partners in this project include IVL Swedish Environmental Research Institute and Chalmers University.

[8] Alternative maritime fuels considered within this Study are methanol, LNG, hydrogen, ammonia, and electricity.

As detailed in Table 4-3, a wide range of emission reduction values were obtained for using LNG. This is because the emission reduction is dependent on engine technology. For this Study, we are assuming that all new vessels will be Tier III compliant and therefore vessels using LNG are likely to use Otto Cycle Dual-Fuel engines (Low-pressure) as this has been found to achieve compliance with Tier III requirements without after treatment (International Council on Clean Transportation, 2023). Therefore, the level of NO_x emissions from using LNG relative to the baseline value is likely to be at the lower end of the range identified. As such, 15% was considered a suitable scale factor.

Table 4-3 Relative NO_x emissions for alternative maritime fuels included in the NMGMT/GMTM scenarios, relative to the baseline fuels of HFO + scrubber and VLSFO/MGO/HVO.

Fuel type	Range of NO_x emissions relative to the baseline fuels	Sources	Value used as scale factor
HFO + scrubber, VLSFO/MGO/HVO (Baseline fuels)	100%	-	100%
Methanol	30% to 40%	DNV (2016); (Sustainability Ships, 2023) Lloyd's Register (2024)	35%
LNG	5% to 80%	WARTSILA (2024); (DNV, n.d.); (SEA / LNG, 2020)	15%
Hydrogen	50%	Ricardo analysis[9]	50%
Ammonia	40%[10]	Wong et.al. (2024); (Man Energy Solutions, 2024)	40%
Electricity	0%	Excluding indirect emissions	0%

Sources: Various, indicated in the table.

[9] EEA (2023) [https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/1-energy/1-a-combustion/1-a-annex-hydrogen-combustion-2023] concluded that "there is currently insufficient information to provide emission factors" for hydrogen as a maritime fuel. However, some recent research evidence from ABS (2022) [ABS releases Guidance on the Potential of Hydrogen as a Marine Fuel - SeaNews] and Lewis (2021) [Optimising air quality co-benefits in a hydrogen economy: a case for hydrogen-specific standards for NOx emissions] suggests the potential for hydrogen combustion during lean-burn engine cycles to lower NO_x emissions. As such, it is assumed that the NO_x emissions from hydrogen is reduced by 50% relative to the maritime fossil baseline fuels.

[10] Both sources provide a NO_x emission of 40% and therefore no range was obtained.

4.2 Ship traffic in the Mediterranean Sea

The Mediterranean Sea is one of the world's busiest areas for maritime traffic due to it being popular for shipping, cruise and ferry routes. It also holds a strategic position at the intersection of three key maritime routes, which include the Strait of Gibraltar, which provides access to the Atlantic Ocean, the Suez Canal, offering a link via the Red Sea to Southeast Asia, and the Bosporus Strait, which connects to the Black sea and extends into Eastern Europe and Central Asia (Plan Bleu, 2021a).

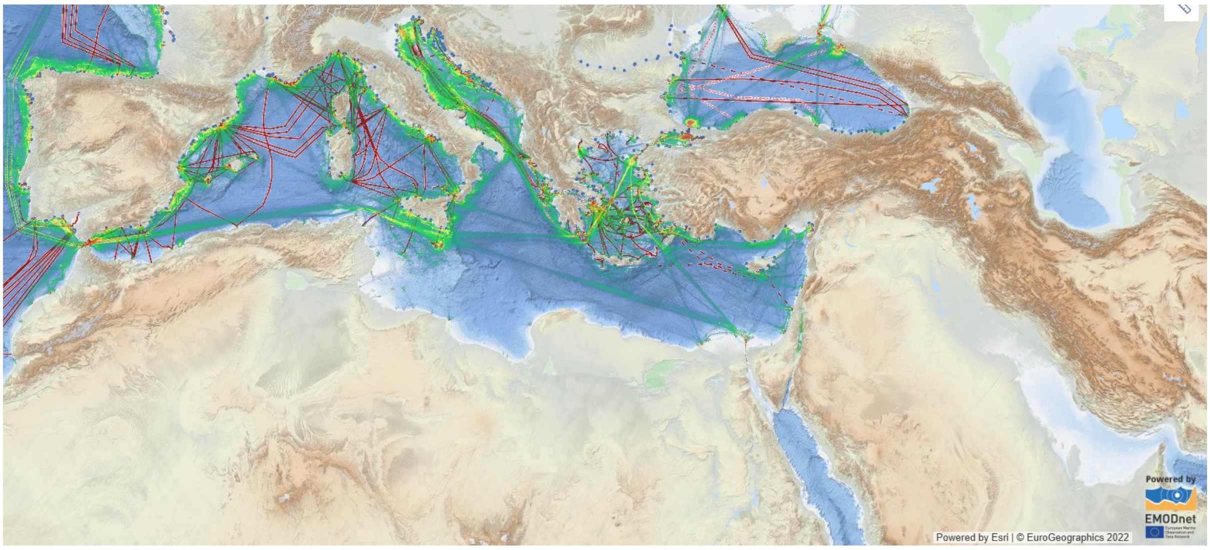
A third of world trade is shipped through the Mediterranean through the Suez Canal to the Strait of Gibraltar (Reynaud, n.d.). Mediterranean countries depend on well-connected ports and cost-effective shipping services (Hoffmann, 2021). There are 480 ports and terminals in the Mediterranean, of which 20% are in the Eastern Mediterranean, east of Greece, and 80% are located in the West and Central Mediterranean (Lloyd's Marine Intelligence Unit, 2008). The Mediterranean has both commercial shipping traffic flows, cruise traffic, ferry traffic, and oil and gas shipping flows (Figure 4-1**Error! Reference source not found.**).

The most significant traffic flows are the Asia-Europe trade route which flows from Suez Canal to Gibraltar and carries goods between Asia and Europe (Lloyd's Marine Intelligence Unit, 2008). A typical such route would be Singapore to Rotterdam via the Mediterranean. Additionally, the Trans-Atlantic route connecting Europe with North America via the Strait of Gibraltar is a major traffic flow. A typical such route would be from a Mediterranean Port (e.g. Piraeus or Valencia) to a North American Port such as New York via the Strait of Gibraltar. Furthermore, maritime traffic bound for the Black Sea from international waters also transits through the Mediterranean (Lloyd's Marine Intelligence Unit, 2008). These voyages, which pass through the Strait of Gibraltar and continue via the Bosporus Strait, include both long-haul Asia-Europe trade and regional feeder services originating from Mediterranean ports.

Additionally, the Mediterranean is busy with routes for intra-mediterranean traffic flows which represented 58% of total mediterranean traffic in 2016 (Khodjet, et al., 2020).

The Mediterranean is also the second biggest cruising region in the world after the Caribbean – Western mediterranean route from Barcelona-Marseille, Genoa, Rome, Naples, to Malta. Eastern Mediterranean cruise route from Venice via Dubrovnik, Piraeus, and finishing in Istanbul (Khodjet, et al., 2020).

Figure 4-1 Map of maritime traffic – the green lines indicate vessel traffic density (2021) and the red lines illustrate regular ferry routes (European Commission, 2025c)



4.3 Fleet operating in the Mediterranean Sea

Figure 4-2 presents the number of vessels per Tier (including Tier 0, Tier I, Tier II, Tier III) for each year from 2021 to 2024.

The number of vessels in 2024 is slightly lower compared to 2023, primarily due to the Red Sea crisis, which led to detours via the Cape of Good Hope, thereby avoiding the Mediterranean in certain cases. As a result, 2023 is used as the reference year for this analysis.

In 2023, approximately 24,000 unique vessels operated in the Mediterranean Sea. Of these, around 3,900 vessels (16%) operated exclusively within flag State waters. As per Regulation 13(1)(b)(ii) of MARPOL Annex VI, ships operating exclusively within flag State waters could be exempted from the NO_x ECA provided that the engines are subject to an alternative NO_x control measure established by the Administration. However, in practice, flag States are not likely to make use of this exemption as the only way to comply with Tier III NO_x limits is through the use of existing aftertreatment technologies, such as SCR or EGR.[11] For this reason, domestic vessels (i.e. operating exclusively within flag State waters) are included in the subsequent analysis on NO_x emissions and assessment of impacts.

Vessels certified as Tier III represented only 8% of the total fleet operating in the Mediterranean in 2023. This proportion has increased from 5% in 2021 to 10% in 2024. The large majority of vessels operating in the Mediterranean Sea in 2023 are Tier I (37%) or Tier II (20%).

In summary, while the share of Tier III vessels is growing rapidly, the current share is still relatively low. This result implies that the introduction of a Med NO_x ECA is expected to have

[11] The US does make use of the exemption under Regulation 13(1)(b)(ii) of MARPOL Annex VI because the Environmental Protection Agency (EPA) does have their own regulations for marine engines operating solely within their waters. However, EPA's regulations match with MARPOL Annex VI for large marine diesel engines. Hence, in practice, similar regulations apply to the domestic fleet.

modest benefits in air pollution abatement in the short term, but benefits are expected to rapidly increase as Tier III vessels represent a larger share of the fleet operating in the Mediterranean Sea.

Figure 4-2 Number of vessels per Tier and year

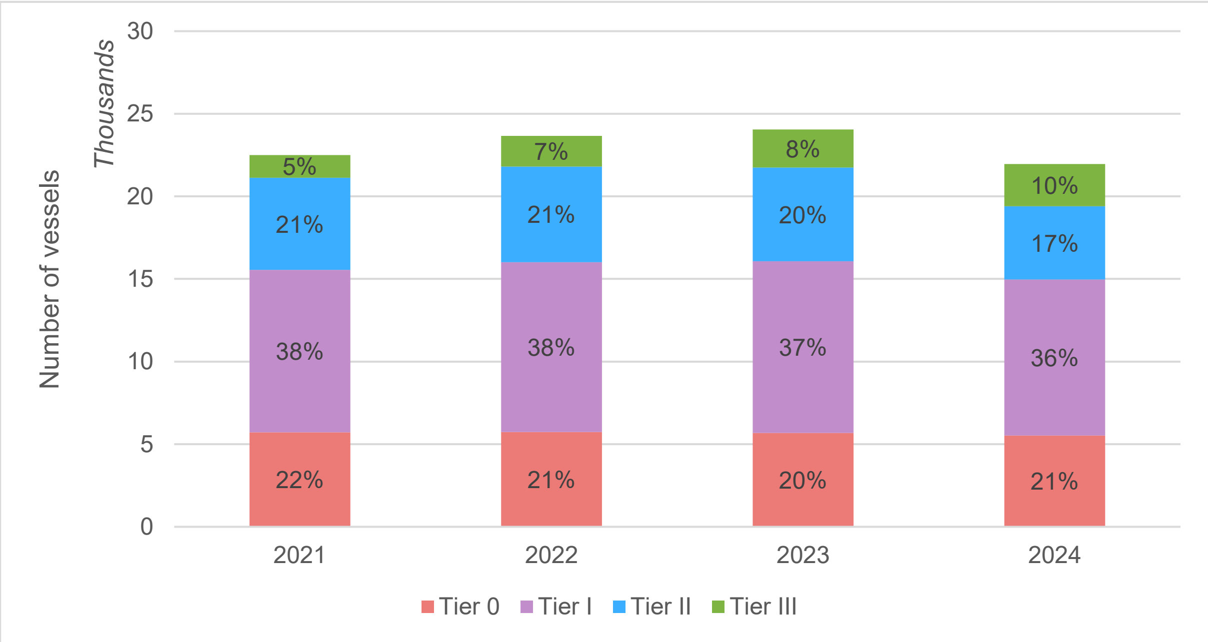
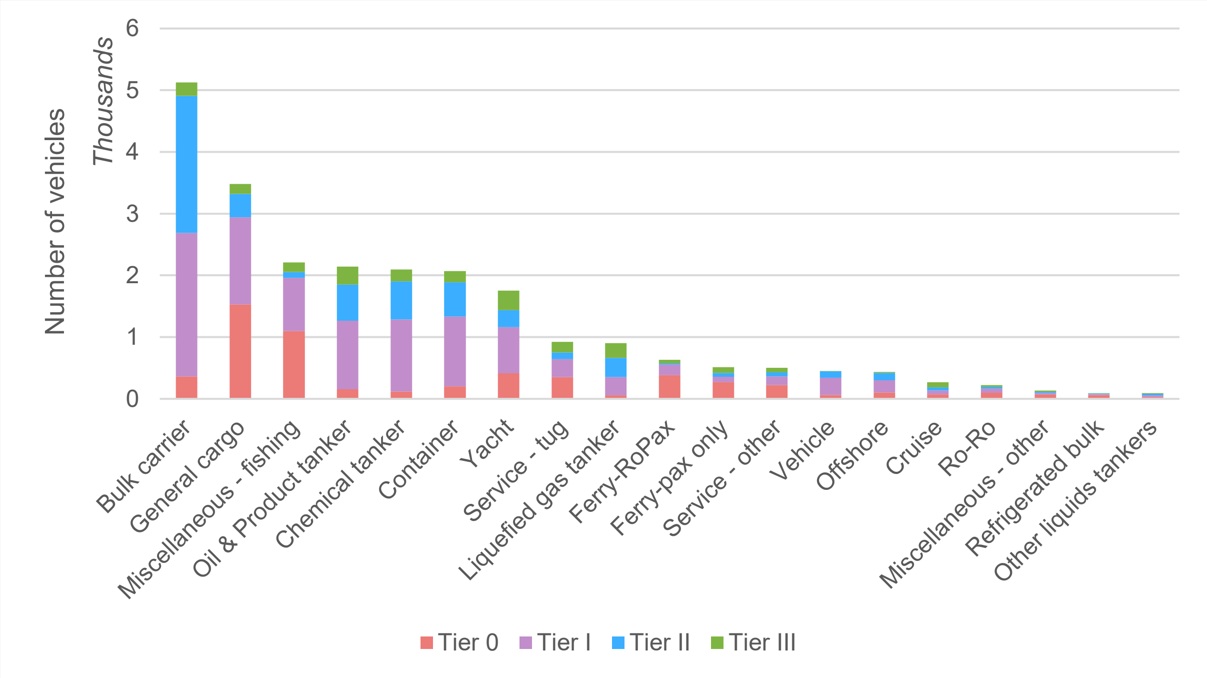


Figure 4-3 presents the number of vessels by Tier and vessel category for 2023. This shows that the fleet operating in the Mediterranean Sea is dominated by bulk carrier and general cargo vessels. This chart also demonstrates that some vessel categories, such as general cargo vessels, tend to be associated to a higher share of older (e.g. Tier 0 and Tier I) vessels, and hence with higher emissions.

Vessels operating exclusively within flag State waters are essentially fishing vessels, tugs and ferry-RoPax vessels. Other vessel categories have a marginal share of operations solely within flag State waters.

Figure 4-3 Number of vessels in 2023 by Tier and type



4.4 Estimation of current NO_x emissions from shipping

NO_x emissions from shipping vessels in scope of this Study (i.e. excluding vessels with engine power lower than 130 kW) were estimated based on the methodology described in section 4.1. Figure 4-4 shows NO_x emissions estimated based on real-world emission factors, which are compared against NO_x emission estimated based on maximum permissible emission factors in the NO_x Regulation.

In 2023, 1,415 ktonnes of NO_x were emitted within the area of application of the Mediterranean Sea by vessels subject to NO_x Regulations (calculated with real-world emission factors). This is 14% lower than the estimated value of 1,637 ktonnes of NO_x, assuming maximum permissible regulatory values in the absence of an NO_x ECA. As described in section 4.1.3, real-world emission factors used for this Study are not capturing non-compliant cases, which is the main reason why real-world figures are lower than those based on maximum permissible values.

NO_x emissions grew from 2021 to 2023, mostly driven by the increased maritime traffic activity over this period. Similarly, NO_x emissions dropped in 2024 due to the reduced traffic in the Mediterranean associated with the Red Sea crisis.

NO_x emissions from vessels operating solely within flag State waters represented around 8% of total NO_x emissions in 2023. This compares against a share of 16% in the number of vessels, which indicates that the domestic fleet tends to be associated with smaller and less emitting vessels.

Figure 4-4 NO_x emissions from shipping within the scope of a potential NO_x ECA in the Mediterranean Sea over the period 2021-2024, based on real-world and regulatory emission factors

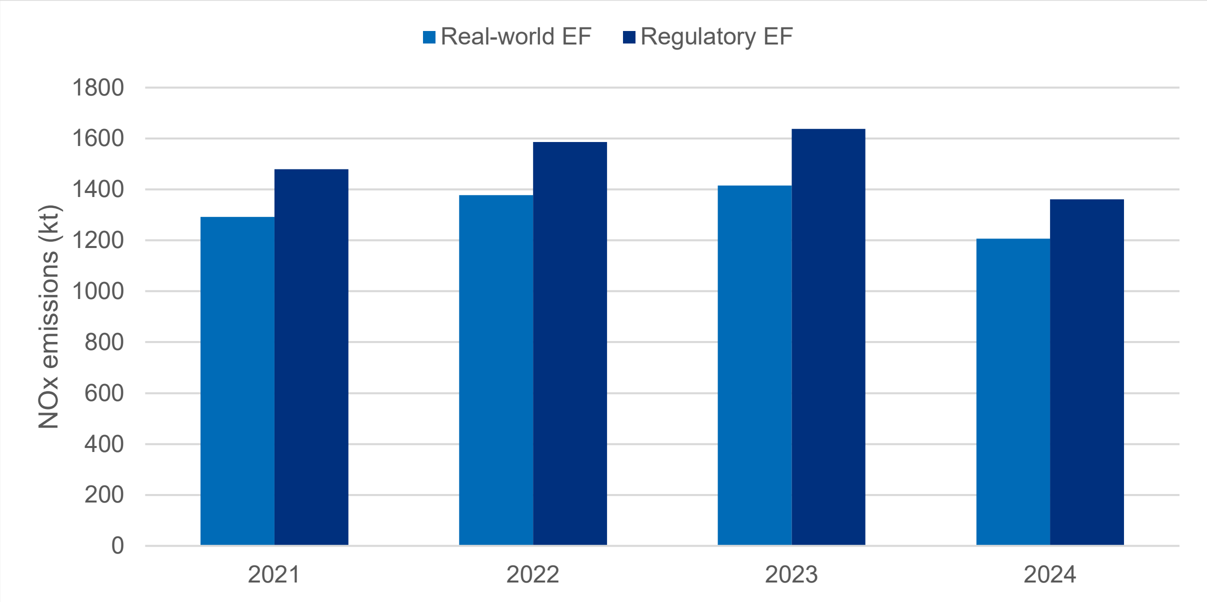
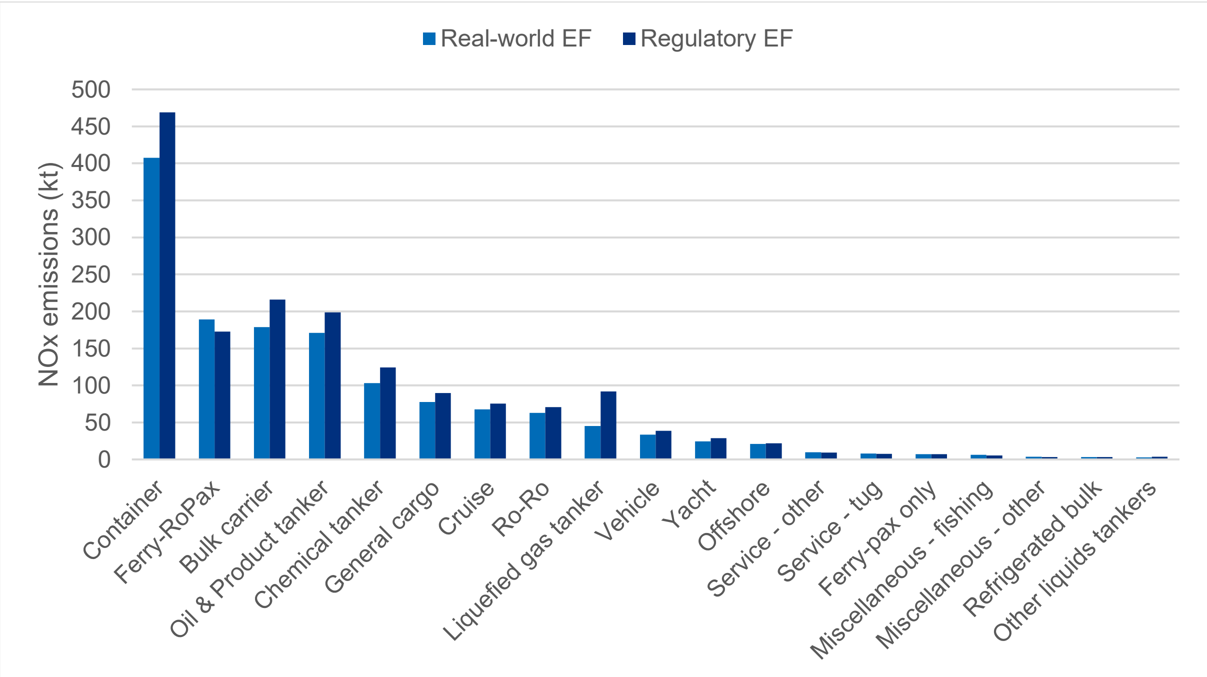


Figure 4-5 shows current NO_x emissions by vessel type, which demonstrates that containerships are the top emitter with around 30% of total NO_x emissions, followed by bulk carriers (14%) and oil & product tankers (13%).

