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IDENTIFICATION AND PROTECTION OF SPECIAL AREAS, ECAS AND PSSAs

Proposal to designate the Norwegian Sea as an Emission Control Area for Nitrogen Oxide and Sulphur Oxides

Submitted by Norway

SUMMARY

Executive summary:	This document proposes to designate the Norwegian Sea as an Emission Control Area for Nitrogen Oxides and Sulphur Oxides.
Strategic direction, if applicable:	4
Output:	4.1
Action to be taken:	Paragraph 37
Related documents:	None

Introduction

1 With this document, Norway proposes to designate the Norwegian Sea as an emission control area (ECA) for nitrogen oxides ($\mathrm{NO_x}$) and sulphur oxides ($\mathrm{SO_x}$) to prevent, reduce and control emissions of $\mathrm{NO_x}$, $\mathrm{SO_x}$ and particulate matter (PM) from ships, pursuant to regulations 13 and 14 and appendix III to MARPOL Annex VI.

2 The background studies for this proposal were carried out in 2022/2023 and concluded that there were benefits for health and the environment by reducing $\mathrm{NO_x}$ and $\mathrm{SO_x}$ emissions from ships in the Norwegian Sea. Furthermore, it was demonstrated that establishing ECAs would be a cost-efficient way to reduce emissions when compared with land-based measures.

3 The North Sea area south of 62°N is already an ECA for $\mathrm{NO_x}$ and $\mathrm{SO_x}$, and a larger geographic coverage of this ECA would bring greater environmental and health benefits as well as providing a more level playing field for shipping in these areas.

4 Annex 1 to this document provides proposed amendments to MARPOL Annex VI to designate the Norwegian Sea as an emission control area for nitrogen oxides and sulphur oxides. Annex 2 to this document includes a complete analysis of how the proposal satisfies the criteria for designation of ECAs as set out in appendix III of MARPOL Annex VI.

Summary of the proposal

5 The area proposed to be designated as a new ECA is the Norwegian Sea as defined in regulation 13.9.4 of MARPOL Annex II. The geographical delimitation of the proposed ECA area is shown in the figure 1 below.

Figure 1: Area proposed for ECA designation, the Norwegian Sea.

Populations and areas at risk

6 The population of Norway in 2022 was about 5.4 million persons, and there is an expected growth of 12-13% in population throughout this century. Today, about 1.4 million of the inhabitants live in communities in the vicinity of the proposed ECA area. With a population of close to 200,000 inhabitants, Trondheim is the biggest city in the area followed by Ålesund with 55,000, Bodø with 43,000 and Tromsø with 42,000 inhabitants. The cities are all major national and international shipping ports.

7 The proposed ECA includes both areas in the mid-latitudes as well as within the polar regions. The general atmospheric circulation in the area is characterized by low pressure weather systems (cyclones) migrating from west and towards east. The average wind speed is generally high. The northern part of the ECA is within the atmospheric Polar Dome. The climate effect of PM emitted within the polar region is larger than the effect of particles emitted further south.

8 The proposed ECA area constitutes widely different environments, from the deep seas to the continental slope and shelf, to the coastal zone with several small islands and fjords. The Vega Archipelago as well as the Geirangerfjord area lie in the proposed ECA area and both are on the World Heritage List. The diversity of the proposed ECA area is unique for Europe. The Norwegian Sea constitutes of particularly valuable and vulnerable areas (SVOs) that are extremely important for biodiversity and biological production. The status as an SVO signals the importance of showing particular care in these areas even though it places no restrictions on commercial activity.

9 The Norwegian Sea has a high biological production and houses a very large biomass of organisms. This large biomass contains key species that serve as food for the fish stocks important for fisheries. Lofoten, Vesterålen, and Senja are the spawning grounds of the world's largest stock of cod, which is crucial for both the ecosystems in the sea and us humans. It is also home to the world's largest cold-water coral reef and mainland Europe's largest seabird colony.

Ship traffic and emissions in the Norwegian Sea

10 During 2019, a total number of 3,450 unique ships registered with an IMO number were identified as having operated in the Norwegian Sea. The general cargo ships, passenger ships and fishing vessels accounts for more than 60% of the sailed distance in the area, and they mostly consist of relatively small ships of less than 5,000 gross tonnes.