Figure 4-5 NO_x emissions from shipping within the scope of a potential NO_x ECA in the Mediterranean Sea over the period 2021-2024 by vessel category, based on real-world and regulatory emission factors

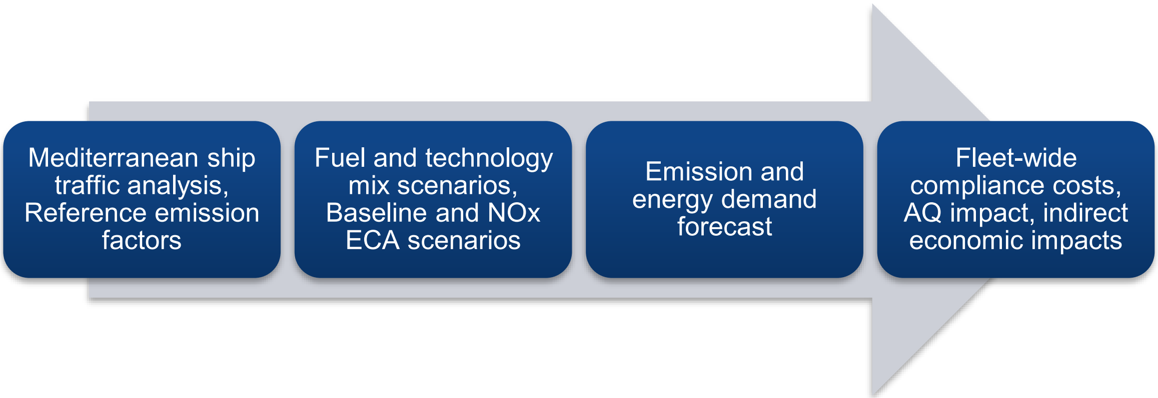


5. IMPACT ASSESSEMENT

This chapter provides a description of the data used, methodology applied and results of assessing the impact of NO_x ECA introduction on the Mediterranean fleet. The air quality (AQ) and economic impact results presented in this section will be used to inform the cost-effectiveness of the proposed Med NO_x ECA in Section 7. The overall approach and general steps taken during this impact assessment are shown in Figure 5-1.

First, through AIS-based traffic data, and reference energy demand and emission factors, the Baseline and NO_x ECA scenario emissions and energy demand are estimated for shipping in the Mediterranean Sea. Applying unit costs for ship compliance and emission external costs, the economic and AQ impact under the NO_x ECA is assessed relative to the Baseline, for the proposed introduction (2032, 2035, 2038) dates and fuel/technology sensitivities. Finally, the indirect impact on the maritime sector, economies and citizens within the Mediterranean Sea area are assessed through a mixture of quantitative (using E3-Modelling's GEM-E3 model[12]) and qualitative assessments.

Figure 5-1 Process diagram for the impact assessment of Med NO_x ECA introduction



5.1 Methodology

Future shipping activity within Mediterranean waters are used to calculate the compliance cost and AQ impacts under both the baseline (without NO_x ECA) and NO_x ECA pollutant (with NO_x ECA introduction) scenarios.

It is assumed that ships operating within the waters of any Mediterranean country (including vessels operating within their own flag State waters) will participate in the introduction of a NO_x ECA and comply with Tier III NO_x emission limits regardless of whether the domestic waters of each country are subject to the MARPOL Annex VI[13]. Hence, the full impact of introducing a Med NO_x ECA on compliance costs and air quality is captured in this Study by considering all shipping traffic operating in the Mediterranean Sea.

[12] E3-Modelling's GEM-E3 model is a multi-regional, multi-sectoral, recursive dynamic computable general equilibrium (CGE) model which provides details on the macro-economy and its interaction with the environment and the energy system (E3-Modelling, n.d.)

[13] Countries that are not parties to MARPOL Annex VI include Algeria, Bosnia and Herzegovina, Egypt, Lebanon and Libya (Table 5-12**Error! Reference source not found.**).

The following sections describe the approach and general assumptions used in assessing the impact of Med NO_x ECA introduction on compliance and air quality costs.

To assess the impact of the proposed designation of a NO_x ECA in the Mediterranean Sea, two NO_x emissions scenarios were considered:

- **Baseline scenarios:** uses the Mediterranean fleet stock projections with no requirement for ships to meet Tier III NO_x emission requirements within the Mediterranean Sea. The use of renewable and low-carbon fuels and technologies is assumed to be only driven by decarbonisation policies (i.e. not directly attributed to the adoption of ECAs), and hence the use of alternative fuels is reflected in the baseline scenarios. Two variants are modelled with different fuel and technology mix assumptions.

- **NO_x ECA scenarios:** considers the introduction of NO_x ECA requiring compliance from relevant Tier III vessels operating in the Mediterranean Sea from the date of introduction. Four different variants are modelled across three introduction dates (2032, 2035 and 2038)

Within this Study, NO_x ECA designation is assessed for all newbuild Tier III vessels operating in the Mediterranean Sea from the date of introduction (following Regulation 13).

The projected ship traffic between 2025-2050 (number of vessels and energy consumption) within Mediterranean waters is estimated within the fleet projection model from Marine Benchmark (see section 5.1.1). At the same time, to consider the interaction between decarbonisation and air pollution measures, two fuel and technology mix scenarios were considered in line with scenarios in the Comprehensive Impact Assessment of mid-term decarbonisation measures at IMO level (see 5.1.2).

5.1.1 Fleet projection model

The Marine Benchmark Fleet prediction model used for this Study has its base in the existing world fleet and the tonne-miles work it performs, total and per market-based vessel type and size segments.

The main drivers of the fleet development are the changes in the structure and growth of the demand for transport. The demand consists of the volume of cargo, cargo properties, handling and packaging, the origin/destination, and the related transport distance. Factors influencing the demand for transport include GDP growth, environmental regulations, among others.

Changes on fleet supply side reflect adaptations to the abovementioned factors. To this comes the age profile of fleet sub-segments, the general new ship investment activity (and related investment barriers), adaptation to safety and environmental regulations, market balance and earnings, uncertainty about future market development, degree of market consolidation, ship newbuilding prices, etc.

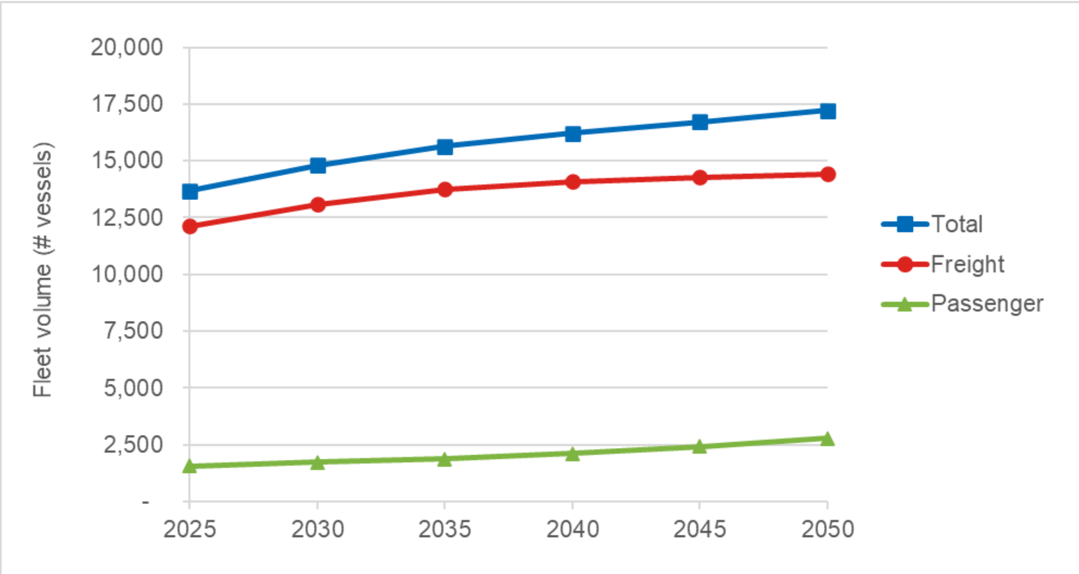
The gap between supply and demand is used to project the number of new builds. The new build projection is distributed per vessel type and size in relation to demand and accessible information on type size distribution projections. The fleet prediction model also has a number of scenarios on energy efficiency forecasting based on available information and existing trajectories.

The above projection is made based on installed power of the future fleet. Projections on energy consumption were made by looking at the relation between installed power and energy consumption of the historic fleet on a granular ship-type level.

A key assumption of the model for this Study is that traffic growth assumptions per vessel type at global level are also applicable in the Mediterranean Sea. To downscale the global forecast to vessels operating in the Mediterranean Sea, the percentage of world fleet energy used in the Mediterranean Sea over the last 15 years by vessel type and size was applied to global fleet projections.

Over the projected period (2025-2050), the total fleet of ships operating in the Mediterranean Sea are expected to increase by 26% from around 13,600 ships in 2025 to 17,200 ships in 2050, see Figure 5-2. The overall increase in Mediterranean fleet size is driven largely by freight ships[14], which make up around 87% of the total fleet in 2025 and are expected to increase by 19% by 2050. Although comprising a smaller share of the total fleet, passenger ships[15] are expected to undergo rapid growth from 2030 onwards, with the passenger fleet expanding by 72% between 2025-2050.

Figure 5-2 Mediterranean fleet stock projections, 2025-2050



Source: Marine Benchmark (2025)

The implementation of existing and future NO_x ECAs close to the Mediterranean Sea (see Section 2.1) means that a large proportion of vessels operating in the Mediterranean Sea are likely to sail across NO_x ECAs, particularly considering the recent adoption of the North East Atlantic ECA and significant traffic flows from the Mediterranean to North European and North American ports. More generally, newbuild vessels operating in the Mediterranean Sea are expected to be equiped with Tier III compliant systems in any case to be able to operate operate flexibly in NO_x ECAs across their lifespan. Because of this, the fleet projection model assumes that all new ships (including those operating within flag State waters only) will be

[14] Freight ships include bulk carriers, tankers, container ships, LNG carriers and ro-ro ships.

[15] Passenger ships include passenger, Ro-Pax and cruise vessel types.

equipped with Tier III-capable emission control equipment at the initial construction stage in order to remain compliant within non-Med NO_x ECAs. The main rationale for this assumption is the need to ensure vessels can be flexibly deployed in both NO_x ECA and non-NO_x ECA areas in international operations or as second-hand assets.

As such, under both the Baseline and NO_x ECA scenarios, it is assumed that all new build ships from 2025 are Tier III-capable. This means that no additional capital costs would be directly attributed to the Med NO_x ECA and compliance costs would be solely in the form of additional operating costs associated with the use of emission control technologies. This is consistent with the approach taken in the Norwegian Sea ECA proposal (IMO, 2023b). Box 1 (section 5.3.3) includes a sensitivity case for a lower uptake of Tier III-compliant vessels in the baseline (75% in 2025 and 90% in 2030) and an analysis of capital costs in such case.

Following the example set by the Norwegian Sea ECA proposal (see Section 2.2), it is proposed that for each of the NO_x ECA scenarios, the Three Dates Criteria is applied to the introduction dates for vessel compliance under MARPOL VI Regulation 13, see Text Box 2-2. Namely, Med NO_x ECA compliance will apply to **order dates** on or after the entry into force date (2029, 2032, 2035), **keel-laying dates** on or after six months of the entry into force of the ECA, or all new-build ships with **delivery dates** on or after the stated introduction date (2032, 2035, 2038), which is set to be three years after the entry into force. This is expected to eliminate the spike in ship orders and delayed deliveries until after the ECA introduction seen following the introduction of the Canadian Arctic waters ECA, which contributed to lower impact on pollutant emissions than assessed in the proposal (Starcrest Consulting Group LLC, 2020).

As it is assumed under both the baseline and NO_x ECA scenarios that all new-build vessels operating in the Mediterranean Sea will be Tier-III capable from 2025 onwards, application of the Three Dates Criteria to the Med NO_x ECA is expected to primarily influence ships operating outside the Mediterranean, but which may pass through during international journeys. By extending the compliance dates for all ships with activities in the Mediterranean, this approach will discourage sudden changes to the geographical distribution of fleets by operators seeking lower operational costs from higher NO_x emission ships. However, the recent approval of the North-East Atlantic ECA, which extends ECA coverage to the North Atlantic waters to the west of the Mediterranean, is expected to significantly reduce the shipping activity in the Mediterranean relating to non-Tier-III ships due to the Tier III compliance required in most European, north African and North American waters.

5.1.2 Fuel and technology mix scenarios

Even if the use of some alternative fuels (e.g. LNG) are expected to ensure compliance with NO_x ECA (see section 4.1.3), their cost is higher than that of emission control technologies (see section 5.3). Therefore, in this Study, the uptake of renewable and low-carbon fuels is not directly attributed to the adoption of ECAs and it is assumed to be only driven by decarbonisation policies. Specific alternative fuel and technology uptake scenarios are considered to form the baseline scenario of this impact assessment.

In 2023, the IMO published an updated “Strategy on Reduction of GHG Emissions from Ships” (herein the “2023 IMO GHG Strategy”) outlining proposed targets and steps towards achieving decarbonisation of international shipping (IMO, 2023b). In particular, the 2023 IMO GHG Strategy aims at achieving net-zero shipping “by or around” 2050, providing indicative checkpoints of 20% (striving for 30%) and 70% (striving for 80%) reduction in GHG emissions by 2030 and 2040 respectively compared to a 2008 baseline. This will rely on a combination of energy efficiency improvements to existing ship designs and, primarily, the uptake of low- and zero-GHG emission maritime fuels, with an interim target for up to 10% of energy consumption by 2030 to come from zero and near-zero GHG emission technologies, fuels and/or energy sources.

During the 83rd session of the MEPC in April 2025, members approved the IMO Net Zero Framework as a mechanism for gradual reducing GHG emissions from vessels over 5,000 GT. Compliance against the base and direct targets will result in a 30% and 43% reduction in GHG fuel intensity by 2030 respectively, and a minimum 65% reduction by 2040 (Lloyd's Register, 2025). In this context, the Net Zero Framework will support the delivery of the 2023 IMO GHG Strategy, and reinforcing the relevance of alternative fuel uptake under the Baseline scenario throughout this Study.

To model the interaction between NO_x emissions performance and potential decarbonisation scenarios for international shipping, two fuel and technology mix scenarios are considered.

Scenario with no global mid-term measures (NGMT). This scenario is aligned with the business-as-usual scenario (BAU) in Comprehensive Impact Assessment (IMO, 2024) and includes existing policies at IMO and EU level.

Table 5-1 Share of energy use per fuel type in Scenario with no global mid-term measures (NGMT)

Element	2030	2040	2050
HFO	25%	20%	15%
VLSFO/MGO/HVO	50%	40%	40%
Bio-methanol/e-methanol	-	-	-
LNG/bio-methane/e-methane	24%	37%	40%
Hydrogen	-	-	-
Ammonia	-	-	-
Electricity	1%	3%	5%

Scenario with global mid-term measures (GMT). This scenario is aligned with Scenario 50 of the Comprehensive Impact Assessment (IMO, 2024) and slightly revised by our fuel experts considering further inputs from recent literature.

Table 5-2 Share of energy use per fuel type in Scenario with global mid-term measures (GMT)

Element	2030	2040	2050
HFO	20%	10%	5%
VLSFO/MGO/HVO	50%	30%	15%
Bio-methanol/e-methanol	5%	5%	10%
LNG/bio-methane/e-methane	20%	25%	20%
Hydrogen	-	2%	5%
Ammonia	3%	20%	30%
Electricity	2%	8%	15%

For this Study, the GMT scenario reflects the current ambition of the IMO towards international shipping decarbonisation, see Section 4.1. As such, the GMT scenario represents the central fuel and technology mix scenario underpinning the following impact assessment of compliance and AQ costs. The NGMT scenario is included as a variant to provide an understanding of the impacts in a limited decarbonisation case but is not considered likely or reflective of current and existing shipping fuel and technology trends. Where not explicitly stated, the results for compliance and AQ costs reflect the fuel and technology mix under the GMT decarbonisation scenario.

5.1.3 Alternative methods for NOx ECA compliance

As shown in Section 4.1.3, alternative maritime fuels offer an alternative method of compliance with Tier-III emissions by producing lower NO_x emissions than conventional maritime fuel (i.e., HFO, MGO). However, the cost, resource availability and variable reduction potential of alternative fuels relative to specific NOx emission control technologies reduces their effective application in maritime shipping solely for the purposes of Tier-III compliance. Therefore, the main method for Tier III compliance explored in this Study is the use of after-gas treatment systems, namely EGR for low-speed, 2-stroke engines typically found on larger freight vessels and SCR for higher-speed, 4-stroke engines (see Section 5.3.2 for more detail). As such, the only alternative fuel uptake within the study period is expected to be driven by decarbonisation targets at regional and IMO-level, and reflected under both the Baseline and NECA introduction scenarios through the GMT fuel mix sensitivity above.

The operational energy demand (and expenditure) of engaging a vessel's Tier III system in the Med NO_x ECA is influenced by the fuel type and associated NO_x emissions. Ships using alternative fuels with lower NO_x emissions relative to the diesel baseline will have a lower energy demand and operational cost from NO_x abatement technologies, as NO_x emissions will need to be reduced to a smaller extent. As such, when assessing the compliance costs in Section 5.3, the NO_x emission scale factors in Table 4-3 are applied to the operational energy demand required by the Tier III systems for ships consuming methanol, hydrogen and ammonia fuel types.

The use of LNG in a dual fuel engine (Otto Cycle) or onshore power supply lowers NO_x emissions sufficiently relative to the use of conventional fuels and would comply with the emission reduction targets required under Tier III limits. In particular, the NO_x Technical Code requires around 76% reduction in NO_x emission between Tier II and Tier III for the typical range of engine speeds for vessel types considered in this Study. As such, NO_x abatement technologies will not be required for these ship types for compliance with Tier III emission limits, so there is no operational energy demand or cost associated with LNG fuelled vessels or for energy sourced from onshore power supply. Similarly, there would be no costs for vessels using non-diesel engines, such as battery-electric vessels.

5.2 Air quality impacts

As a result of lower NO_x emissions from shipping in the Mediterranean Sea, there will be associated air quality benefits at both marine and land environments. To quantify the air quality benefits, the reduction in emissions as a result of the potential ECA was determined and was subsequently used in combination with a damage cost function. This provided a monetary value of the air quality benefits which includes benefits associated with health, ecosystems and reduced damage to buildings and materials.

5.2.1 Approach and assumptions for modelling air quality impacts

Projected emissions

The projected emissions were calculated for each of the scenarios detailed in Section 5.1, for each year between 2025 and 2050 based on real-world emission factors per unit of energy consumed as described in Section 4.1.3. Predicted energy consumption was obtained for the years 2025 to 2050 at five-year intervals from the fleet projection model. The projected emissions were also adjusted to consider future changes in fuel use as some fuels will produce less NO_x emissions.

Air quality impact

To determine the air quality impact of the reduced NO_x emissions from the potential NO_x ECA, a damage cost approach was used to quantify the monetary value of the adverse effects caused by air pollution, encompassing health impacts, ecosystem degradation, and damage to buildings and materials. Population-weighted air pollution concentrations in the atmosphere caused by NO_x emissions were derived using the SHERPA model developed by JRC (Pisoni, et al., 2024). It should be noted that this represents average exposure levels to air pollution in the EU, however, given similarities in population density in coastal areas across the Mediterranean Region, this is considered a valid approximation. The exposure to air pollution from shipping in the Mediterranean, compared to exposure to land-based sources, was derived from the European Commission´s 2019 Handbook of External Costs of Transport (European Commission, 2019).

The specific methodology to appraise health and non-health impacts from air pollution concentration levels are described hereafter.

Health impacts

The inhalation of air pollution emissions leads to a higher risk of respiratory and cardiovascular diseases (e.g., bronchitis, asthma, lung cancer). These negative health effects lead to medical treatment costs, production loss at work (due to illness) and, in some cases, even death. For human health impacts, impact pathways established in Third Clean Air Outlook (CAO3) (EC, 2022a) and Ambient Air Quality Directive Impact Assessment (AAQD IA) (EC, 2022c) were adopted. Specifically, the Study obtained baseline incidence values, concentration-response functions (CRF) and impact values (specific to each health impact) from CAO3 (EC, 2022a).

A key feature of these studies is the implementation of a tiered approach, combining the latest evidence to quantify the health impacts of air pollution. The first tier focuses on premature mortality caused by long-term exposure to air pollution, using concentration-response functions recommended by the WHO in 2021 (WHO, 2021). The second tier examines additional health outcomes based on the 2013 HRAPIE recommendations, including chronic bronchitis in adults, bronchitis in children, cardiovascular and respiratory hospital admissions, infant mortality, and lost working days. The third tier incorporates more recent evidence, considering health impacts such as asthma in children, lung cancer, and stroke, with a sensitivity analysis including conditions like COPD, Type 2 diabetes, and myocardial infarction. This tiered approach to health impact assessment has been integrated into the present study

Non-health impacts

Non-health impacts, including damage to materials and buildings, as well as losses to crops and biodiversity, were modelled with the methodology set out in the European Environment

Agency study 'Costs of air pollution from European industrial facilities 2008–2017' (EEA, 2021).

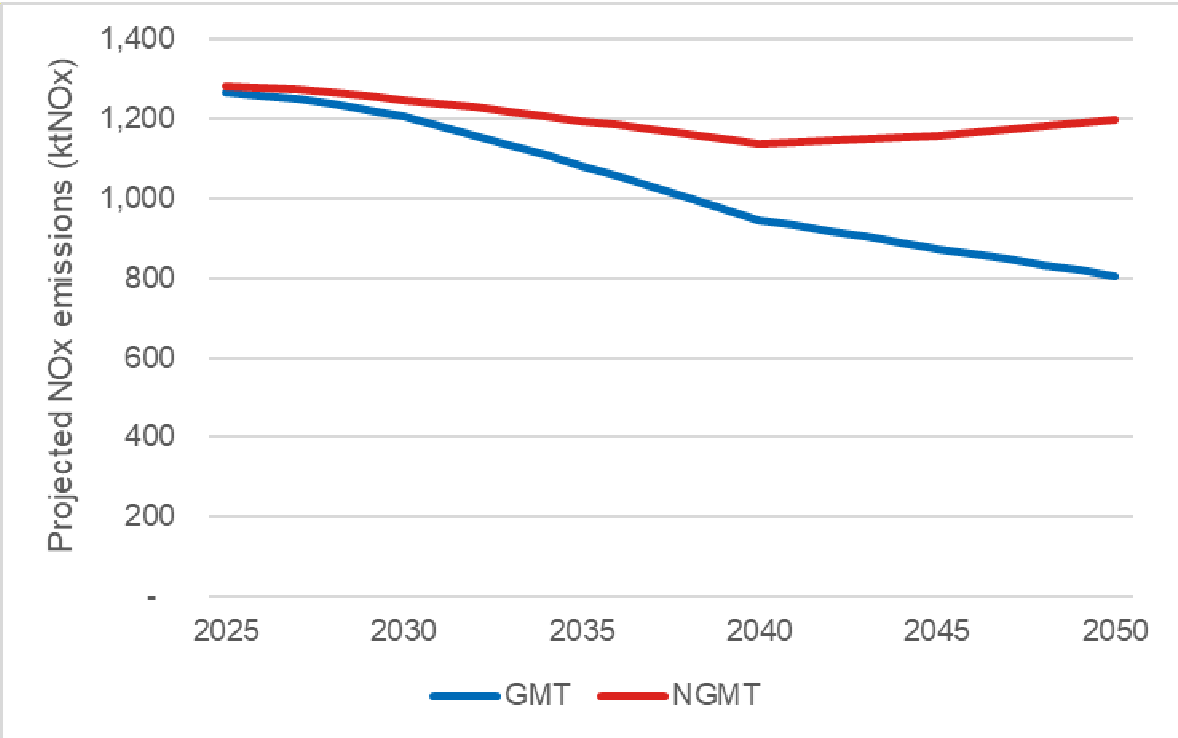
5.2.2 Projections in the baseline

Following the methodology described above, NO_x emissions from shipping, in the absence of a Med NO_x ECA, have been estimated over the period 2025-2050 for the two decarbonisation scenarios (GMT and NGMT) (Figure 5-3). NO_x emissions projections in the baseline are driven by two key factors:

- First, energy consumption is increasing in line with increased transport activity.
- Second, a higher uptake of alternative fuels leads with lower NOx emissions.

In both scenarios, NO_x emissions decrease in the baseline compared to 2025 levels, but there is a more significant drop under the GMT scenario driven by the higher uptake of alternative fuels. Whereas under the NGMT scenario, projected NO_x emissions start to increase after 2040 as a result of increasing NOx emissions from increased transport activity outweighing the NO_x emission reductions resulting from alternative fuel uptake.

Figure 5-3 Projected NOx emissions from shipping in the baseline, under global mid-term measures (GMT) and no global mid-term measures (NGMT) scenarios.



Source: Ricardo modelling for this Study

5.2.3 Projections in NO_x ECA scenarios

A time series of the projected emissions from shipping in the Mediterranean is shown in Figure 5-4 shows how the total NO_x emissions from shipping will change as result of implementing the NO_x ECA for different implementation dates under the NGMT scenario. Whereas Figure 5-5, indicates the same except for under the GMT scenario.

Figure 5-4 Projected NO_x emissions from shipping under the NGMT scenario for different NO_x ECA implementation dates. Source: Ricardo modelling for this Study

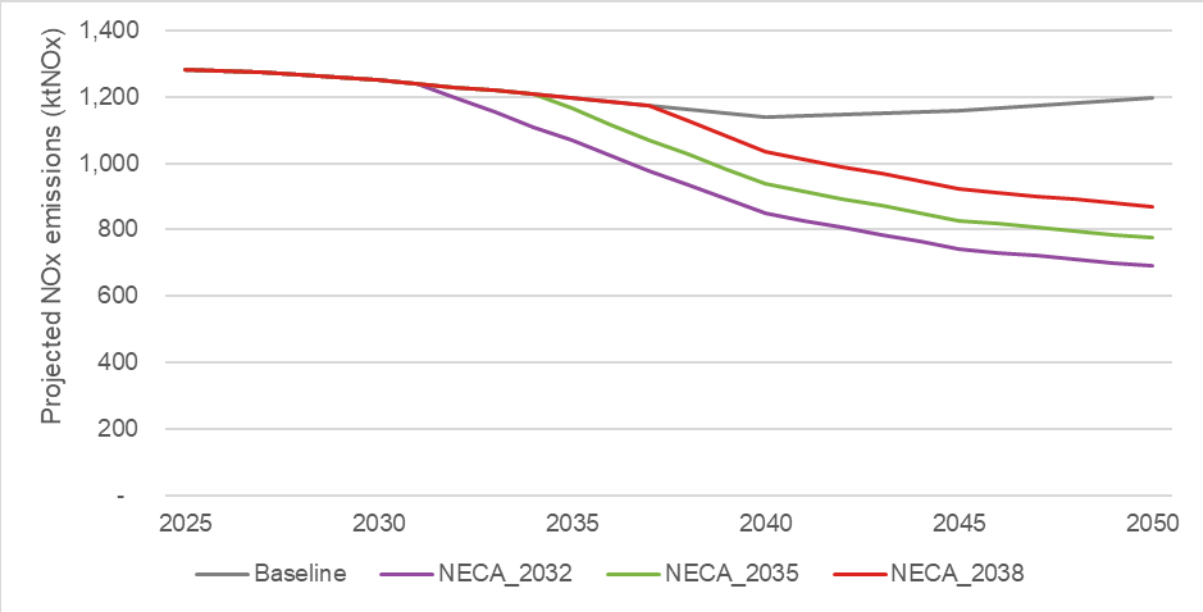
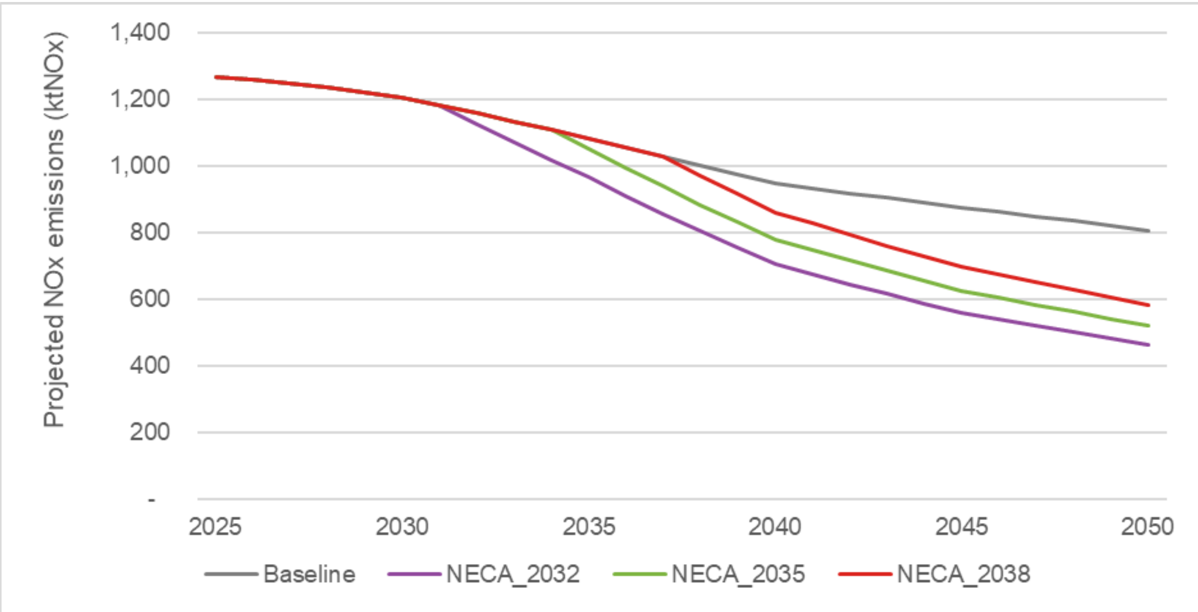


Figure 5-5 Projected NO_x emissions from shipping in the Mediterranean under the GMT scenario for different NO_x ECA implementation dates



Source: Ricardo modelling for this Study

As detailed in Figure 5-4 and Figure 5-5, the NO_x ECA would result in an annual reduction of NO_x emissions from shipping in the Mediterranean by a factor of between 1.4 and 1.7 by 2050 for both the NGMT and GMT scenario, dependent of the implementation date of the NO_x ECA. As expected, the earlier the implementation date, the earlier reductions in annual NO_x emissions are experienced, but also the higher in-year emissions reduction. This is because an earlier introduction leads to more vessels compliant with Tier III NO_x emission limits on a cumulative basis. Additionally, the projected annual NO_x emissions are lower for the NO_x ECA scenarios in the GMT scenario.

5.2.4 Health impacts

The health benefits for the period 2031 to 2050 are shown in Table 5-3 for the different NO_x ECA implementation dates, and for both the NGMT and GMT scenario.

Table 5-3 Health benefits for the period 2031-2050 in for both the NGMT and GMT scenario

Health impact	Unit	NECA 2032		NECA 2035		NECA 2038	
		NGMT	GMT	NGMT	GMT	NGMT	GMT
Chronic Mortality (30yr +) deaths	Total life years lost	-219,648	-169,872	-156,978	-119,040	-100,398	-74,522
Infant Mortality (1 month-1yr)	Total life years lost	-1,771	-1,370	-1,266	-960	-809	-601
Chronic Bronchitis (18yr +)	Change in cases	-42,728	-33,045	-30,537	-23,157	-19,530	-4,497
Bronchitis in children aged 6 to 12	Change in cases	-12,648	-9,782	-9,040	-6,855	-5,781	-4,291
Stroke	Change in cases	-2,929	-2,266	-2,094	-1,588	-1,339	-994
Myocardial infarction	Change in cases	-1,955	-1,512	-1,397	-1,060	-894	-663
Diabetes Mellitus Type 2	Change in cases	-397	-307	-284	-215	-181	-135
Lung Cancer	Change in cases	-743	-574	-531	-402	-339	-252
Asthma symptom days (children 5-19yr)	Change in cases	-8,460	-6,543	-6,047	-4,585	-3,867	-2,870
Cardiovascular hospital admissions	Change in hospital admissions	-3,470	-2,684	-2,480	-1,881	-1,586	-1,177
Respiratory Hospital Admissions (All ages)	Change in hospital admissions	-3,603	-2,787	-2,575	-1,953	-1,647	-1,222
Minor Restricted Activity Days (MRADs all ages)	Number of restricted activity days	-8,391	-6,490	-5,997	-4,548	-3,836	-2,847
Workday Lost	Number of workdays lost	-2,677	-2,070	-1,913	-1,451	-1,224	-908

As detailed in the above table, the introduction of a NOx ECA in the Mediterranean will result in benefits for all health diseases, including reduced life years lost to premature death. Specifically, in the GMT scenario and between 2031 and 2050, the introduction of a NOx ECA in the Mediterranean will reduce the total life-years lost from chronic mortality by approximately

170,000 with a 2032 implementation date, approximately 120,000 with a 2035 implementation date and approximately 74,000 with a 2038 implementation date. Similarly, in the NGMT scenario and between 2031 and 2050, the introduction of a NOx ECA in the Mediterranean will reduce the total life-years lost from chronic mortality by approximately 220,000 with a 2032 implementation date, approximately 160,000 with a 2035 implementation date and approximately 100,000 with a 2038 implementation date.

Of the health diseases, the introduction of a NO_x ECA in the Mediterranean will benefit chronic bronchitis (18yr +) the most. In the GMT scenario and between 2031 and 2050, there is an estimated reduction of approximately 33,000 cases with a 2032 implementation date, an estimated reduction of approximately 23,000 cases with a 2035 implementation date and an estimated reduction of approximately 5,000 cases with a 2038 implementation date. Similarly, there are predicted reduced cases of bronchitis in children aged between 6 and 12. In the GMT scenario and between 2031 and 2050, there is an estimated reduction of approximately 9,000 cases with a 2032 implementation date, an estimated reduction of approximately 7,000 cases with a 2035 implementation date and an estimated reduction of approximately 4,000 cases with a 2038 implementation date.

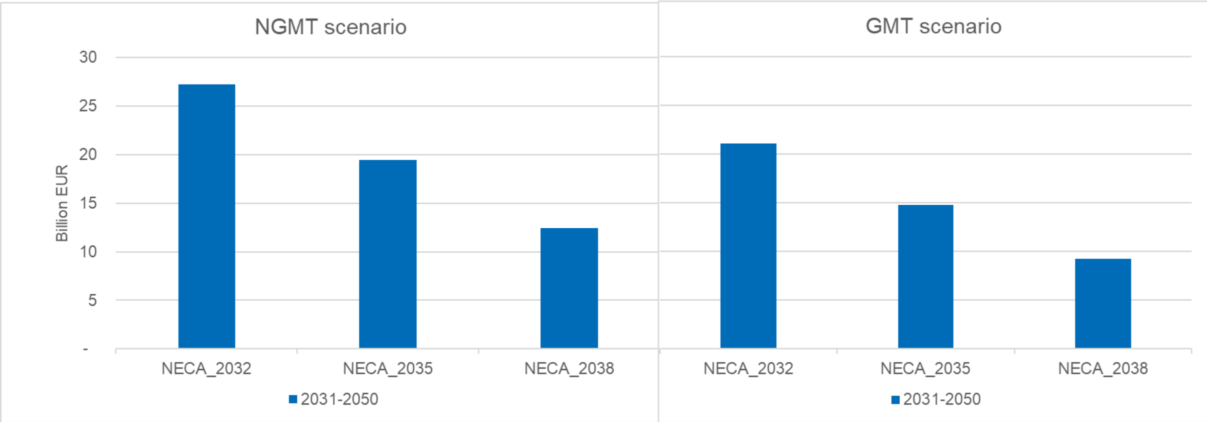
Additionally, the introduction of a NO_x ECA in the Mediterranean will result in a decrease in cardiovascular and respiratory hospital admissions. In the GMT scenario and between 2031 and 2050, there is an estimated reduction of approximately 5,000 cardiovascular and respiratory hospital admissions with a 2032 implementation date, an estimated reduction of approximately 4,000 cardiovascular and respiratory hospital admissions with a 2035 implementation date and an estimated reduction of approximately 2,000 cardiovascular and respiratory hospital admissions with a 2038 implementation date.

Overall, the estimated health benefits are greater with an introduction date of 2032, relative to 2035 and 2038.

5.2.5 Air quality impact results

The air quality benefits (i.e. reduction in air pollution damage costs, accounting for health impacts, damage to materials and buildings, as well as losses to crops and biodiversity) for the periods 2031-2040 and 2041-2050 are shown in Figure 5-6**Error! Reference source not found.** for the different NO_x ECA implementation dates and for both NGMT and GMT scenarios.

Figure 5-6 Cumulative air quality benefits for each NO_x ECA implementation start date in both the NGMT and GMT scenarios (billion EUR)



Source: Ricardo modelling for this Study

As detailed in the above figure, the introduction of a NO_x ECA in the Mediterranean is expected to result in cumulative air quality benefits of approximately between € 27 billion and € 12 billion in the NGMT scenario and between € 21 billion and € 9 billion in the GMT scenario in the period 2031-2050, dependent of the NO_x ECA implementation date. Implementing the NO_x ECA in 2032 will result in higher air quality cost benefits relative to implementing the NO_x ECA in 2035 or 2038. Additionally, the air quality cost benefits are greater in the NGMT scenario.

5.3 Economic impacts

This section presents the approach, assumptions and results of the assessment of economic impacts for the implementation of the proposed Med NO_x ECA. The costs assessed in this section relate to the direct compliance costs placed on fleet operators (and potentially passed on to end-consumers) through increased investment and energy demand of technologies or methods required to meet Tier III emission limits. Indirect economic impacts on the maritime sector and wider society are discussed in subsequent sections.

5.3.1 Approach and assumptions for modelling compliance costs

The total compliance costs placed on fleet operators with activities in the Mediterranean Sea resulting from Med NO_x ECA introduction can be separated into two components: the investment cost required to purchase and install additional Tier III-compliant NO_x abatement technology (capital expenditure, CAPEX); and the ongoing cost of operating the equipment through additional energy and feedstock requirements (operating expenditure, OPEX).

However, as it is assumed that all newbuild vessels will be Tier III-capable from 2025 onwards, the Baseline and NO_x ECA scenarios have the same investment requirements across the full period 2025-2050, with no subsequent additional CAPEX placed on fleet operators through introduction of the Med NO_x ECA. Only additional operating costs associated with the use of emission control technologies are directly attributed to the Med NO_x ECA in this Study.

The ongoing additional energy demand and cost of complying with Tier III limits within the proposed Med NO_x ECA was calculated by considering the forecasted annual energy demand of relevant ships in the Mediterranean fleet[16] and the unit energy cost of the selected NO_x abatement technologies, see Section 5.3.2. Also, scale factors were applied to correct for lower fleet-average energy demands from NO_x abatement technology as alternative marine fuel uptake under the NGMTM and GMTM decarbonisation scenarios will reduce NO_x emissions independent of the Baseline or NO_x ECA scenarios (see Section 4.1.3 for more detail).

Finally, to provide a comparison against current fleet costs, the additional total compliance cost under the NO_x ECA scenarios (for each introduction date) is compared to the existing (2021) total cost of ownership (TCO) for ships operating in the Mediterranean within three periods, 2025-2030, 2031-2040 and 2041-2050, as calculated by (Maersk McKinney Moller Center, 2021).