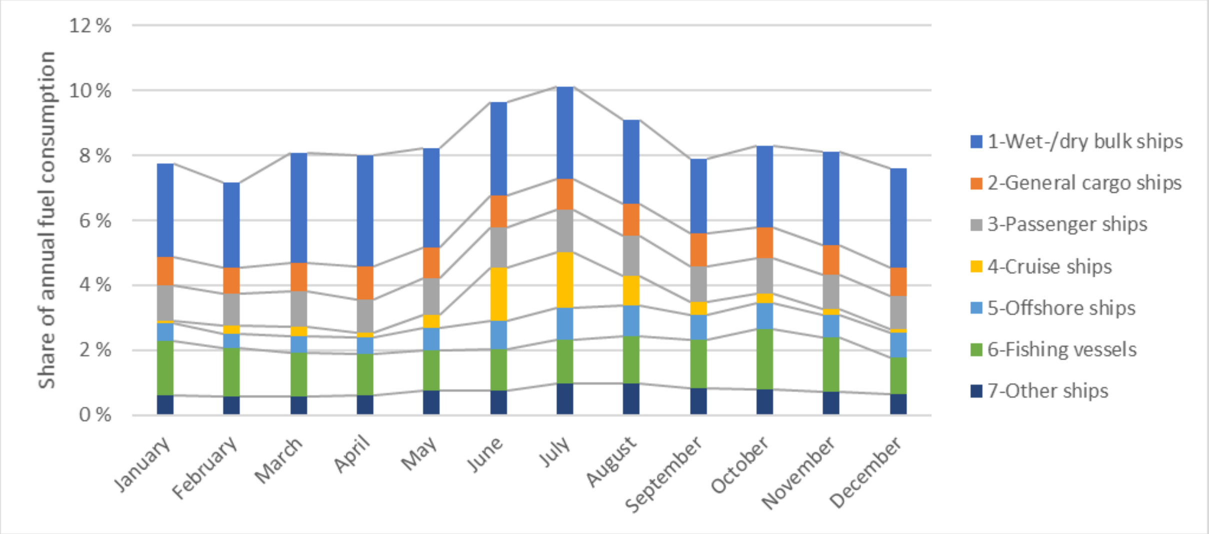

Figure 2. Monthly distribution of ship fuel consumption.

11 Figure 2 shows the aggregated fuel consumption throughout the sample year of 2020. Most ship types are found to have a relatively uniform consumption level throughout the year, except for cruise and fishing vessels which have a more seasonal profile.

12 Through IMO, Norway has established ship routeing measures off the coast of northern Norway on the Vardø–Træna section from 1 July 2007. These consist of a series of traffic separation systems (TSS) connected to recommended routes. The map below shows that the ship traffic is mainly concentrated in two flows along the Norwegian coast one, with mainly smaller ships, as coastal ship traffic well within 12 nautical miles from shore, and the other with the larger vessels in the TSS and associated sailing routes further offshore. The coastal and inshore ship traffic is close to populated areas, vulnerable nature and landscape areas.