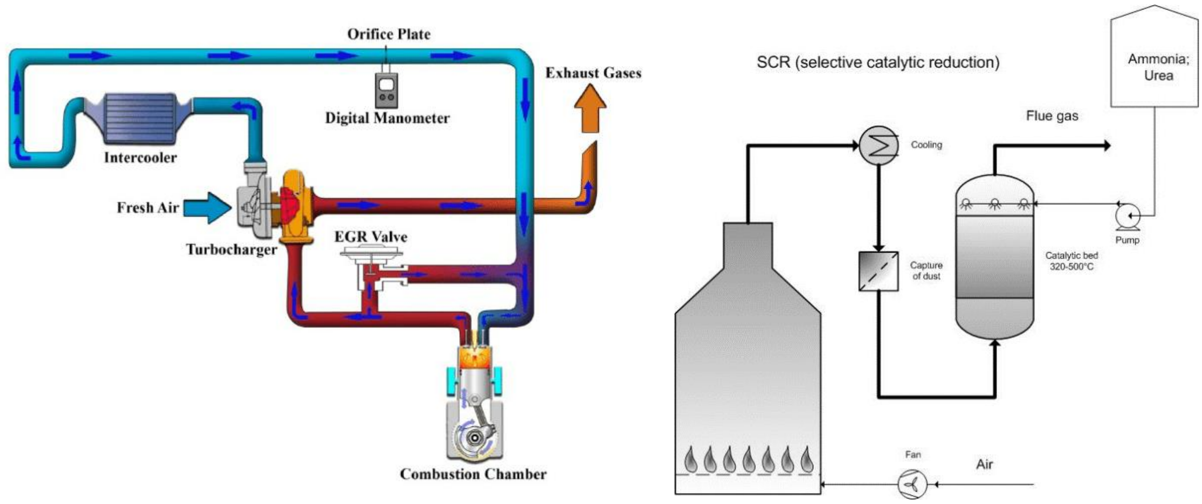
5.3.2 Costs and availability of NO_x emission abatement technology

In the following section, EGR and SCR as the main NO_x abatement technologies are described, along with their associated investment and operational costs.

EGR reduces NO_x emissions by modifying the inlet air to reduce the internal temperature and subsequent NO_x emissions produced during combustion. Recirculation of around 30% of the exhaust gas increases the heat capacity and lowers the oxygen content of inlet air during combustion, which subsequently reduces the temperature and NO_x formation within the combustion unit (Alfa Laval, 2020), see Figure 5-7 (left).

SCR is an exhaust aftertreatment system which splits NO_x emissions into molecular nitrogen and water vapor after production and release from the engine, see Figure 5-7 (right). A nitrogen-based reductant, typically ammonia or urea, is injected into the exhaust system where it mixes with the exhaust gas containing NO_x and is chemically separated into harmless nitrogen and water in the catalyst (EPA, 2003).

Figure 5-7 Diagrams showing NOx emission abatement processes using an EGR system (left) and SCR system (right).



Source: (Gomaa, et al., 2011), (EMIS, 2020)

[16] Compliance applies to those ships subject to Regulation 13, namely the new-build Tier III-capable ships, including vessels solely operating within flag State waters.

Both options can be applied to a range of engine and vessel types and applications. The primary motivation for designation of NO_x abatement technologies is considered to be cost effectiveness. During designation of the North Sea ECA, it was demonstrated that SCR is most cost-effective for 4-stroke main engines, whilst EGR is most cost-effective for 2-stroke engines (Incentive Partners & Litehauz, 2012). Further research carried out in this study confirmed this conclusion. For two-stroke low-speed engines, EGR application is an equally reliable technique compared to SCR for Tier III NO_x compliance. While EGR previously operated at engine loads of 15-85%, these limitations have been addressed in modern systems, and recent industry data shows substantial market adoption with Tier III NO_x abatement engine orders by 2022 including 1,292 SCR systems and 724 EGR systems[17], demonstrating that EGR has achieved commercial viability for the dominant segment of the global merchant fleet that relies on two-stroke propulsion systems.

Therefore, the designation of SCR and EGR abatement technologies are distributed between vessel types with 4-stroke and 2-stroke main engines respectively, see Table 5-4.

Table 5-4 Designation of MCP, main engine type and NO_x abatement technology for each vessel type in study scope

Vessel type	Maximum continuous power (MCP)	Speed range	Engine type	NO_x abatement technology
Bulk carrier	8,000	Low	2-stroke	EGR
Tanker	9,400	Low	2-stroke	EGR
Container ship	30,900	Low	2-stroke	EGR
LNG carrier	9,400	Low	2-stroke	EGR
Passenger ship	39,600	Medium	4-stroke	SCR
Ro-ro	11,000	Medium	4-stroke	SCR
Ro-pax	25,300	Medium	4-stroke	SCR
Cruise ship	39,600	Medium	4-stroke	SCR

Source: Ricardo analysis, Incentive Partners & Litehauz (2012), (EPA, 2009).

The use of these technologies will result in increased costs for vessel operators related to capital expenditure (CAPEX) and operational expenditure (OPEX).

CAPEX for NO_x abatement technology

Constructing Tier III compliant vessels will involve an increase in CAPEX costs relative to Tier II-compliant vessels due to additional hardware and installation costs associated with EGR and SCR systems (UKP&I, 2022). There may also be additional costs due to design modifications to existing vessels to accommodate the NO_x emission reduction systems.

[17] MAN Energy Solutions. (2022). Tier III NOx abatement engine orders pass 2,000 mark. Available at: https://www.man-es.com/company/press-releases/press-details/2022/05/05/tier-iii-nox-abatement-engine-orders-pass-2-000-mark

As part of this Study, a comprehensive literature review was conducted to produce SCR and EGR costs, involving public sources, regulatory documents and indicative cost data collected by the National Technical University of Athens (NTUA) for key vessel types. For CAPEX, we have estimated a cost of €52 per kW engine power for EGR, and €69.5 per kW engine power for SCR, see Table 5-5. Furthermore, installing the abatement technology on to the vessels we have added on top of the equipment a 30% installation fee following the approach of (Incentive Partners & Litehauz, 2012). This fee corresponds to all the labour that goes into installing the equipment and while installation costs may vary depending on vessel type and layout, the overall CAPEX estimates remain within a reasonable margin of error, being a value representative of the sector as a whole taking into consideration different vessel specificities.

OPEX for NO_x abatement technology

The cost of OPEX will vary depending on the technology used and energy demand of the main engine when the abatement technology is in operation. In our Study, we have assumed maximum continuous power (MCP) outputs, based on the North American ECA feasibility study (EPA, 2009), for the different vessel typologies in the scope of this proposal, see Table 5-4.

For SCR, the main operational expenditure is urea consumption as the reductant (Zhang, 2021). Urea, which is dependent on natural gas as a main feedstock, has a very volatile price due to complex supply chains and geopolitical influences, with vessel bunkering prices ranging between EUR 130-350/tonne (DNV, 2020)[18]. Other additional costs include periodic replacement of the catalyst involved in the NO_x emissions reduction process (ABS, 2020) and costs from increased system complexity (additional sensors, pumps, and control systems) (DNV, 2021).

For EGR, operational costs primarily come from accelerated engine wear and higher maintenance due to increased soot contamination (Ishiki, 2000) which requires more frequent lubricating oil changes and component inspections (Agarwal, 2011), potential loss in fuel efficiency due to an increase in fuel consumption (Zheng, 2004), and increased maintenance due to the introduction of new failure points such as coolers and valves which require rigorous monitoring (T. Han, 2015). Furthermore, for both technologies, increased training is required for crews in order to know how to operate the systems and respond to failures/emergencies (ABS, 2023)

OPEX costs for SCR are four times higher than EGR, with the former having a value of 11.5 EUR/MWh while the later has a value of 2.7 EUR/MWh, see Table 5-5. This cost difference primarily stems from SCR systems requiring a continuous supply of urea (or ammonia-based reducing agents) to facilitate the NO_x reduction process, leading to higher reagent (and operational) costs than EGR. Moreover, the catalyst elements within the SCR reactor degrade over time and require periodic replacement, adding further to maintenance expenses (Kostova I., 2023)). Energy consumption is also a factor, as SCR systems require additional power for urea injection and exhaust gas treatment (Zannis TC, 2022). EGR on the other hand does not reagents or other consumable feedstock, leading to lower overall operational costs.

[18] USD 150 – 400/tonne

Table 5-5 CAPEX and OPEX for NO_x abatement technologies, in EUR/kW main engine power.

Engine type	Technology	Cost type	Study value[19]	Literature Range [20, 21]
2-stroke	EGR	CAPEX	**52 EUR/kW**	49 – 60 EUR/kW
2-stroke	EGR	OPEX	**2.7 EUR/MWh**	1.85 - 3.96 EUR/MWh
4-stroke	SCR	CAPEX	**69.4 EUR/kW**	26.3 – 143 EUR/kW
4-stroke	SCR	OPEX	**9.11 EUR/MWh**	3.2 – 9.5 EUR/MWh

Source: Ricardo analysis, NTUA (2025), (Danish Environmental Protection Agency, 2012), (Transport & Environment, 2016)

5.3.3 Presentation of results on fleet-wide compliance costs

This section presents the results for fleet-wide compliance costs resulting from introduction of a Med NO_x ECA for the range of start years (2032, 2035, 2038), above the costs arising from the Baseline scenario without NO_x ECA introduction.

Table 5-6 presents the additional cumulative costs over three indicative periods over the relevant study period, 2031-2040 and 2041-2050, along with the average annual cost within each period from implementation year of the NO_x ECA.

Table 5-6 Additional cumulative (average annual for period) costs in million €

NO_x ECA introduction year	2031-2040	2041-2050	Total (2031-2050)
2032	667 (83)	1,638 (215)	2,305 (121)
2035	319 (61)	1,305 (171)	1,624 (101)
2038	91 (35)	933 (123)	1,025 (79)

Source: Ricardo analysis for this Study

For the first period 2031-2040, NOx ECAs for all three introduction dates will be in place and accrue associated compliance costs. The cumulative costs over this period ranges from €91 million for the 2038 NOx ECA introduction, to €667 million for the 2032 introduction date which is active for most of the 2031-2040 period. Similarly, all three introduction dates fall before the final 2041-2050 period, so full-period compliance across both NOx ECA introductions will result in cumulative costs ranging from €933 million for 2038 introduction date to €1,638 million for 2038 introduction date.

Across the full Study period 2025-2050, the annual costs are expected to increase gradually from the date of NOx ECA introduction, due to an increase in vessels required to engage with Tier III emission requirements whilst operating in the Mediterranean Sea. For the 2032 NOx ECA introduction, annual compliance costs start at around €17 million in 2032 due to the OPEX costs of existing Tier III ships to engage NOx abatement systems, and continues to increase

[19] Values for CAPEX include a 30% installation fee, values without installation fee would be of 40 and 53.4 EUR/Kw for EGR and SCR respectively.

[20] (Danish Environmental Protection Agency, 2012)

[21] (Transport & Environment, 2016)

to around €215 million by 2050 as the Mediterranean fleet reaches full penetration of Tier III compliant vessels. After 2050, the main drivers of changes in fleet-wide cost compliance will be changes to energy demand from the Mediterranean fleet, either through change in the fleet volume or operational demand of the existing fleet.

The percentage increase in vessel-level TCO from the introduction of a Med NO_x ECA is presented in Table 5-7 for freight vessels to provide a comparison of the additional compliance costs with existing fleet operating expenditure under the Baseline. Results from (Maersk McKinney Moller Center, 2021) are used to calculate a fleet-weighted average TCO under the baseline.

Table 5-7 Percentage cumulative cost (OPEX only) increase due to NO_x ECA compliance for freight vessels only, by introduction date and interval period.

NO_x ECA introduction year	2031-2040	2041-2050
2032	0.06%	0.14%
2035	0.03%	0.11%
2038	0.01%	0.08%

Source: Ricardo analysis for this Study, (Maersk McKinney Moller Center, 2021)

The projected impact of NO_x ECA implementation on total costs is expected to be relatively modest across all scenarios, illustrating that NO_x ECA implementation will not place significant financial burden on fleet operators. The cumulative cost increase from the Baseline remains below 0.2% for all three NO_x ECA introduction dates across the full study period 2025-2050. The percentage cost increase is lowest for earlier years, when a smaller share of the total Mediterranean fleet is required to comply with Tier III emission limits. As seen for nominal compliance costs in Table 5-7 above, an increase in Tier III-capable fleet stock share in later years increases the percentage cost increase with plateauing growth to below 0.2% by 2050.

Box 1 - CAPEX sensitivity analysis

To consider the impact of slower adoption of Tier III compliant newbuild vessels on operator investment requirements, a CAPEX sensitivity was considered which assumes a gradual phase-out of non-Tier III new build vessels between 2025-2035. Under the CAPEX sensitivity, there will be 70% Tier III share of new build vessels in 2025 for the Baseline scenario, rising to 90% by 2030 and 100% by 2035, see Table 5-8 below. This compares to the main analysis which assumes a complete phase out of non-Tier III compliant vessels by 2025. This sensitivity has been included in addition to the main analysis to capture the possibility that intra-Med operations (where vessels are not affected by external NO_x ECAs) may not be built with Tier III compliance from 2025, with this sensitivity analysis providing an upper bound estimation for required CAPEX investment across the Mediterranean fleet.

Table 5-8 Annual share of Tier III compliant new build vessels under the main and CAPEX sensitivity analyses, 2025-2040.

Scenario	Sensitivity	2025	2030	2035	2040
Baseline	Main	100%	100%	100%	100%
Baseline	CAPEX	70%	90%	100%	100%

Source: Ricardo analysis for this Study.

Therefore, under the CAPEX sensitivity, some new build vessels in the Baseline scenario will be non-Tier III compliant up till 2035, leading to additional CAPEX investment for NO_x abatement technology by operators under the NO_x ECA scenarios. By considering the volume of non-Tier III compliant vessels between 2025-2035, the cumulative additional CAPEX investment under the CAPEX sensitivity was calculated for all three NO_x ECA introduction dates across each study period, see Table 5-9.

Table 5-9 Additional cumulative CAPEX investment (average annual for period) costs between the main and CAPEX sensitivity analysis, in million €.

NO_x ECA introduction year	2031-2040	2041-2050
2032	184 (61.3)	-
2035	-	-
2038	-	-

Source: Ricardo analysis for this Study.

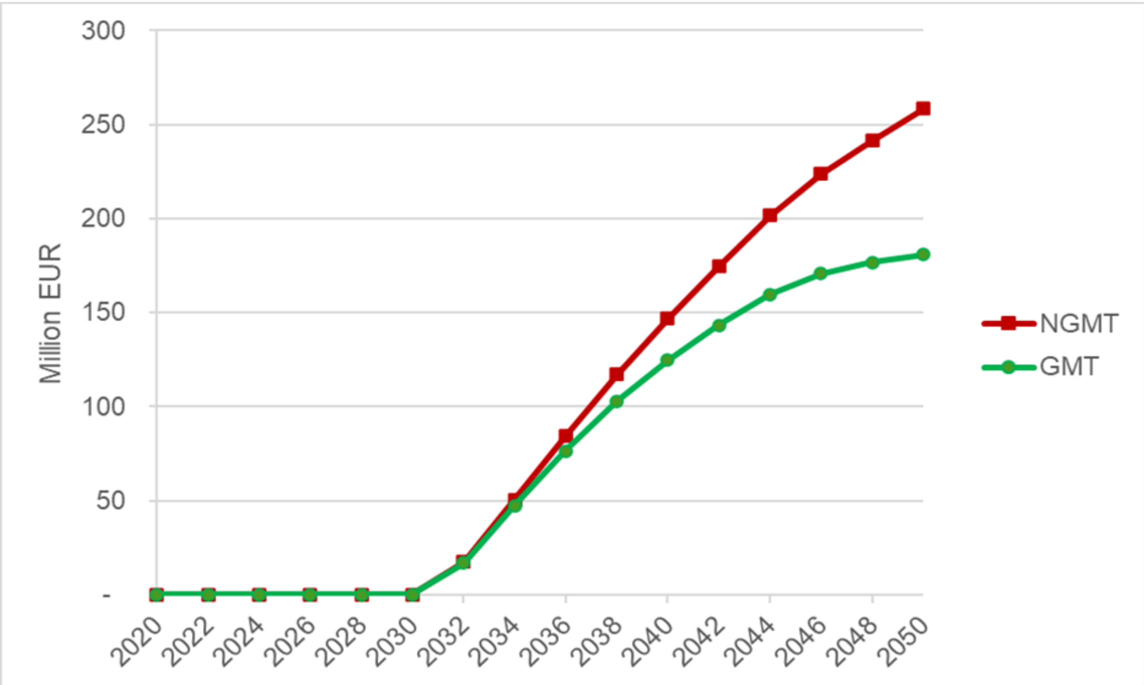
For the first period 2031-2040, NO_x ECAs for all three introduction dates will be in place, but only the 2032 introduction date occurs prior to the phase out of non-Tier III compliant new build vessels. Therefore, the 2032 introduction year is the only NO_x ECA scenario which requires additional CAPEX investment compared to the Baseline for operators to comply with Tier III requirements. Over the 2031-2040 period, the cumulative costs are €184 million for the 2032 NO_x ECA introduction, with no additional costs under the later 2035 and 2038 introduction date. As the 2041-2050 period falls after the phase-out of non-Tier III compliant vessels, there are no additional CAPEX costs associated with the CAPEX sensitivity for either of the NO_x ECA introduction dates.

The cumulative cost from CAPEX investment between 2031-2040 for the 2032 NO_x ECA introduction date is less than 30% of the cumulative OPEX cost for operating the NO_x abatement technology over the same period within the main analysis (see Table 5-6), such that slower adoption of Tier III vessels than considered in the main analysis would have a minor impact on total compliance costs for vessel operators.

5.3.4 *Comparison to NGMT scenario*

The GMTM decarbonisation scenario is considered the most realistic fuel and technology mix scenario reflective of decarbonisation targets for the maritime sector announced by the IMO and EU, see Section 5.1.2. In addition, the NGMTM scenario was included within the impact assessment as a sensitivity to explore the impact of lower decarbonisation ambition, i.e., lower alternative marine fuel uptake, on compliance and AQ costs. The annual fleet-wide compliance costs for the NO_x ECA 2032 scenario across the full period 2025-2050 under both NGMT and GMT decarbonisation scenarios are presented in Figure 5-8.

Figure 5-8 Annual fleet-wide compliance costs (OPEX only) for NO_x ECA introduction in 2032 under the GMTM and NGMTM decarbonisation scenarios



Source: Ricardo analysis for this Study

As the GMT scenario involves a faster and deeper penetration of alternative marine fuels across the Mediterranean fleet, the corresponding fleet-average NO_x emission factor is lower than for the NGMTM scenario, where a large share of the fleet remains dependent on Diesel marine fuel in 2050, see Section 5.1.2. As such, fleet-wide reliance on NO_x abatement technologies is higher in NGMT than the GMT, requiring greater operation (OPEX) of these technologies for Tier III compliance under the NO_x ECA scenario. Subsequently, greater operational energy demand and cost from NO_x abatement technology under the NGMT scenario results in a cost gap between the two decarbonisation scenarios.

Overall assessment of total costs of NO_x ECA

Overall, the implementation of the Med NO_x ECA will have a small but modest impact on vessel operating costs. The total increase in costs under the NO_x ECA scenario remains below 0.2% of baseline annual TCO across the full Study period and for all introduction dates and is driven by OPEX costs from NO_x abatement technologies. Operational costs vary by technology, with SCR (for 4-stroke engines) incurring higher ongoing costs than EGR (for 2-stroke engines) due to reagent used and maintenance requirements. As such, the Med NO_x ECA is expected to have no significant direct economic impact on vessel operators, with a stabilisation of costs over the longer-term. Furthermore, the compliance cost impact of NO_x ECA introduction is expected to be lower under the likely maritime decarbonisation forecasts between 2031-2050, with adoption of cleaner alternative fuels by the Mediterranean fleet aligning the proposed Med NO_x ECA with wider decarbonisation strategies and policies.

5.4 Impacts on the maritime sector

This section presents the impacts on the maritime sector, focusing on the costs and benefits incurred or enjoyed by the maritime industry resulting from the implementation of the Med NO_x ECA. These includes impacts on three aspects, including impacts in terms of modal shift and re-routing, impacts on ports and impacts on short sea shipping.

5.4.1 Impacts on shipping costs

Results presented in Table 5-7 represent the average increase in total shipping costs for freight vessels. Assuming a full cost pass-through rate from shipping operators to shippers[22], these increases would be also reflected in freight rates perceived by shippers. This means that on average freight rates are not expected to increase beyond 0.3%.

Even if total costs for passenger vessels were not analysed in the same level of detail, percentage increase in total costs for cruises are expected to below those of freight vessels, given the higher operating costs of cruises. Hence, impacts on cruise prices are expected to be negligible.

5.4.2 Impacts on short sea shipping

Smaller ships, often involved in coastal traffic, which forms a significant part of short sea shipping (IMO, 2016a), will be required to adapt to the NO_x Tier III standards following the implementation of the Med NO_x ECA. This could potentially result in increased costs (CAPEX), primarily due to the higher expenses associated with compliance technologies and engines for newbuilds. There is a slightly higher density of non-Tier III compliant vessels within the Ro-Ro and Ro-Pax fleets compared to the overall Mediterranean fleet, with 71% of total Ro-Ro and Ro-Pax vessels not Tier III compliant compared to 68% in the overall fleet (see section 4.3). In addition, Ro-Pax vessels typically have 4-stroke engines and so would rely on SCR technology for compliance, which has higher operational costs than the EGR alternative, see Section 5.3.2 for more detail.

However, passenger (non-freight) vessels have higher average ages and slower replacement rates compared to freight vessels and the overall fleet. Globally, the average age of all ships

[22] This is a common assumption in the shipping industry given the high level of competition within the market, see for example (European Commission, 2025d).

was 22.2 years in 2023, whilst passenger ship types[23] had an average age of 24.2 years (UNCTAD, 2024). Moreover, 47% of passenger ship vessels had an average age over 20 years, compared to 41.8% for all ship types. Therefore, longer replacement rates for passenger vessels may result in slower uptake of additional compliance costs for this vessel segment.

As such, small passenger ships will likely transition to Tier III compliant engine systems at a slower rate than the overall fleet, but with higher cost implications on fleet operators due to SCR technology and high energy consumption. Any additional OPEX investment in the near- to medium- term potentially passed on to passengers through elevated travel costs.

Box 2 - Cost impacts on the Barcelona-Rome ferry (Ro-pax) short sea shipping connection

To evaluate the extent to which higher operational costs for short-sea shipping connections may be passed on to consumer prices and influence future demand, the impact on a specific ferry connection in the Mediterranean Sea is considered. Namely, the ferry connection between Barcelona and Civitavecchia (Rome) was selected due to its high trip frequency and potential for modal shift due to a viable alternative road connection if sufficiently high costs from Med NO_x ECA compliance are passed from operators to consumers through a surcharge on passenger tickets. Key characteristics about the Barcelona-Civitavecchia route are outlined in Table 5-10.

Table 5-10 Barcelona-Civitavecchia ferry connection route characteristics.

Variable	Units	Value
Route distance (one-way)	Nautical miles	439
Route duration (one-way)	Hours	19.5
Average ticket price[24]	€	59 - 120
Weekly trips (one-way)	# trips	7
Typical vessel size	Gross tonnage (GT)	63,000
Typical vessel capacity	# passengers (vehicles)	3,500 (1,000)
Build year	Year	2008

Sources: (SEA-DISTANCES.ORG, 2025), (Grimaldi Lines, 2025), (Open Ferry, 2025a), (Open Ferry, 2025b)

The alternative road route would follow the Mediterranean coast North-East through Spain and France, before entering Italy and travelling south to Rome. The total road trip distance is around 1,350km, and would take around 16 hours for average passenger car speed and traffic levels. Although the road route distance is significantly longer than the ferry connection, the durations are comparable which may present a risk to future demand for the ferry connection if ticket price costs were subject to significant increases.

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[23] It is assumed that the UNCTAD vessel category "Other types of ships" predominantly contains passenger vessel types and excludes the main freight vessel types (i.e., Bulk carriers, container ships, general cargo, oil tankers).

[24] As of May 2025, the typical ticket price for the Barcelona-Civitavecchia (Rome) ferry route ranged from €59 for a single passenger to €120 for a passenger with a car, from the Grimaldi booking website: Grimaldi Lines - Book your ferry ticket - Sardinia, Sicily and more

To calculate the potential impact of NO_x ECA compliance on ticket prices along this route, the OPEX from NO_x abatement technology (SCR for Ro-pax vessels) per passenger was calculated and compared to the typical ticket revenue along this ferry connection. Energy consumption for an indicative vessel currently operating along the route was extracted from THETIS-MRV (EMSA, 2023) and assumed to remain constant for Tier III compliant vessels deployed following NO_x ECA implementation. Route distance and trip frequency data (see Table 5-10) and abatement technology costs (see Table 5-5) were used to calculate the annual additional OPEX cost expected from ferries operating along the route. As considered within the main analysis of fleet-wide compliance costs, the study assumption that all new-build vessels will be Tier III complaint from 2025 onwards means no additional CAPEX contribution to compliance costs is considered. Average ticket revenue per trip is calculated using the average passenger and vehicle occupancy[25] along this route and 2025 ticket prices from the route operator's website (see Table 5-10).

Compliance costs from additional OPEX from running NO_x abatement (SCR) technology will amount to €13,700 per trip for Tier III compliant vessels operating along the Barcelona-Civitavecchia ferry connection, compared to an estimated average ticket revenue of €103,000 per trip. Therefore, if 100% of Med NO_x ECA compliance costs were passed through to consumers, ferry ticket prices would rise by around 13% when considering a Tier III vessel in isolation.

Vessels operating on this route were built on 2008 and may be replaced in 2038 assuming a 30 years lifespan. This means that additional OPEX linked to Tier III compliance would only start towards the end of the 2031-2040 period. It is also assumed that vessel operators with multiple ferry vessels and/or routes in the Mediterranean may seek to gradually phase-in Tier III compliant vessels across the study period as vessels reach end-of-life and distribute Tier III vessel compliance costs across vessels/routes. This case study assumes that by distributing Tier III compliance costs operators could pass on between 50% and 100% of additional costs on a specific route.

Results on increased ticket prices are presented in Table 5-11. This shows a relatively modest price increase in the short-mid term (2031-2040), with more significant price raises in the long term (2041-2050).

Table 5-11 Ticket price increases for the Barcelona-Civitavecchia route in each 10-year period, as a percentage increase in 2025 prices (%).

Variable	2031-2040	2041-2050
% increase in 2025 ticket price	2-4%	7-13%

Sources: Analysis from this Study

The higher compliance costs relative to price (or total shipping costs) seen for this particular ferry route compared to the overall fleet average arises from: the use of SCR technology

[25] From energy consumption data by total passengers and per passenger for an indicative vessel operating on the Barcelona-Civitavecchia route, the average number of passengers was calculated (EMSA, 2023). It is assumed that only passengers with cars use the route, and the number of vehicles per passenger is aligned with the EU average passenger car occupancy rate of 1.3 (Eurostat, 2023). This results in an average car occupancy of 75% maximum capacity, and average passenger occupancy of 28%.

with higher running costs as opposed to EGR installed on the freight fleet (representing 85% of the overall fleet); and high ferry energy demand meaning fuel consumption represents a significant share of total costs along this ferry route, with associated higher SCR (urea) costs.

Whilst this represents a non-negligible increase in current ticket prices, a recent review of the extension of the EU ETS to the Maritime sector showed that ETS surcharges ranged from €2 - €53 (ranging from 3-11% of existing ticket costs) across a selection of EU ferry connections, with no modal shifts so far observed from introduction of this policy (European Commission, 2025d). Therefore, the increase in passenger ticket prices from pass-through of NO_x ECA compliance costs is expected to have limited impact on this ferry route, and should not incentivise a modal shift to alternative (road) routes. It should be considered that road transport is likely to experience increased costs related to the transition to low carbon technologies and fuels.

Although this case study focussed on the Barcelona-Rome ferry connection, these results are expected to broadly reflect impacts felt on other short sea shipping connections, although the specific vessel and fleet size, trip frequency, typical capacity and regional cost levels need to be accounted for when extrapolating these findings to other ferry routes covering non-EU countries or different connection characteristics.

In summary, the proposed NO_x ECA will have an impact on short sea shipping costs in the Mediterranean, with a limited cost impact in the near-term, given lower replacement rates for ferries, but increasing gradually as Tier III compliance reaches 100% of the Mediterranean fleet. Therefore, whilst the proposed Med NO_x ECA will lead to improved air quality in coastal areas and ports frequented by short sea shipping, they will also introduce some economic challenges for operators.

Short sea shipping routes typically offer essential connectivity to small islands or remote areas; hence, it is important to assess potential implications on connectivity from the expected price increase. In principle, an increase in the price of these connections could reduce demand and compromise their financial sustainability, which would in turn reduce supply of services, negatively impacting connectivity. However, it should be noted that most short sea shipping connections to small islands and remote areas (particularly in EU countries) are protected by public service obligations (PSO) that fix the maximum price and minimum supply of these services (e.g. minimum frequency and capacity). As such, connectivity impacts from the additional OPEX would be largely mitigated by PSO contracts.

5.4.3 Impacts on modal shift

The impact on society from expected changes in modal shifts is qualitatively assessed in the section, for both freight and passenger shipping.

Overall, the analysis finds no significant evidence to suggest that the proposed Med NO_x ECA will lead to a shift in transport modes of current shipping routes due to changes in voyage costs.

Shipping operations benefit from considerable economies of scale, enabling vessels to transport large volumes of cargo along established maritime trade routes (IMO, 2022). The cost increases associated with the proposed Med NO_x ECA are relatively low (less than 0.3%) when considered on a per tonne-kilometre basis, and the waterborne route remains the most cost-effective option compared to the least-cost all-land alternative.

For context, previous analyses undertaken for the Med SO_x ECA estimated the increase in marine freight rates necessary for an all-land alternative to become economically viable (IMO, 2022). Based solely on cost competitiveness, the findings indicated that freight rates would need to rise by between 1.6 and 32.3 times for land-based routes to be competitive. However, it is important to note that these results do not take into account other factors influencing modal choice, such as transit time, flexibility, and service reliability. The ratios were generally lower for manufactured goods, typically transported via containerised shipping, with freight rate increases ranging from 1.6 to 4.3 times. This suggests that containerised transport costs would need to increase by 1.6 to 4.3 times before all-land alternatives could become economically feasible. For raw materials and agricultural products, the required freight rate increases were significantly higher, making a switch to all-land alternatives far less feasible than for containerised goods.

In light of the estimated marginal changes in costs associated with the proposed Med NO_x ECA, there is no evidence to suggest that a significant mode shift would occur as a result of the ECA's implementation. This means that there is no expected change to the labour market, or on communities from shifting pollution between transport modes.

However, to the extent that the cost impact is somewhat higher for short sea shipping connections, compared to the general fleet, specific modal shift risks for short sea shipping connections would need to be evaluated in more detail.

Stakeholders in the interviews recognized that while modal shift, particularly from short sea shipping to road transport, is a risk that needs to be closely monitored, the Med NO_x ECA by itself is not likely to drive any significant shift to road transport in general terms. Modal shift effects would be mostly associated with wider climate and environmental policies concerning the shipping sector, such as EU ETS and Fuel EU.

5.4.4 Impacts on port competition and re-routing risks

The analysis examines the potential for competitive distortions between Mediterranean ports within the Med NO_x ECA in countries that are signatories to MARPOL Annex VI, and ports either outside the Med NO_x ECA or in countries that have not ratified MARPOL Annex VI. Ports in non-ratifying countries (Algeria, Bosnia and Herzegovina, Egypt, Lebanon and Libya, see Table 5-12)**Error! Reference source not found.** are not subject to the same implementation and enforcement requirements, potentially creating an uneven competitive landscape.

Table 5-12 Ratification status of MARPOL Annex VI among Contracting Parties

Contracting Parties	Parties to MARPOL Annex VI	Contracting Parties	Parties to MARPOL Annex VI
Albania	x	Libya	
Algeria		Malta	x
Bosnia and Herzegovina		Monaco	x
Croatia	x	Montenegro	x
Cyprus	x	Morocco	x
Egypt		Slovenia	x
France	x	Spain	x
Greece	x	Syria	x
Israel	x	Tunisia	x
Italy	x	Türkiye	x
Lebanon			

To mitigate cost increases linked to Tier III compliant vessel technologies, shipping companies may opt to deviate some of their routes to avoid calling at ports where Med NO_x ECA is effectively implemented and enforced. Typically, it is only possible to deviate traffic from a specific port when the port is not the final destination (or origin) of cargo, but it is solely used for transhipment operations. When financially advantageous, shipping companies may shift transhipment operations from Med NO_x ECA ports to other ports outside the Med NO_x ECA or in non-ratifying countries. This could be a risk for international routes (e.g. Asia to Europe or Europe to North America) calling at transhipment hubs in the Mediterranean. Such strategic shifts could undermine the competitive position of ports within the Med NO_x ECA, impacting regional trade dynamics.

This risk mirrors challenges observed with the implementation of the EU Emissions Trading System (EU ETS) for maritime transport, where transhipment relocation is a primary concern for EU ports. Liner companies could have the flexibility to reconfigure transhipment hubs within a route, provided alternative ports offer comparable service levels (e.g. in terms of distance, capacity, and fees).

Given the proximity of transhipment ports within the Med NO_x ECA and ports in non-ratifying countries in the Mediterranean, transhipment relocation between these two groups is the main re-routing risk analysed in this study. Table 5-13 shows main container ports in non-ratifying countries. Among these, the Egyptian ports of East Port Said, Port Said and Damietta, and to a lower extent, the port of Beirut in Lebanon are major transhipment ports in the Mediterranean which could have a larger potential to attract further transhipment traffic.

Table 5-13 Main container ports in Contracting Parties that have not ratified MARPOL Annex VI (main transhipment hubs in bold)

Country	Main container ports
Algeria	Bejaia, Djen-Djen

Country	Main container ports
Bosnia and Herzegovina	-
Egypt	Alexandria, **Damietta, East Port Said, Port Said,** El Dekheila, Sokhna
Lebanon	**Beirut**
Libya	Qasr Ahmed

However, the very limited increase in costs expected from the application of the potential Med NO_x ECA (less than 0.3% on total shipping costs as per Section 5.3) is not expected to provide a financial incentive for re-routing, considering costs associated with re-routing including one-off implementation costs or additional fuel costs (if sailing distance is larger).

A recent report from the European Commission on the implementation of EU ETS in 2024 (European Commission, 2025d) finds no concrete evidence of a general trend in relocation of container transhipment activities, whereby neighbouring non-EU ports would profit from a decrease in port activity at EU ports. This is in a context where cost increases from EU ETS were estimated at 3.7% in 2024 with an expectation of larger cost increases in 2026, following the end of the phase-in period of EU ETS for shipping. The report found that changes in container operations in 2024 seem mainly related to the ongoing impacts of the Red Sea crisis, which resulted in many shipping companies deviating their routes around South Africa, via the Cape of Good Hope.

When comparing to the EU ETS benchmark, it becomes apparent that Med NO_x ECA is not likely to lead to significant re-routing risks. Med NO_x ECA compliance costs are on average more than 10 times lower for shipping companies, significantly reducing the risk of transhipment relocation.

The findings from the qualitative analysis are reinforced by the interviews with stakeholders. Stakeholders believe that re-routing due to the NO_x ECA is unlikely as the costs of changing shipping routes are high and the presence of existing ECAs in Northern Europe and the Atlantic limits opportunities for rerouting. Stakeholders highlighted that route choices are typically based on strong economic and logistical factors, making rerouting an unattractive option. Ferry routes to remote or island regions are also not expected to be affected as they are often protected by public service obligations (PSO), subsidies, or exemptions due to their essential nature.

5.4.5 Other impacts on ports

Other impacts to be considered in the analysis include potential air quality improvements, public health benefits for port communities, regulatory compliance, and economic considerations for the shipping industry and port infrastructure.

Air quality improvements in port areas: The implementation of the proposed Med NO_x ECA is anticipated to significantly reduce nitrogen oxide (NO_x) emissions from ships. This reduction is expected to result in marked improvements in air quality across the Mediterranean region, particularly in coastal, densely populated areas where numerous ports and vulnerable communities are located.

NO_x emissions, along with fine particulate matter (PM2.5 and PM1), are typically present at higher concentrations near ports than other pollutants (within 1 to 10 kilometres from the port area in nearby cities) (EEA, 2024), such as sulphur oxides (SO_x) or certain metals, with levels often 1.5 to 2 times higher, as analysed in the Port of Marseille (Le Berre, et al., 2024). This underscores the impact of port activities on local air quality. In fact, many of Mediterranean coastal areas and ports have recurrently faced challenges in meeting air quality standards related to NO_x emissions, with some of these exceeding the 2030 limited value of 20 $\mu g/m^3$ for NO_2 emissions (EEA, 2024). As a result, a reduction in NO_x emissions is expected to deliver direct benefits to the health and well-being of port workers and surrounding populations by reducing exposure to these harmful pollutants.

It is also important to highlight that the ECA will not only apply to larger ships operating within the area but will also address coastal and short sea shipping, which is particularly relevant for ports. This category includes smaller vessels, such as passenger ships and general cargo ships, which operate closer to populated areas (IMO, 2016a). The measures introduced under the NO_x ECA will therefore affect a broad range of vessels, contributing to a significant improvement in air quality in port areas, which are often more susceptible to the effects of concentrated pollution.

At the same time, as indicated by a consulted port authority, air quality benefits in port areas would be somewhat mitigated with the adoption of onshore power supply (OPS) in ports, following the requirements of the Alternative Fuel Infrastructure Regulation and Fuel EU Regulation for EU ports. The increasing use of OPS significantly reduces emissions at berth, which would already lead to significant air quality benefits.

Health benefits for port communities: The reduction in air pollution associated with the NO_x ECA is expected to deliver public health benefits as well, particularly to regions located in coastal areas, many of whom reside in or around port areas and may be disproportionately impacted by this pollution. These populations are frequently exposed to harmful levels of air pollutions from shipping activities.

Contribution to regulatory compliance: The international implementation of the ECA is expected to alleviate the pressure on regional, national and sub-national authorities to introduce their own measures to reduce ship emissions. This could include port-specific regulations, which may now be deemed unnecessary due to the global scope of the ECA (IMO, 2022). Also, for EU Member States bordering the Mediterranean, the Med NO_x ECA could reinforce and align their strategies and objectives with existing regulations.

In summary, the Med NO_x ECA is expected to lead to improvements in air quality in and around Mediterranean ports, resulting in potential health benefits for port communities. It aligns with existing EU regulations, which are expected to be the main drivers for future developments in port infrastructure for alternative fuels and shore power.

5.5 Other impacts on economies, citizens and authorities

This section reviews impacts of increasing maritime transport costs on the economies of Mediterranean countries, focusing on changes in prices, in gross domestic product (GDP) and total employment at country level, as well as in other aspects such as environmental biodiversity and cultural heritage.

5.5.1 Impact on prices

Projected changes in maritime transport costs (see Table 5-7) were used as an input to estimate a coefficient that can be incorporated in GEM-E3 model[26] to indicate the associated impacts on transport margins. This coefficient was then applied to adjust import and export prices for goods transported via maritime routes, impacting both Mediterranean countries as importers and exporters. This methodological approach considers the different transport margins applied for each respective good by each respective transport mode. These cost adjustments influence bilateral trade flows and the wider macroeconomy. This consistent general equilibrium framework captures both the direct and indirect effects of increasing transport costs and provides insights on the broader implications for prices within the Mediterranean region at a national level of disaggregation.

Overall, modelling results indicate that:

- Increases in shipping costs affect import prices depending on the level of additional duties applied per product and per country (resulting from the structure of the economies, imports level, etc.)
- Countries/Sectors with high import dependency exhibit increased prices, reflecting the additional duty rates implemented. At the same time, the decrease in demand may lead to an excess of supply of capital and labour, which may reduce the unit costs of production in other sectors, particularly labour-intensive sectors such as construction, and lead to reduced prices those sectors.
- Overall, impact on goods' prices is marginal, with maximum price increases estimated at 0.03%.
- Price increases are higher in small island countries like Malta or Cyprus, as these tend to be largely dependent on imports (particularly for fuels and consumer goods). However, modelled price increases in these countries are still marginal.

Results are presented for countries available in the GTAP database[27] (see Table 5-14)

[26] GEM-E3 is s a large scale multi-sectoral CGE model designed to simulate the operation of the economic system (by country) with particular focus on the representation of bilateral trade transactions by origin-destination, product and transport model. The model captures changes in global trade that are driven by competitiveness, policies/regulations/standards, infrastructure, prices, supply/demand constraints.

[27] The Mediterranean countries that we will not be able to analyse via the model are: Bosnia and Herzegovina; Libya; Monaco; Montenegro; Palestine (Gaza Strip).

Table 5-14 Countries available in the GTAP database

Country code	Country name	Country code	Country name	Country code	Country name
ALB	Albania	GRC	Greece	SVN	Slovenia
DZA	Algeria	ISR	Israel	ESP	Spain
CYP	Cyprus	ITA	Italy	SYR	Syria
CRO	Croatia	LBN	Lebanon	TUN	Tunisia
EGY	Egypt	MLT	Malta	TUR	Türkiye
FRA	France	MAR	Morocco		

For illustration purposes, Figure 5-9, Figure 5-10 and Figure 5-11 below present results for the NO_x ECA 2032 scenario on prices of agriculture goods, fuels and consumer goods, respectively.