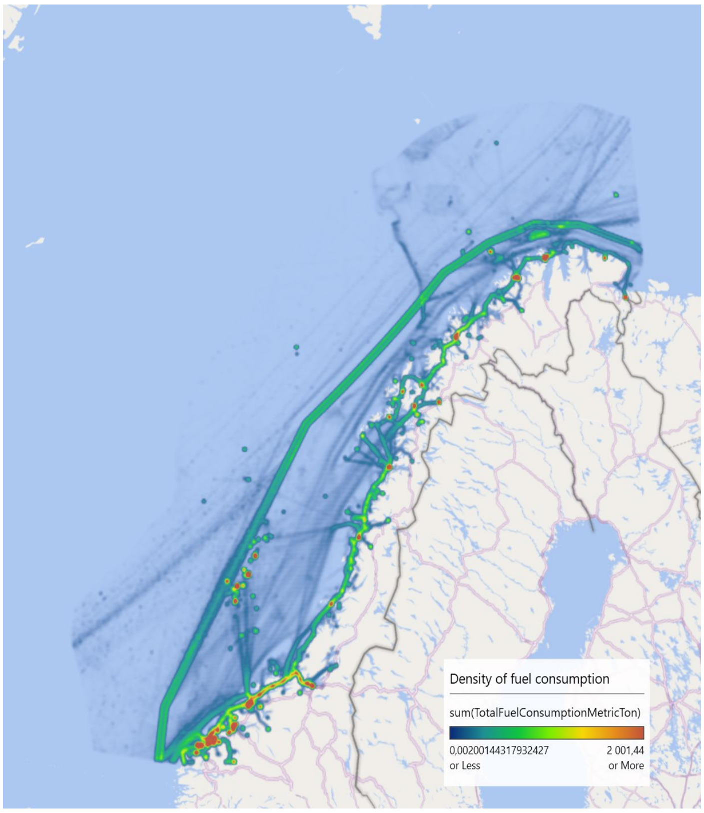

Figure 3. Density of fuel consumption by ships in the Norwegian Sea, 2020

13 While the aggregated fuel consumption is evenly distributed between the two main traffic flows, the different emission components are unevenly distributed. This is characterized by the fact that the larger ships, dominating the traffic separation systems, emit a somewhat higher proportion of NO_x, since a larger proportion of these ships have large two-stroke engines. This is even more prominent with SO_x emissions, where a larger proportion of the ships in the TSS use residual fuels with a sulphur content of up to 0.5%. However, this picture is offset by the fact that a substantial proportion of emissions from large ships originate from LNG tankers that use boil-off gas from the cargo, and thus have very low NO_x and PM emissions and no SO_x emissions. In total, roughly 50% of the emissions components are distributed within and outside the 12 nm limit. Furthermore, outside the two main shipping lanes, there is considerable activity from supply and service vessels in connection with petroleum activity, as well as fishing vessels.

14 The emission reduction potentials from introducing an NO_x, SO_x and PM emission control area in the Norwegian Sea are found based on ship activity and emission modelling, and then adjusted in three steps:

- The 2020 baseline emission inventory applies AIS ship activity data for 2019 as it is more representative than the following Covid years. The 2019 emission inventory is then adjusted for the 2020 sulphur cap as specified under MARPOL Annex VI.

- The 2030 reference scenario is built on adjusting the uptake of fuels, technologies and operational changes assumed to be present in 2030.

- The 2030 ECA scenario is built on adjusting the uptake of fuels, technologies and operational changes assumed in the 2030 reference scenario, to account for the expected impacts of new ECA regulations.

15 The final difference between the 2030 reference scenario and the 2030 ECA scenario is then used as a basis for the final impact assessment of introducing an ECA in the Norwegian Sea. The framework for ship traffic analysis and modelling of ship emissions and reduction potentials is centred around the DNV's *MASTER* model. The results for the three scenarios are presented in table 1 below.

Table 1. The emission reduction potentials from introducing a NO_x, SO_x and PM emission control area in the Norwegian Sea.

Emission component	2020 baseline (tonnes/year)	2030 reference scenario (tonnes/year)	2030 ECA scenario (tonnes/year)	Maximum Feasible NO_x Reduction scenario (tonnes/year)
NO_x emissions (tonnes)	57,850	46,180	46,180	16,500
SO_x emission (tonnes)	5,230	4,600	1,690	-
PM_{10} emissions (tonnes)	3,570	3,100	1,800	-
$PM_{2.5}$ emissions (tonnes)	3,270	2,840	1,650	-

16 The designation of an ECA to reduce and control emissions of NO_x, SO_x and PM from ships in the Norwegian Sea will have different timelines of effectiveness depending on the emission components. The SO_x emission is directly linked to the sulphur content in the fuels and will be reduced either by switching to compliant fuels or by using exhaust gas cleaning systems. Consequently, the SO_x emission in the 2030 ECA scenario will be reduced by 2,910 tonnes/year, which is a reduction of 37% following the implementation of the new requirements.