Figure 5-9 Change in price of agriculture goods under NOx ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model

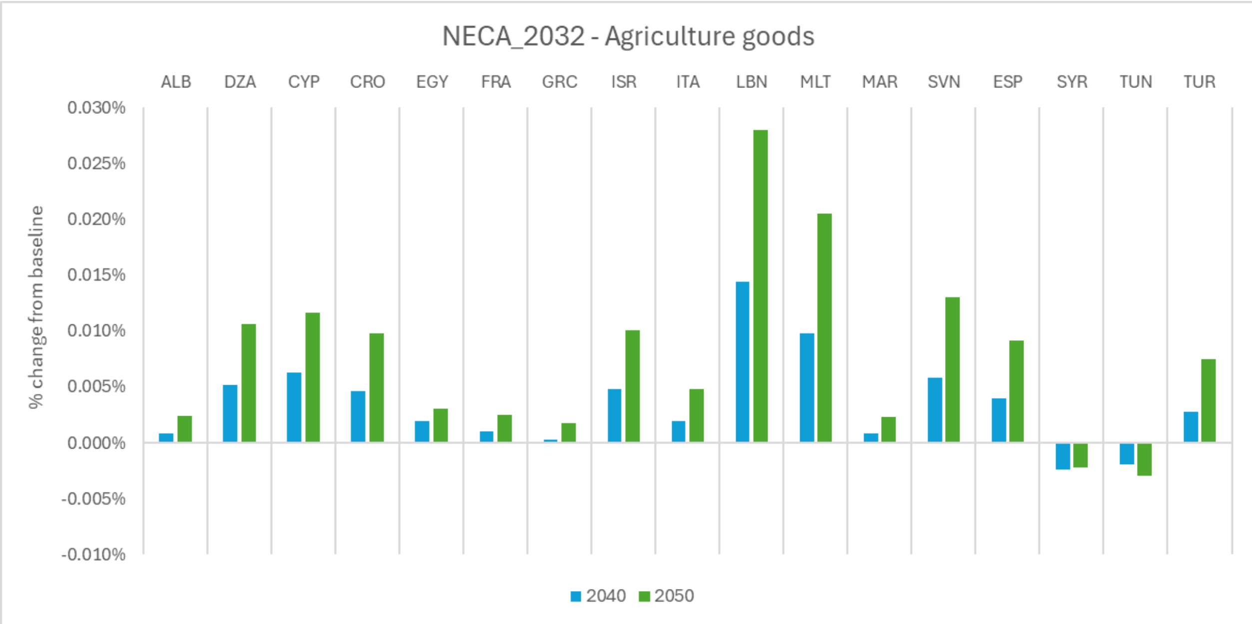


Figure 5-10 Change in price of fuels under NOx ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model

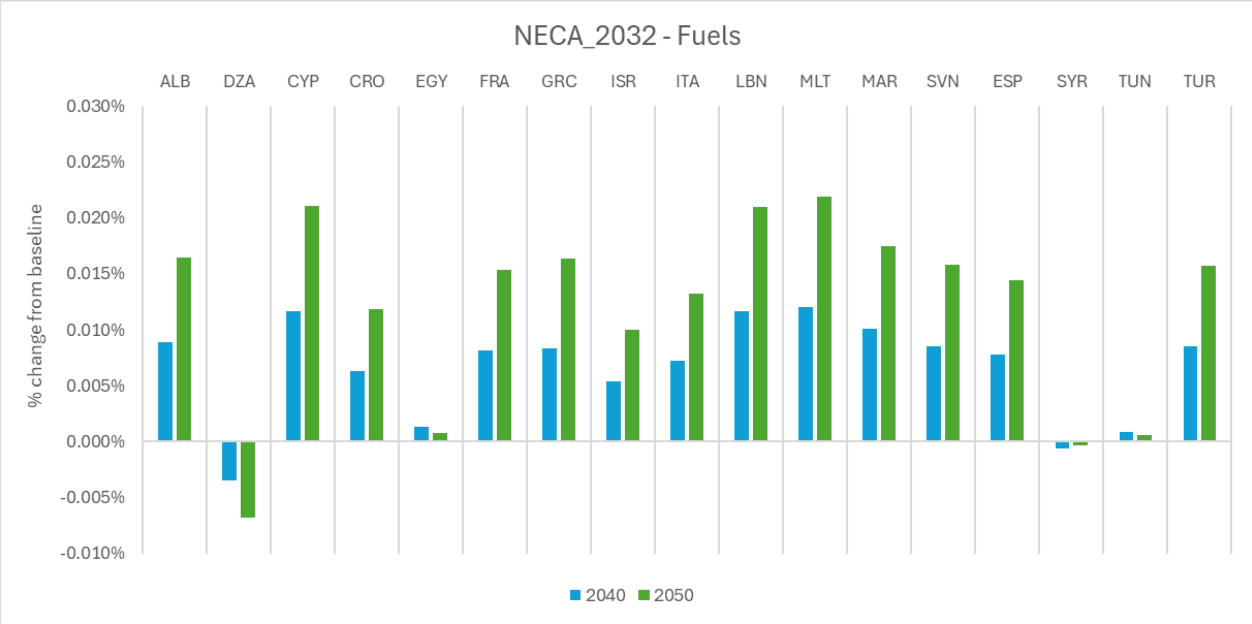
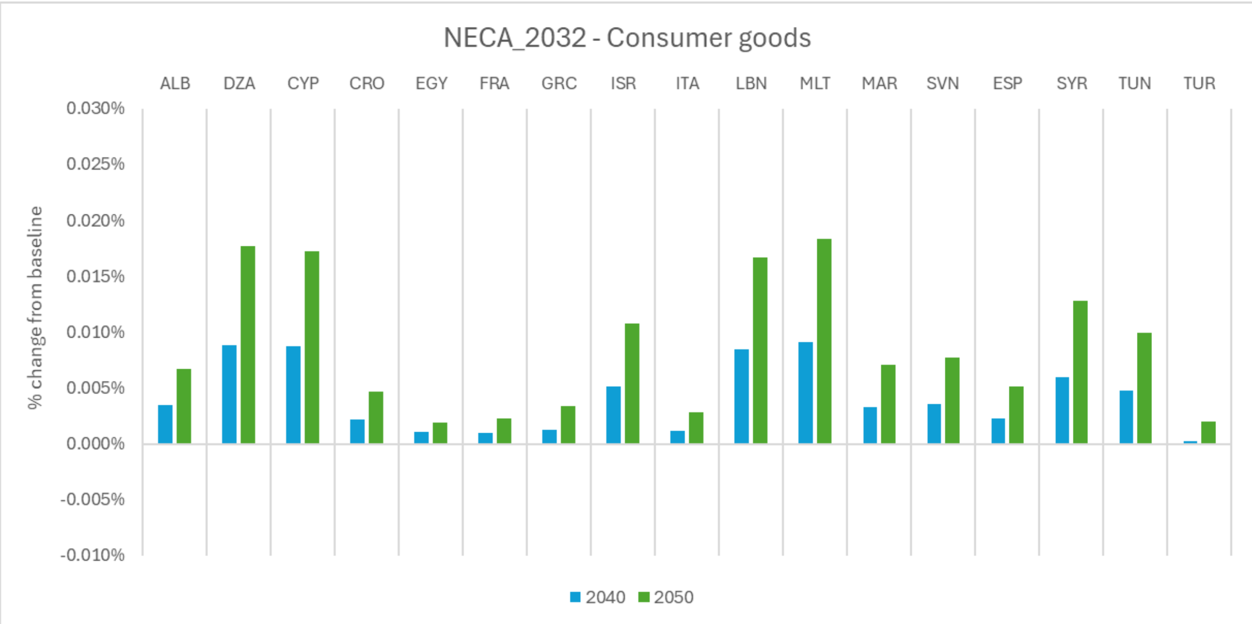


Figure 5-11 Change in price of consumer goods under NOx ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model



5.5.2 Impact on gross domestic product and total employment

The GEM-E3 model described above was also used to estimate macroeconomic impacts for Mediterranean countries in terms of GDP and employment levels.

Overall, modelling results indicate that:

- Higher transport costs affect both the prices of imported goods and the prices of exported goods, when using water transport means.

- Macroeconomic impacts are marginal, given small changes in transport costs (i.e. less than 0.3%)
- Highest impacts are equivalent to 0.01% of baseline GDP in the medium and long-term for some countries.
- Highest GDP losses are registered in Syria and Tunisia, although still marginal. The first is a consumption-based economy with high exposure on agricultural goods, for which transport margins are an important price component. The second economy is more open (i.e. more dependent on maritime trade) and is affected by higher export and import costs particularly in consumer goods.
- Employment effects follow macroeconomic trends and are of a small magnitude.

For illustration purposes, Figure 5-12 and Figure 5-13 below present results for the NO_x ECA 2032 scenario on GDP and employment. Results for later adoption scenario considering a later adoption of the Med NO_x ECA (2035) delay the introduction of economic impacts, but do not differ significantly from impacts under NO_x ECA 2032 once the policy is implemented.

Figure 5-12 Gross domestic product (GDP) change under NOx ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model

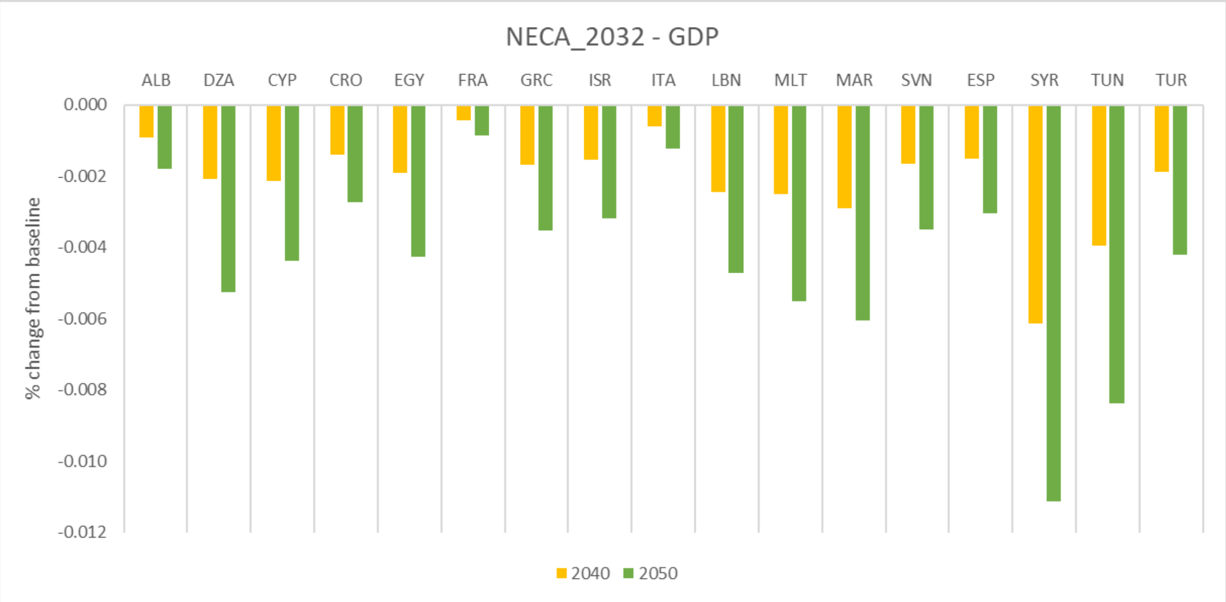
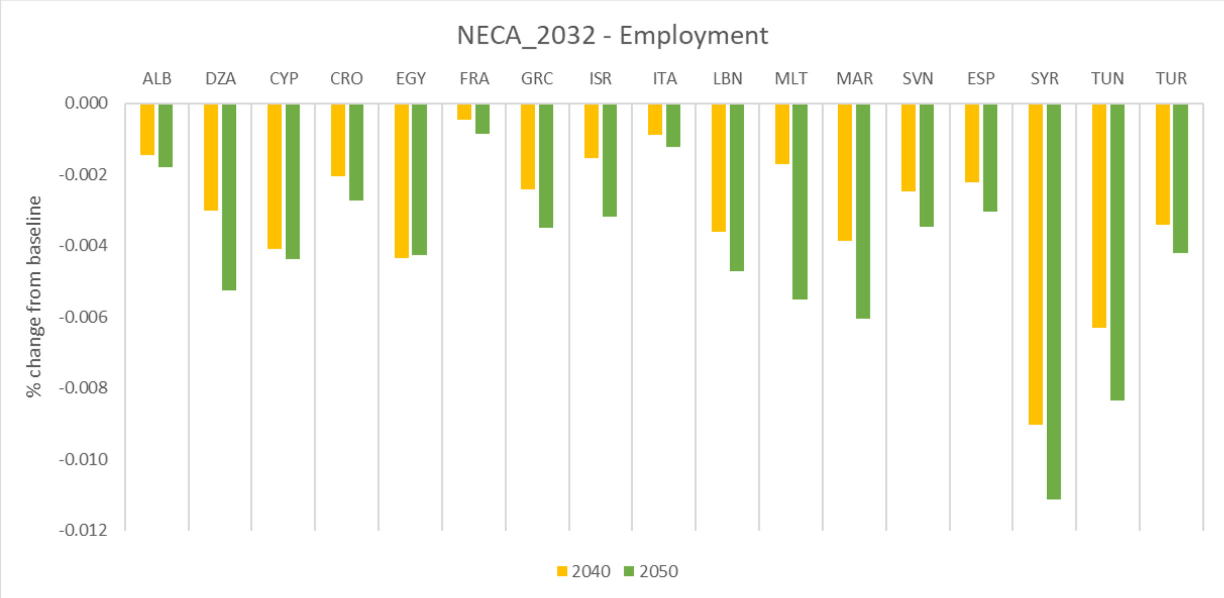


Figure 5-13 Employment change under NO_x ECA 2032 scenario by year compared to the baseline. Source: GEM-E3 model



In addition to the impacts outlined above, Plan Bleu is currently preparing a short paper examining the potential effects of a Med NO_x ECA on the fisheries and tourism sectors. The paper is based on questionnaire responses and is still under development. Key insights from this publication will be incorporated into this report once it becomes available.

5.5.3 Impact on environmental biodiversity

The Mediterranean Sea is recognised as a sensitive ecosystem with high marine biodiversity (17,000 listed marine species) (IMO, 2022). However, it continues to experience environmental degradation driven by anthropogenic factors, including acidification, pollution and habitat loss (IMO, 2022).

The impact of implementing the Med NO_x ECA on biodiversity in the region is quantified under the damage cost approach, along with impacts on health and material damage (Section 5.2). This section, however, provides a qualitative assessment of the effects of nitrogen deposition in the Mediterranean, along with information on indicators for monitoring these impacts.

Nitrogen oxides (NO_x) can have a significant impact on biodiversity, particularly within sensitive ecosystems. Atmospheric deposition is one of the major sources of nitrogen and phosphorus for some regions of the Mediterranean sea with more than 18,199 gN month-1 deposited to the whole Mediterranean Sea (Richon et al., 2018).Shipping in the Mediterranean contributes significantly to emissions of air pollutants, including NO_x and particulate matter (PM) (Fink, et al., 2023). A study modelling the potential impact of NO_x emissions in the Mediterranean found that the potential contribution from ships on total NO_2 concentration, including nitrogen deposition, was high on the main shipping routes and in coastal regions, ranging from 25% to 85% of the total NO_2 concentration (Fink, et al., 2023). Models in the same study showed high values (over 300mg) in cities and densely populated regions, with the highest impact of NO_2 concentration near major ports (Fink, et al., 2023). Without further control measures, NO_x emissions from ships are projected to grow in the Mediterranean and are likely to exceed emissions from land-based sources in the EU after 2030 (Fink, et al., 2023). There are multiple potential impacts of nitrogen deposition which can affect biodiversity in the Mediterranean. Firstly, it can cause nutrient loading, which alters nutrient cycling processes and alters microbial community (Ji-Young Moon et al., 2016). Nitrogen enrichment can favour the growth of certain algal species, some of which produce toxins harmful to marine life. The Mediterranean is an oligotrophic sea with naturally low nutrient levels, meaning that there is a high rate of endemic species which are sensitive to any changes in nutrient levels (European Environment Agency, n.d.). Atmospheric deposition of NO_x contributes to acidification and eutrophication in both terrestrial and aquatic ecosystems, leading to adverse effect on species composition, habitat quality, and overall ecosystem resilience (IMO , 2010).

Key indicators of nitrogen deposition in marine coastal systems:

- Long-term trends in surface seawater N:P ratios (The ratio of dissolved inorganic nitrogen (DIN) to dissolved inorganic phosphorus (DIP) in seawater. Deviations from the Redfield ratio above 16:1 indicate nutrient imbalance.

- Direct measurements of aerosol deposition fluxes (direct measurement of nitrogen concentrations in wet and dry nitrogen deposition events from shipping emissions, land-originating NOx emissions) (Fink, et al., 2023).

There is substantial evidence indicating that NO_x ECAs and broader ECAs positively impact environmental biodiversity for the marine ecosystems. The reduction of NO_x emissions reduces acidification and eutrophication in marine environments, benefiting a wide range of marine species and habitats. Reducing emissions from ships not only benefits marine environments but also improves air quality in coastal and inland areas. Lower levels of NO_x emissions contribute to healthier forests, grasslands and other terrestrial habitats, supporting diverse plant and animal life (Assessment and Standards Division Office of Transportation and Air Quality U.S. Environmental Protection Agency, 2009), although, even when nitrogen deposition is reduced, the recovery of biodiversity especially in highly impacted ecosystems is likely to be slow and may require active management interventions. In the specific case of the proposed Mediterranean NO_x ECA, environmental benefits are anticipated, with NO_x emissions from maritime transport projected to fall from approximately 1,200 kt NO_x under the baseline scenario to around 600 kt NO_x in 2035 (a 50% reduction), and further to 200 kt NO_x by 2050 (a reduction of over 80%), as presented in Section 5.2.3.

However, there are also concerns that the use of EGR systems commonly used by ships in ECAs can have a negative environmental impact if contaminated water is discharged. In EGR systems, a water treatment system is used to clean and cool the recirculated exhaust gas before it re-enters the engine. The water used is typically fresh water, which is recirculated in a closed loop and treated to remove contaminants. A bleed-off system is also required to manage excess water generated during the process. Since 2018, regulations for the discharge of EGR bleed-off water were adopted by IMO Resolution MEPC.307(73). In particular, the EGR bleed-off water byproduct requires treatment to less than 15 PPM, which aligns with the requirement for bilge water. However, the actual bleed-off water flow rates are relatively small, and water disposal to sea is strictly regulated under established international guidelines. Proven commercial treatment technologies are readily available, and these environmental requirements have not affected the commercial viability of EGR systems in marine applications.

5.5.4 Impact on Cultural Heritage

The Mediterranean region is an important region for cultural heritage sites. Across the Mediterranean, there are 49 cultural UNESCO World Heritage Sites located on coastal areas, such as Alexandria in Egypt, Venice in Italy and the island of Delos in Greece (ECMWF& the Union for the Mediterranean, n.d.).

Air pollutants emitted by ships contribute to the corrosion and soiling of cultural heritage sites, accelerating the deterioration of historic buildings and monuments (IMO, 2022). Nitrogen oxides (NO_x) and particulate matter (PM_{10}) are particularly harmful, with substantial evidence showing their role in the corrosion of calcareous stone, such as limestone, and in surface discolouration (Di Turo, et al., 2016). Moreover, pollutants originating from sources located far beyond urban areas can also potentially affect cultural heritage.

The designation of a Med NO_x ECA is expected to significantly reduce NO_x emissions within the region (Section 5.2.3), thereby contributing to lower pollutant concentrations and supporting the preservation of cultural heritage sites vulnerable to air pollution-related degradation. This is consistent with the objectives and expected impacts from previous ECAs. For instance, in the North-East Atlantic, the newly approved ECA that will be implemented in 2027, is expected to improve the protection of 148 UNESCO World Heritage Sites (ICTT, 2024).

5.5.5 Impact on authorities

The implementation of a Med NO_x ECA is expected to increase the administrative burden on public authorities, particularly with respect to the costs of enforcement, monitoring, and administrative coordination. While the exact scale of these impacts may vary depending on national capacities and existing infrastructure, they represent an important consideration in the planning and policy process. However, potential synergies with the recent implementation of the Med SO_x ECA should also need to be taken into account, together with synergies derived from the experience in implementing existing NO_x ECAs.

To mitigate these challenges, authorities could benefit from cross-regional sharing of best practices, which can enhance the efficiency and consistency of implementation. Furthermore, burden-sharing arrangements among international stakeholders could help to more effectively allocate compliance responsibilities and alleviate pressure on individual administrations.

Stakeholders highlighted the need for consistent and systematic enforcement mechanisms at ports to uphold NO_x ECA requirements. However, all stakeholders identified current enforcement as a key challenge, citing limited capacity among port authorities and inconsistent practices across the Mediterranean. Stakeholders warned that this gap would undermine the effectiveness of the NO_x ECA as there is a risk of some ports applying less stringent enforcement procedures.

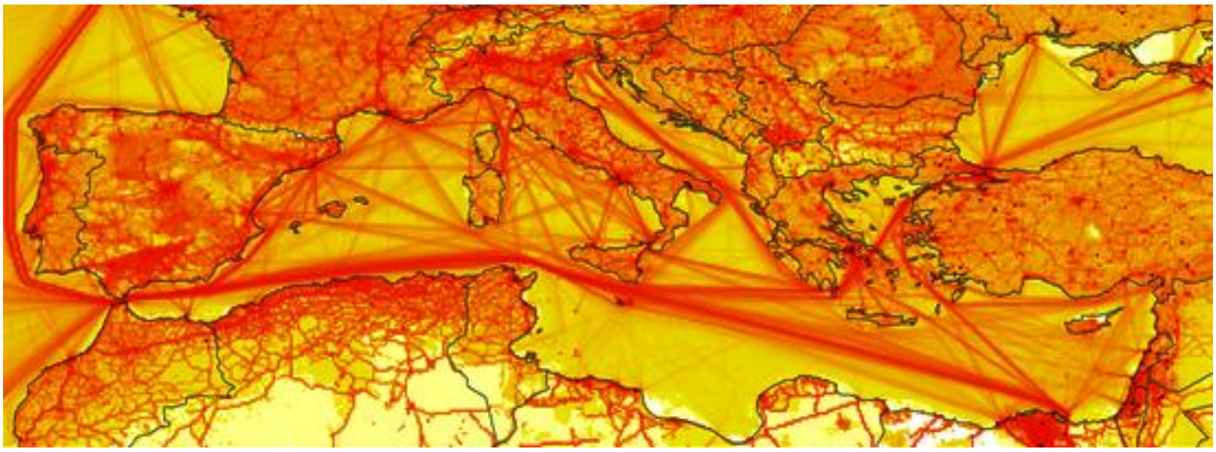
To address enforcement challenges, stakeholders recommended establishing a regional working group, potentially coordinated by REMPEC, to develop uniform inspection and enforcement criteria for NO_x ECA compliance. A harmonised monitoring scheme across all Mediterranean ports was viewed as essential to ensure all contracting parties enforce the NECA consistently, regardless of port location.

6. ALTERNATIVE MEASURES FOR LAND-BASED SOURCES

6.1 Land-based NO_x emissions data

NO_x emissions from land-based sources in Mediterranean coastal States were analysed using gridded emissions data from the Centre on Emission Inventories and Projections (CEIP) (EMEP CEIP, 2025). Figure 6-1 below shows the relevant NO_x emissions in the Mediterranean Sea for 2022.

Figure 6-1 NO_x emissions in the Mediterranean Sea (2022)



Source: (EMEP CEIP, 2025)

The assessment covered the following countries, as classified under the EMEP:

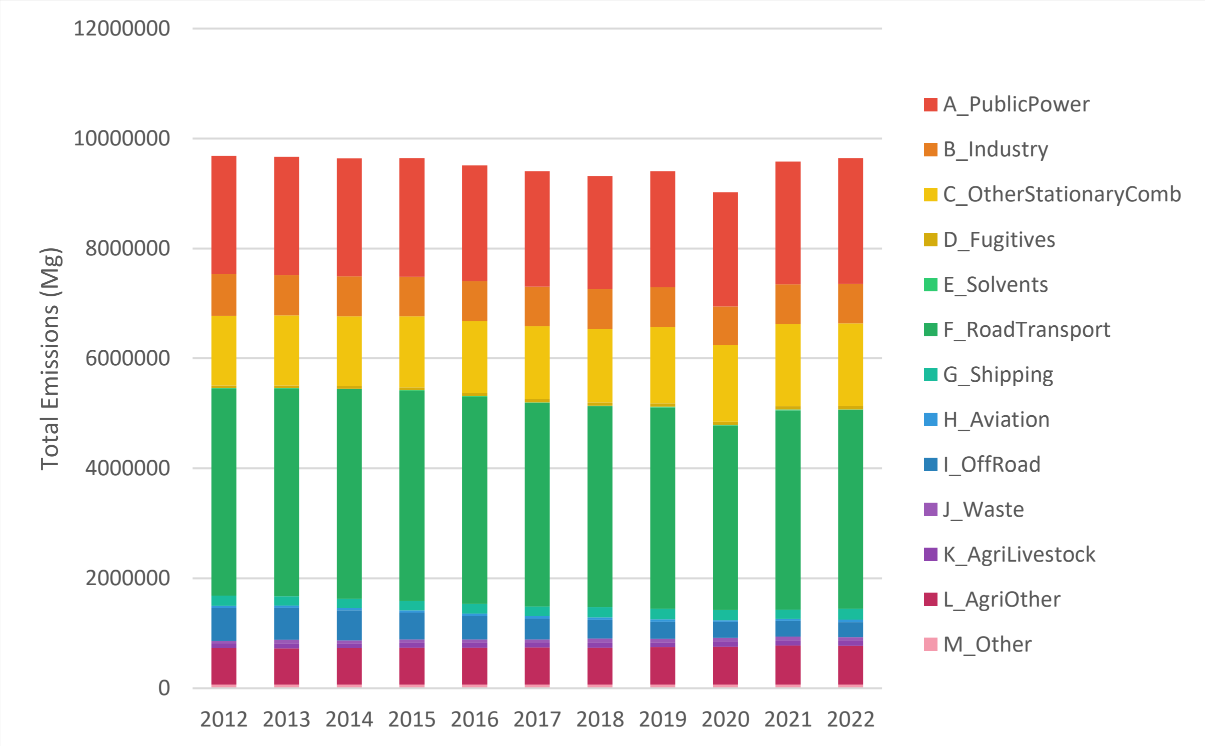
- **European countries**: Albania, Bosnia & Herzegovina, Croatia, Cyprus, France, Greece, Italy, Malta, Monaco, Montenegro, Slovenia, Spain, and Türkiye.
- **Non-European regions**:
    - *Modified Remaining Asian Areas (MRAA) within the former official EMEP domain*: Israel, Lebanon, and Syria.
    - *North Africa*: Tunisia, Morocco, Algeria, Libya, and Egypt.

The EMEP data is categorised into sectors according to the Gridded Nomenclature for Reporting (GNFR). This is a classification system used in air pollution inventories to group emission sources to specific sectors. National sector totals for 2022 (most recent publication date) were extracted and it was determined that the three highest NO_x emitting sectors in 2022 were:

1. Road transport (F_RoadTransport)
2. Public power (A_PublicPower)
3. Other stationary combustion (C_OtherStationaryComb)

To support further analysis, national sector totals were also extracted for the period 2012 – 2022. As shown in Figure 6-2, while some variation in trends is observed, the sectors identified above consistently remain the highest emitters throughout the time series, with only minor variations across the other sectors.

Figure 6-2 Total national NO_x emissions (Mg) per sector from 2012-2022 for land-based sources



An analysis was conducted to define a buffer zone between coastal and inland sources, evaluating the extent of land-based emissions affecting the Mediterranean. Seven ports across the North, South, East, and West of the region were identified. These include: the Port of Algiers (Algeria), the Port of Barcelona (Spain), the Port of Marseille (France), the Port of Piraeus (Greece), the Port of Tanger Med (Morocco), the Port of Tripoli (Libya), and the Port of Valencia (Spain). Satellite imagery of these ports was examined to measure the distance between the coast and visible land-based emission sources, such as road transport, Non-Road Mobile Machinery (NRMM), and industrial facilities. The maximum observed distance was approximately 5 km from the coastline, with an average of around 2 km across all ports. The total NO_x emissions from these two buffer distances were compared as part of a sensitivity analysis. Table 6-1 below shows the comparison between the two buffer totals, ranked highest to lowest emissions.

Table 6-1 Comparison of land-based sector NO_x emission totals for 2km and 5km buffer zones, ranked by total emissions

GNFR Sector	2km sum of total emissions (Mg/year)	5km sum of total emissions (Mg/year)	Difference (Mg/year)
A_PublicPower	529,562.3	533,528.6	3,966.2
G_Shipping	362,315.3	364,528.2	2,212.8
F_RoadTransport	288,616.6	336,130.2	47,513.6
B_Industry	141,867.4	148,945.7	7,078.3
C_OtherStationaryComb	80,995.2	93,052.1	12,056.8

GNFR Sector	2km sum of total emissions (Mg/year)	5km sum of total emissions (Mg/year)	Difference (Mg/year)
L_AgriOther	22,864.8	26,916.7	4,051.9
I_OffRoad	20,155.3	22,645.6	2,490.2
H_Aviation	15,324.2	17,019.1	1,694.9
D_Fugitives	7,197.7	7,253.9	56.2
J_Waste	4,344.0	5,050.5	706.5
E_Solvents	2,237.8	2,375.2	137.4
M_Other	1,865.1	2,352.2	487.1
K_AgriLivestock	1,656.5	2,127.5	471.0

Table 6-1 demonstrates that expanding the buffer from 2 km to 5 km results in a relatively small increase in total NO_x emissions (about 5%), suggesting that the majority of significant land-based emission sources affecting the Mediterranean are concentrated within the first 2 km from the coastline. The sectors with the highest emissions are public power (A_PublicPower), shipping (G_Shipping) and road transport (F_RoadTransport). Increasing the buffer distance highlights that road transport has the most substantial increase in emissions between the 2 km and 5 km buffers (+47,513.62 Mg/year), suggesting that a large portion of these additional emissions occur beyond the immediate coastal influence zone. Similarly, emissions from other stationary combustion and industry also exhibit the largest differences across the buffer distances.Given that the increase in emissions beyond 2 km is relatively minor and that a 2 km buffer represents the average observed extent of land-based sources directly impacting the Mediterranean, it is recommended as the appropriate boundary for this analysis.

6.1.1 Projections

Officially reported projected emissions data which is submitted by the Parties to the Air Convention (CLRTAP) were compiled to identify the sectors with the highest projected emissions (European Environment Agency, 2025). It is important to note that projections data is not available for all the Mediterranean coastal States. The following countries submitted data:

- Croatia
- Cyprus
- France
- Greece
- Italy
- Malta
- Monaco
- Slovenia
- Spain

All listed countries provided national projections for 2030. The top three highest national emitting projected sectors for are:

1. Road transport (F_RoadTransport)
2. Industry (B_Industry)

3. Agriculture – other (L_AgriOther)

Scaling factors were calculated based on the 2022 and 2030 national sectoral emissions. An average of these scaling factors was then taken for each sector and then applied to the countries which did not supply projections data. The scaling factors were applied on the 2km buffer zone totals and then ranked from highest to lowest, the emission totals can be found in Table 6-2.

Table 6-2 Scaled projected NO_x emissions (Mg) by sector for 2030 within the 2km buffer zone, ranked from highest to lowest emissions

Sector	Scaled 2030 NO_x Emissions Within 2 km buffer (Mg/year)
A_PublicPower	477,660.6
G_Shipping	402,982.2
F_RoadTransport	203,017.1
B_Industry	130,859.4
C_OtherStationaryComb	915,11.4
L_AgriOther	23,659.1
H_Aviation	15,470.9
I_OffRoad	10,410.4
J_Waste	3,097.8
E_Solvents	2,053.3
K_AgriLivestock	1,699.0
Sum of all sectors	**1,362,421.0**

Compared to the 2022 sector totals within the 2 km buffer, the scaled projected totals for 2030 show an overall decrease in emissions; however, the ranking of emitting sectors remains unchanged.

6.1.2 Recommendations

Although shipping (G_shipping) is among the top emitters within the 2km coastal buffer, it is being analysed separately under the scope of the proposed Mediterranean NO_x ECA. Therefore, this analysis focuses on identifying the other major land-based sources that can be targeted to mitigate NO_x emissions.

Based on both the 2022 emissions data and projections for 2030, the most significant land-based contributors to NO_x emissions in Mediterranean coastal states are:

- Road transport (F_RoadTransport)
- Public power (A_PublicPower)
- Industry (B_Industry)
- Other Stationary Combustion (C_OtherStationaryComb)

Road transport consistently has the highest emissions among land-based sources and the largest increase when expanding the buffer zone from 2km to 5km, reflecting its widespread inland presence. Public power remains a major source, particularly near urban and industrial coastal areas. Industry and other stationary combustion are similar as they are ranked fourth and third within the 2022 national totals and third and fourth in the buffer totals and projected buffer totals respectively (excluding shipping), highlighting that both their contributions to on-land emissions is significant.

Although agriculture – other (L_AgriOther) ranked third in the 2030 national projections, its emissions are typically located further inland, with less impact within the coastal buffer zone. For this reason, it is not prioritised as a key sector for land-based measures.

Overall, road transport, public power, industry and other stationary combustion are recommended as the high-emitting land-based sectors to target.

6.2 Assessment of land-based measures and their implementation

This section reviews existing and planned emission reduction measures in the identified high-emitting sectors identified in Section 6.1.2: road transport, industry, public power and other stationary combustion. These sectors represent the highest sources of land-based NO_x emissions across Mediterranean coastal States. The following assessment focuses on identifying relevant policies, assessing their implementation status, and evaluating their air quality and climate impacts.

6.2.1 EU Member States

This assessment draws on publicly available national documentation submitted by EU Member States, including:

- National Air Pollution Control Programmes (NAPCPs) (European Commission, 2025)
- National Energy and Climate Plans (NECPs) (European Commission, 2025)
- European Environment Agency's Policies and Measures (PaMs) database (European Commission, 2025)

Across the Mediterranean EU Member Coastal States, countries are taking a diverse set of actions to address NO_x emissions.

Road Transport: France, Greece, Italy, Malta, Slovenia, and Spain have introduced extensive packages to support electrification, fleet renewal, public transport expansion, and low-emission zones. Spain and France also have ambitious modal shift policies aimed at reducing private vehicle use.

Public Power: Decarbonisation is underway through coal phase-out policies, renewable energy integration, and efficiency upgrades in existing power stations. France, Greece, Italy, and Spain are leading in this area, with timelines for coal retirement and large-scale investment in solar and wind.

Industry: Measures generally align with the EU Industrial Emissions Directive, focusing on the implementation of Best Available Techniques (BAT). Cyprus, France, Italy, and Spain have reported energy efficiency upgrades and improved emissions controls in medium and large combustion installations.

Other Stationary Combustion: Countries such as Slovenia, Malta, and Cyprus are addressing emissions from heating through clean biomass programs, boiler replacement schemes, fuel switching (e.g. away from fuel oil) and public awareness campaigns for efficient fuel use.

A subset of Member States provided quantitative estimates of NO_x reductions from their planned or adopted PaMs. The data has been extracted from their NAPCPs and are summarised in Table 6-3 below. The data represents the reduction in annual emissions as a result of all PaMs considered in each Member State for adoption in both 2025 and 2030.

Table 6-3 Projected total NO_x emission reduction from PaMs considered for adoption (kt/year)

Country	2025 (kt/year)	2030 (kt/year)
Croatia	0.97	1.74
Malta	0.4075	0.1107
Slovenia	1.3	3
Spain	64.3	89.2

Spain demonstrates the most significant anticipated NO_x reductions, indicating both the scale of planned measures and scope of reporting. Several Member States have yet to quantify projected impacts, pointing to potential data gaps in implementation tracking and emissions modelling.

Based on this analysis, these measures are expected to yield moderate to high NO_x reduction potential, particularly in the transport and public power sectors.

6.2.2 Non-EU Mediterranean Coastal States

This section is about Non-EU Member States, based primarily on the most recent submissions to the United Nations Framework Convention on Climate Change (UNFCCC), including:

- Biennial Update Reports (BURs) (UNFCCC, 2025)
- Biennial Transparency Reports (BTRs) (UNFCCC, 2025)
- National Determined Contributions (NDCs) (UNFCCC. Secretariat, 2024)
- Other publicly available national climate policy documentation

Where available, these sources were used to identify air pollution-related policies relevant to NO_x reduction in land-based sectors.

Across non-EU Mediterranean coastal States, significant progress is being made in addressing emissions from the same four key sectors:

Road Transport: Countries such as Albania, Egypt, Lebanon, Monaco, Morocco, Syria, Tunisia, and Türkiye are prioritising transport sector transformation through public transport investment, modal shift policies, and electric vehicle incentives. Morocco has introduced the Euro VI emission standards to regulate vehicular emissions.

Public Power: Almost all non-EU States assessed are pursuing renewable energy expansion, including solar, wind, and hydroelectric power to displace fossil fuel reliance in the electricity sector. Israel, for example, plans to fully phase out coal by 2026, replacing capacity with combined-cycle gas plants.

Industry: Efforts across countries such as Bosnia and Herzegovina, Israel, Lebanon, Morocco, Tunisia, and Türkiye focus on promoting energy efficiency, clean technologies, and modernisation of production systems. Montenegro has introduced carbon pricing for industrial installations.

Other Stationary Combustion: Building sector measures include retrofits, insulation standards, and fuel switching. Monaco has banned the use of fuel oil in heating, and Israel has introduced green building regulations to support sustainable construction practices.

Unlike EU Member States, non-EU countries generally do not provide quantified NO_x reduction projections. This limits the ability to directly assess and compare policy impacts across the region. However, this assessment suggests that substantial investments are being made in improving road transport and renewable energy. The scale and pace of implementation varies depending on national capacity, but policies are increasingly improving across the countries.

6.3 Cost assessment of land-based control measures

This section evaluates the available data on the cost of implementing land-based control measures as outlined in Section 6.2. Cost data has been primarily compiled from two sources: NAPCPs and NECPs. These two sources differ in scope, with NAPCPs reporting costs specifically for air pollution measures, while NECPs provide broader estimates covering climate and energy investments across sectors.

Cost data has been compiled from NAPCPs from the EU Member States that border the Mediterranean and they only apply to the PaMs which have been listed within the NAPCP reports. The cost data remains extremely limited as only a handful of countries provided costs, as seen in Table 6-4 below.

Table 6-4 Reported cost of measures from NAPCPs

Country	Total Cost of PaMs (all sectors) (€)	NO_x-Specific Reduction Costs from PaMs (€)
Croatia	1132 million	-
Cyprus	-	8.41 million
Slovenia	312.3 million	-

Croatia and Slovenia provided estimates for the total cost of implementation across all sectors included in their PaMs, however these figures are not disaggregated by pollutant. Cyprus is the only country that reported NO_x specific cost estimates, but this is not sector specific.

Some EU Member States included planned investment costs for 2021 – 2030 in their NECPs. These are broad estimates, and most countries only provided total cost of measures across all sectors (including those outside of the top four highest emitting sectors identified in Section 6.1.2).

Table 6-5 Reported cost of measures from NECPs

	Planned Measures Budget (€)				
	Road Transport	**Public Power**	**Industry**	**Other Stationary Combustion**	**Total cost of all sectors**
Croatia	323.05 million	-	-	3.28 billion	-
Cyprus	1.4 billion	-	400 million	-	-
Greece	-	-	-	-	3.5 billion
Italy	-	-	-	-	70 billion
Malta	-	-	-	-	435 million
Slovenia	0.74 billion	1.1 billion	0.4 billion	0.9 billion	28 billion
Spain	-	-	-	-	86 billion

While these figures help illustrate the scale of planned investment, it should be noted that most NECPs do not separate costs by pollutant, cost estimates often include multiple policy objectives and sectoral reporting is inconsistent across Member States.

6.3.1 Limitations and implications for cost-effectiveness assessment

The limited availability and comparability of cost data creates challenges for determining cost-effectiveness ratios of land-based measures for countries bordering the Mediterranean. While some Member States report substantial investment figures, very few provide cost per tonne of NOx reduced. Therefore, there is a need to review the cost effectiveness of land-based measures from countries that do not border the Mediterranean.

6.3.2 Cost effectives of land-based measures from countries not bordering the Mediterranean

A further review of the NAPCPs from EU countries that do not border the Mediterranean was undertaken. Whilst the findings for this were similar to the EU countries reviewed above, one country, Romania did report the cost abated (costs in EUR per tonne of abated pollutant) of three land-based packages of measures. These are detailed in Table 6-6. Additionally, as part of the literature review undertaken for this Study, the cost effectiveness of land-based measures was taken from previous ECA proposals, including countries outside the EU. These are also included in Table 6-6.