17 As the PM emissions are closely linked to sulphur content and fuel oil quality, the PM emissions are assumed to be reduced accordingly. As a result, the PM_{10} and $PM_{2.5}$ emissions are estimated to be reduced in the 2030 ECA scenario by 1,300 tonnes/year and 1,190 tonnes/year respectively, which for both is a 58% reduction following the implementation of the new requirements.

18 The introduction of a NO_x ECA will mean gradual phasing-in of ships that meet NO_x Tier III requirements, as only new ships or new engine installations/major engine conversions will be subject to the regulations. The NO_x emission reductions depend solely on the rate at which newbuilds or ships with modified engines operates in the area. The NO_x reduction will therefore come gradually over the following years after the introduction of the NO_x ECA. Fleet renewal and engine modifications are anticipated to take place over a 20-year period, influencing the NO_x emissions. As a result, the proposed ECA designation could reduce the NO_x emissions by an average of 1,500 tonnes/year from 2030 and onwards to 2050. The maximum feasible NO_x reduction scenario (from 2050) estimates that it can be reduced to an annual NO_x emission of 16,500 tonnes, which is a reduction of 65% from the 2030 reference scenario.

19 The introduction of an ECA in the Norwegian Sea will therefore contribute to a significant reduction of ship emissions. Although more than 50% of the ship emissions take place far out to sea, there is still a major proportion that impacts human health and contributes to increased deposition of nitrogen and sulphur along the coast.

Harmful effects of NO_x, SO_x and PM emissions from shipping

20 Several Norwegian cities and urban areas in the proposed ECA area have challenges with air quality exceeding the Norwegian air quality criteria for PM_{10} and NO_x. Even though the contribution from ships is considered to be moderate, any reduction in emissions from ships will improve the ambient air quality and contribute towards compliance with local air quality criterion.

21 NO_x emissions from ships have an impact on human health and any additional NO_xemitted from ships will contribute to extra ozone formation and an increased negative impact on human health and the terrestrial environment.

22 The overall findings concerning health impact of SO_x emissions from ships is that emission reduction will have a positive effect on health and the local environment, especially where the ship emissions are close to densely populated areas, such as in ports and close to city centres.

23 Emissions of NO_x and SO_x from ships contribute up to 20-25 % of total deposition in specific areas. Excess nitrogen and sulphur contribute to both eutrophication (by NO_x) and acidification (by NO_x and SO_x). Northern Norway is an area with generally low deposition of sulphur and nitrogen and an additional supply of nitrogen and sulphur from ships has a negative impact on vegetation and vulnerable ecosystems.

Control of land-based sources

24 The emissions of pollutants from land-based sources have been reduced substantially during the past decades. The reductions are due to measures like regulations, the use of new technology, economic factors, changes in behaviour and others. The cost for the different measures is covered by several parties, ranging from the consumers/inhabitants, business enterprises and factories, municipalities, and the state government (budget).

25 Switching from a fuel oil with a sulphur content of 0.50% to 0.10% or using exhaust gas cleaning systems would increase total fleetwide OPEX costs in the proposed ECA area to about $30 million per year. The consequent reduction in SO_x emissions will be close to 3,000 tonnes per year and the unit costs for the fuel shift will then be about $10,300 per tonne SO_x.

26 The abatement cost of ECA designation of $10,300 per tonne SO_x are only marginally higher compared to the listed land-based controls in the North American ECA application. An estimated PM abatement cost of $23,100 per tonne with ECA designation is within the lower part of the interval for different land-based control measures.

27 The unit cost for the NO_x emission reduction is estimated to be about $1,670 per tonnes NO_x with a yearly cost of $2.5 million and is assumed to be comparable for both maritime and land-based industry. There are several factors varying both over time and with geography that make it difficult to directly compare the abatement costs from this ECA designation with land-based control measures. Still, the figures indicate that the abatement cost of an ECA designation is comparable to other land-based control measures.

28 The benefit of introducing ECAs has been estimated using two different approaches. The total health impact of the reduced exposure to emissions is a reduction in mortality of almost two deaths in 2030. Using the Norwegian "Value of a statistical life" the economic benefit adds up to $8.5 million.