Table 6-6 Cost effectiveness of land-based measures

Country	Source	Land base measure	Cost effectiveness (Euro per tonne of NOx reduced)
Romania	PaMs submitted with NAPCP (Anon., 2023)	Rail transport package	11,090
		Package energy supply	13,186
		Road transport package	10,594
United States	Proposal to Designate an Emission Control Area for the Commonwealth of Puerto Rico and the United States Virgin Islands for Nitrogen Oxides, Sulphur Oxides and Particulate Matter (IMO, 2010)	Non-specific	180 - 11,000
France	Assessment of the environmental impacts and health benefits of a nitrogen emission control area in the North Sea (PBL Netherlands Environmental Assessment Agency, 2012)	Non-specific	900 - 6,500
Canada	Proposal to designate Canadian Arctic waters as an emission control area for nitrogen oxides, sulphur oxides and particulate matter (IMO, 2023c)	Non-specific	180 - 2,700

As detailed above, the cost effectiveness of land measures ranges significantly between and within the countries, with the minimum cost effectiveness equalling 180 EUR per tonne of NO_x reduced compared with the maximum cost effectiveness of 11,000 EUR per tonne of NO_x reduced. Given that France is the only country that borders the Mediterranean included above, its values (900-6,500 EUR per tonne of NO_x) are considered the most suitable proxy for the cost effectiveness of land measures within countries that borders the Mediterranean.

7. COST-EFFECTIVENESS OF NO_X ECA INTRODUCTION

This section presents the cost-effectiveness of introducing a NO_x ECA in the Mediterranean Sea. This analysis compares direct air quality benefits (in terms of mitigated impacts on health, buildings and ecosystems from NO_x emissions) with direct economic impacts (in terms of compliance costs from the use of emission control technologies), presented in detail in Section5. Indirect economic impacts on the maritime sector and wider society are discussed in sections 5.4 and 5.5, but not included in the cost-effectiveness analysis.

The modelling of air quality and economic impacts considers different scenarios for the adoption of the Med NO_x ECA, based on the three different adoption dates (2032, 2035, 2038). These scenarios are compared against a baseline scenario which captures the evolution of the fleet in the absence of a NO_x ECA. Since the use of alternative fuels is assumed to be driven only by decarbonisation measures, fuel and technology mix scenarios are embedded in the baseline scenario. The main method for Tier III compliance explored in this technical and feasibility study is the use of after-gas treatment systems, namely EGR for low-speed, 2-stroke engines typically found on larger freight vessels, and SCR for higher-speed, 4-stroke engines.

Key indicators of the cost-effectiveness analysis include the net present value (NPV), the benefit-cost ratio (BCR), and NO_x abatement cost. These are presented for each NO_x ECA introduction date and compared against previous NO_x ECA proposals and alternative land-based measures for reducing NO_x emissions (see section 5).

Net Present Value

Absolute NPV is the difference between total discounted benefits and costs, with a positive value reflecting net benefit of implementation and negative values reflecting net cost. In this Study, a social discount rate of 3.5%[28] was assumed. The NPV from NO_x ECA implementation at each introduction year and for the GMT and NGMT fuel/technology sensitivities are provided in Table 7-1.

The NPV is positive across all scenarios considered, reflecting that benefits outweigh costs for all introduction years and fuel/technology mix sensitivities. The NPV is highest for earlier introduction of the NO_x ECA, as the benefits from NO_x ECA implementation start earlier and have a higher influence in the near-term. Under the central GMT fuel/technology sensitivity, the NPV ranges from €9,818 to €3,956 for 2032 and 2038 introduction respectively. The NPV for the NGMT sensitivity is higher than GMT across both introduction years, as the lower adoption of alternative fuels under NGMT results in higher fleet-average emissions (see Section 5.1.2) and places greater emphasis on the emission reduction contribution from NO_x abatement technology to meet Tier III limits under the NO_x ECA scenario.

[28] The social discount rate is used to put a present value on costs and benefits, it measures the rate at which a society would be willing to trade present for future consumption. A social discount rate of 3.5% is a standard value recommended in number of cost-benefit analysis guidelines, such as the UK Green Book.

Table 7-1 Net Present Value (NPV) for each introduction year and fuel technology sensitivity under the NO_x ECA scenario, in million Euro. Source: Ricardo analysis for this Study

NO_x ECA introduction date	GMT	NGMT
2032	9,818	12,546
2035	6,596	8,631
2038	3,956	5,308

Benefit-cost ratio (BCR)

The BCR is the ratio of total discounted benefits (emission reduction) over discounted (compliance) costs during the full period 2025-2050. The BCR provides an easily comparable metric for cost-effectiveness which reflects the extent of benefits from implementation as a multiple of the required investment.

For the central GMT fuel/technology sensitivity, the proposed NO_x ECA has an estimated BCR between 9.04 – 9.16 for the three introduction dates. For the NGMT sensitivity, as for NPV, the BCR is slightly higher at between 9.32 – 9.41, reflecting the greater emphasis placed on NO_x abatement technology to directly reduce emissions and lower contribution from lower-emission alternative fuel adoption.

NO_x abatement cost

The NO_x abatement cost refers to the compliance cost per tonne of NO_x reduced and is a key indicator for cost-effectiveness to compare against alternative land-based measures for reducing NO_x emissions described in Section 6.3.

Table 7-2 presents the NO_x abatement cost ranges from this Study for both the GMT and NGMT sensitivities, alongside abatement costs from previous NO_x ECA proposals. The central GMT sensitivity has an abatement cost of around €530 per tonne NO_x reduced, which is slightly higher than the NGMT sensitivity where the use of NO_x abatement technology is more cost-efficient due to lower alternative fuel shares as discussed above.

The Med NO_x ECA abatement cost is at the lower-end of the cost range of previous NO_x ECA feasibility studies summarised in Table 7-2 below, highlighting the high cost-effectiveness of the proposed Med NO_x ECA. The lower abatement costs seen for the Med NO_x ECA may reflect that no additional CAPEX cost contribution is expected for Tier III compliance, due to the continued technical improvement of SCR/EGR hardware and the operational need for Tier III compliance in other NO_x ECAs. Moreover, previous NO_x ECAs have assumed that SCR technology is the primary mechanism for Tier III emission compliance, whilst EGR systems have emerged as a more cost-effective abatement technology for freight vessels in recent years.

Hence, the **proposed designation of the Med NO_x ECA offers strong cost-effectiveness compared to both land-based measures and previously implemented NO_x ECAs**.

Table 7-2 NO_x abatement cost ranges from this Study and previous NO_x ECA proposals, Euro per tonne NO_x reduced in 2025 prices. Note: to compare, currency and price level corrections have been made[29]. Source: Ricardo analysis for this Study, various studies below.

Study	Publication year	Assumptions & sensitivities	Abatement cost (EUR per tonne NOx)
Feasibility Study for Mediterranean NO_x ECA (Ricardo, 2025)	2025	GMT, SCR and EGR	**530**
		NGMT, SCR and EGR	**514**
Technical Support Document for North American ECA (EPA, 2009)	2009	SCR	2,361
Technical Support Document for US Caribbean Sea ECA (EPA, 2010)	2010	SCR	570
Proposal for Baltic Sea ECA (MEPC 70/5/1) (IMO, 2016b)	2016	SCR	1,675 - 2,347
Baltic NO_x ECA - Economic impacts (Centre for Maritime Studies, University of Turku, 2010)	2010	SCR and EGR	1,471 – 1,893
Economic Impact Assessment of a NOX Emission Control Area in the North Sea (Incentive Partners & Litehauz, 2012)	2012	SCR and EGR	2,443
Proposal for Norwegian Sea ECA	2023	SCR	1,480
Proposal for North East Atlantic ECA	2023	SCR	2,566

[29] Where abatement costs are not provided in Euro at 2025 price levels, the non-Euro currency is converted to Euro using the historic currency conversion rate from (ECB, 2024), and then inflated from historic to 2025 price levels using the GDP deflator from (Eurostat, 2025b).

8. RECOMMENDATIONS AND ROADMAP FOR MED NOX ECA DESIGNATION

8.1 Draft recommendations for the decision-making process for the Med NO_x ECA designation

This Study provides evidence needed to address criteria set out in Appendix III of MARPOL Annex VI, relating to the designation of Emission Control Areas (ECAs), and provides a comprehensive assessment of environmental, economic and social impacts from the possible designation of the Med NO_x ECA. This includes an analysis of direct air quality benefits (in terms of mitigated impacts on health, buildings, crops and ecosystems), direct economic impacts (in terms of compliance costs from the use of emission control technologies), and indirect impacts on the maritime sector and wider impacts on economies and citizens.

Building on the assessment of direct benefits and costs, this Study presents an analysis of the cost-effectiveness of the Med NO_x ECA, compared to previous ECA proposals, and abatement measures for land-based sources. This analysis shows that the Med NO_x ECA is expected to deliver net socioeconomic benefits in any of the scenarios considered, as direct benefits largely outweigh additional compliance costs. Net socioeconomic benefits are higher with an earlier introduction of the Med NO_x ECA.

The additional compliance costs associated with the potential Med NO_x ECA are not expected to lead to significant indirect impacts on citizens and wider economies, as modelled impacts on prices, GDP and employment are expected to be marginal, even in countries heavily dependent on maritime imports (e.g. island countries).

The analysis of the short sea shipping case study points to somewhat higher cost impacts on this specific segment compared to the global fleet. However, given lower replacement rates on this segment, cost impacts are expected to be relatively limited on average in the near term with more significant impacts in the long term. These cost impacts could in turn have implications for the supply of these services and connectivity. Although this risk is expected to be quite limited across the Mediterranean in the near term, it may need to be properly addressed with specific mitigation measures where needed.

On the basis of the main findings of this Study, the following draft recommendations were derived:

- **Contracting Parties are encouraged to work together on a joint and coordinated proposal on the designation of the Mediterranean Sea an ECA for NO_x**. This Study presents evidence of net benefits associated with the potential Med NO_x ECA. The recent adoption of the North-East Atlantic ECA, along with other existing and planned ECAs for NO_x, already mandates Tier III compliance for large proportion of new build vessels sailing on the Mediterranean Sea, which minimises additional investment in Tier III-compliant technologies of a possible Med NO_x ECA. In addition, the higher commercial maturity of EGR as a Tier III-compliant technology, with lower operational costs compared to SCR, further reduces additional compliance costs compared to previous NO_x ECA proposals. The Study does not identify any major risks or shortcomings related to possible indirect impacts on wider economies and citizens. In terms of impacts on the maritime sector, only specific cost impacts on short-sea shipping routes may require a detailed risk assessment and potential mitigation measures.

- **Contracting Parties are encouraged to explore bringing forward, to the extent possible, the entry-into-force date of a potential Med NO_x ECA**. The analysis of cost-effectiveness demonstrates higher net benefits with an earlier introduction of the Med NO_x ECA, while no apparent shortcomings were identified as a result of an earlier introduction. At the same time, an earlier introduction of the Med NO_x ECA would also better align with the timeline of the North-East Atlantic ECA, minimising regional imbalances. According to the roadmap on the process for the designation of a Med NO_x ECA presented in Section 8.2, the earliest entry-into-force date considered is 2029.

- **Contracting Parties are encouraged to incorporate any unforeseen shortcomings or lessons learnt identified during the implementation of the SO_x ECA in the Mediterranean Sea into the proposal for a potential Med NO_x ECA.** The Mediterranean SO_x ECA entered into force in May 2025. As such, this can be treated as a pilot for the NO_x ECA, de-risking the implementation of the proposed NO_x ECA. This would require closely monitoring any implementation issues, with a particular focus on enforcement associated with the SO_x ECA in a consistent and structured basis. This process should involve participation of both relevant industry organisations and public authorities in charge of overseeing and enforcing this regulation.

- **Contracting Parties are encouraged to set up a dedicated monitoring and evaluation framework to assess environmental, economic and social impacts following implementation of a potential Med NO_x ECA**. This framework could include defined KPIs, such as improvements in air quality, public health outcomes, shipping compliance rates, and the economic impact on ports and shipping operators.

- **It would be important for all Mediterranean coastal states to ratify and effectively implement MARPOL Annex VI by the date of the submission of the Med NO_x ECA proposal to the International Maritime Organisation (IMO).** The analysis of potential re-routing or port competition does not provide evidence of major risks. However, to ensure a level playing field between Mediterranean ports and ensure effective enforceability of the potential Med NO_x ECA, all Mediterranean coastal states should be in a position to implement and enforce MARPOL Annex VI rules.

- **It would be important that targeted capacity building and awareness-raising activities are further strengthened at the national and regional levels to support the consistent and effective implementation of a potential Med NO_x ECA**. This includes technical training for enforcement and other relevant authorities on the verification of NO_x compliance requirements under MARPOL Annex VI, including Tier III engine certification, onboard verification, and enforcement procedures. In addition, this training could be complemented by the promotion and piloting of advanced monitoring technologies, thereby encouraging Contracting Parties to explore innovative approaches to compliance verification. The experience gained through the implementation of the Med SO_x ECA should also be systematically utilised to identify good practices and capacity gaps. Furthermore, close cooperation between Contracting Parties, relevant industry stakeholders, and public authorities responsible for enforcement is encouraged to promote knowledge sharing and ensure harmonised implementation across the region.

- **REMPEC, in cooperation with the IMO, will continue to provide technical assistance and capacity-building support on MARPOL Annex VI to Contracting Parties, including guidance on its ratification as well as support for the effective implementation and enforcement of its provisions, as well as financial support and resource mobilisation.** This support would include regional workshops, national training sessions, the development of practical guidance documents, and the exchange of lessons learned from both the implementation of the Med SO_x ECA and from experience gained in other established NO_x ECAs. Furthermore, targeted support could be extended to address specific needs of vulnerable segments in the maritime sector through the formulation of targeted mitigation strategies, for instance, for short sea shipping routes.

8.2 Roadmap towards the Med NO_x ECA designation

The roadmap outlines the process leading to a potential proposal to designate the Mediterranean Sea, as defined in Article 1 of the Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean (the "Barcelona Convention"), as a NO_x ECA under Annex VI of MARPOL.

Developed within the framework of the Barcelona Convention, the roadmap includes information on key milestones, timeline, and actions required to support this designation. Key actions are categorised as follows:

- Regional actions (2025-2027): Activities related to REMPEC coordination, consultations and endorsement by Focal Points of REMPEC, and review and approval processes by the MAP Focal Points and Contracting Parties to the Barcelona Convention (COP). These steps focus on regional consensus-building, technical and feasibility studies, and preparation of the joint and coordinated proposal.
- Global actions (beyond 2027): Submission of the formal proposal to the International Maritime Organization (IMO), engagement with IMO's Marine Environment Protection Committee (MEPC), participation in global regulatory review and approval processes, adoption of amendments to MARPOL Annex VI, and eventual entry into force of the Mediterranean NO_x ECA.

According to the roadmap on the process for the designation of a Med NO_x ECA presented in Table 8-1, the earliest entry-into-force date considered is 2029. A second possible entry-into-force date considered in this study is 2032, in case the preparatory process and decision-making at the regional (Barcelona Convention) and global (IMO) levels would require more time.

Table 8-1 Roadmap towards the designation of a Med NO_x ECA

Milestones	Dates	Actions
Regional actions (2025-2027)		
Technical and Feasibility Study	January-December 2025	Completion of a study to address the criteria and procedures for designation of emission control areas laid down in Appendix III to MARPOL Annex VI (this Study) and a draft Roadmap outlining the process leading to a potential proposal to designate the Mediterranean Sea.
Regional Expert Meeting on the possible designation of the Med NO_x ECA pursuant to MARPOL Annex VI	18-19 November 2025 (TBC)	Presentation of the results of the Study and discussion on the submission process for a potential proposal to designate the Med NOx ECA under MARPOL Annex VI.
Submission of draft IMO proposal to **Focal Points of REMPEC**	April 2027 *Q2 2027* (TBC)	Submission of a Note by the Secretariat (REMPEC), including draft IMO submission and the draft Roadmap, to the 17th *(TBC)* Meeting of the Focal Points of REMPEC.
Review and consideration by **Focal Points of REMPEC** *17th (TBC) Meeting of Focal Points of REMPEC*	May 2027 *Q2 2027* (TBC)	Review and consideration of the Note by the Secretariat (REMPEC), including draft IMO submission and the draft Roadmap. Discussion on: • whether or not to submit a proposal to IMO for the designation of the proposed Med NO_x ECA, • the most appropriate timing for such a submission, if any, and • the effective date of entry into force of the proposed Med NO_x ECA, if any.

Milestones	Dates	Actions
Submission of draft IMO proposal to **MAP Focal Points**	July 2027 (TBC) *Q3 2027*	Submission of a draft COP Decision on the joint and coordinated proposal for the designation of the proposed Med NO_x ECA and the Roadmap to the IMO to the Meeting of the MAP Focal Points. *Subject to agreement being reached at the 17th (TBC) Meeting of the Focal Points of REMPEC.*
Endorsement of ECA proposal by **MAP Focal Points** *Meeting of MAP Focal Points*	September 2027 (TBC) *Q3 2027*	Approval of the draft COP Decision on the joint and coordinated proposal for the designation of the proposed Med NO_x ECA and the Roadmap towards its designation to the IMO.
Submission of draft IMO proposal to **Contracting Parties to the Barcelona Convention and its Protocols**	October 2027 (TBC) *Q4 2027*	Submission of draft COP Decision on the joint and coordinated proposal for the designation of the proposed Med NO_x ECA and the Roadmap towards its designation to the IMO to COP 25 (*TBC*). *Subject to agreement being reached at the Meeting of the MAP Focal Points.*
Endorsement of ECA proposal by **Contracting Parties to the Barcelona Convention and its Protocols** *25th (TBC) Meeting of the Contracting Parties (COP 25, TBC)*	December 2027 (TBC) *Q4 2027*	Adoption of COP Decision on the joint and coordinated proposal for the designation of the proposed Med NO_x ECA and the Roadmap towards its designation to the IMO.

Milestones	Dates	Actions
Global actions (beyond 2027)		
Submission of the proposal to the IMO	Winter 2028 *Q1 2028* (TBC)	Submission of the joint and coordinated proposal for the designation of the proposed Med NO_x ECA to the IMO. This will include a proposed amendment to MARPOL Annex VI. *Subject to agreement being reached at COP 25 (TBC).*
Presentation and review of the proposal *87th (TBC) session of the IMO's Marine Environment Protection Committee (MEPC 87)*	Spring 2028 *Q2 2028* (TBC)	• Presentation of the joint and coordinated proposal for the designation of the proposed Med NO_x ECA to the IMO, together with a proposed amendment to MARPOL Annex VI); • Assessment of and, agreement to, the said proposal, if any; and • Consideration and approval of a draft amendment to regulation 13 of MARPOL Annex VI related to the designation of the proposed Med NO_x ECA, if any, and request to the IMO Secretary-General to circulate it in accordance with article 16(2) of MARPOL, with a view to adoption at the next session of the IMO's MEPC, if any.
Circulation of the draft amendment to regulation 13 of MARPOL Annex VI	Spring 2028 *Q2 2028* (TBC)	Circulation of the draft amendment to regulation 13 of MARPOL Annex VI related to the designation of the proposed Med NO_x ECA by the IMO Secretary General to all Members of the Organisation and all Parties, *at least six months prior to its consideration*. *(Provided agreement was reached at MEPC 87 [TBC])*
Adoption of the draft amendment regulation 13 of MARPOL Annex VI *88th (TBC) session of the IMO's Marine Environment*	Autum 2028 *Q4 2028* (TBC)	• Consideration and adoption of the draft amendment to regulation 13 of MARPOL Annex VI related to the designation of the proposed Med NO_x ECA, if any; and • Determination of the date of bringing into force of the amendment to regulation 13 of MARPOL Annex VI related to the designation of the proposed Med NO_x ECA, if any, in accordance with article 16(2)(f)(iii) of MARPOL.

Milestones	Dates	Actions
Protection Committee (MEPC 88)		
Acceptance of the amendment to regulation 13 of MARPOL Annex VI	Summer 2029 *Q2 2029* (TBC)	Deemed acceptance of the amendment to regulation 13 of MARPOL Annex VI related to the designation of the proposed Med NO_x ECA, if any. In accordance with article 16(2)(f)(iii) of MARPOL: *period shall be not less than ten months*.
Entry into force of the amendment to regulation 13 of MARPOL Annex VI	Autum 2029 *Q4 2029* (TBC)	Bringing into force of the amendment to regulation 13 of MARPOL Annex VI related to the designation of the proposed Med NO_x ECA, if any. In accordance with article 16(2)(g)(ii) of MARPOL: *six months after its acceptance*.
Entry into force of the Med NO_x ECA	TBC *(earliest Q4 2029)*	Effective entry into force of the Med NO_x ECA, if any.

Notes: Meetings of Contracting Parties (COPs) to the Barcelona Convention; Meeting of Focal Points for UNEP/MAP (United Nations Environment Programme's Mediterranean Action Plan)

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