Validation of the emission reduction potentials by introducing an ECA area in the Norwegian Sea in 2030 using updated 2022 ship activity data and projections for NO_x, SO_x and PM emissions

29 In early 2023, when a full 2022 data set was available, it was decided to re-evaluate the estimated emission reduction potentials by introducing an ECA in the Norwegian Sea in 2030 to validate the conclusions in this study. The emission data assessment updated from the 2020 baseline to the 2022 inventory shows that the conclusions made are still valid and will remain unchanged.

Conclusions

30 Ship emissions contribute to air pollution and have negative effects on human health and the ecosystem in and around the Norwegian Sea. The designation of the proposed ECA will reduce these negative effects and the cost of reducing these ship emissions is comparable to the costs for land-based controls.

Proposed amendments to MARPOL

31 The NO_x Tier III requirements apply to ships constructed on or after a certain date while operating in an ECA. The definition of "ship constructed" is given in regulation 2.1.28 of MARPOL Annex VI: *"Ships constructed means ships the keels of which are laid or that are at a similar stage of construction."*

32 A study by Ward Van Roy et al[*] highlighted that many keels are being laid prior to the entry-into-force date of a NO_x ECA and sold at a later stage. When the keel is laid, the ship can be built, delivered and put into operation several years later. This practice delays the positive health and environmental effects represented by new NO_x ECAs and hampers a level playing field among the "new ships" operating in the area.

33 MSC.1/Circ.1500/Rev.2 provides guidance on drafting of amendments to the SOLAS Convention and related mandatory instruments and chapter 4.2.1 gives guidance on the format of application dates including the "three dates criteria" (building contract, keel laid and delivery date).

34 The three dates criteria are also used in MARPOL Annex VI, for example, in regulation 2.2.1 where "A ship delivered on or after 1 September 2019" is defined using the "three dates criteria".

35 Norway is of the view that using the keel laying date and the current definition of ship constructed delays the desired effect of new regulations and propose to use the "three dates criteria" for the designation of the new NO_x ECA in the Norwegian Sea.

36 Annex 1 to this document contains proposed amendments to MARPOL Annex VI in order to designate the Norwegian Sea as an emission control area for nitrogen oxides and sulphur oxides.

Action requested of the Committee

37 The Committee is invited to consider the proposals and information contained in this document and to take action as appropriate.

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[*] Ward Van Roy, Kobe Scheldeman, Benjamin Van Roozendael, Annelore Van Nieuwenhove, Ronny Schallier, Laurence Vigin, Frank Maes.2022. Airborne monitoring of compliance to NO_x emission regulations from ocean-going vessels in the Belgian North Sea.

ANNEX 1

PROPOSED AMENDMENTS TO MARPOL ANNEX VI

(Designation of the Norwegian Sea as an emission control area for nitrogen oxide and sulphur oxides)

(new text is shown as underlined and text to be deleted as ~~strikethrough~~):

Regulation 2

A new paragraph 1.34 is added after paragraph 1.33, as follows:

"1.34 Ship constructed on or after [1 April 2026] means:

.1 for which the building contract is placed on or after [1 April 2026]; or

.2 in the absence of a building contract, the keels of which are laid or which are at a similar stage of construction on or after [1 October 2026]; or

.3 the delivery of which is on or after [1 April 2030]."

Regulation 13

The existing text of paragraph 5.1.2 is replaced by the following:

".2.1 that ship is constructed on or after 1 January 2016 and is operating in the North American Emission Control Area or the United States Caribbean Sea Emission Control Area;

.2.2 that ship is constructed on or after 1 January 2021 and is operating in the Baltic Sea Emission Control Area or the North Sea Emission Control Area;

.2.3 that ship is constructed on or after [1 April 2026] as defined in regulation 2.1.34 and operates in the Norwegian Sea Emission Control Area."

Paragraphs 6.3 and 6.4 are amended, and a new paragraph 6.5 is added after paragraph 6.4, as follows:

"6.3 the Baltic Sea Emission Control Area as defined in regulation 1.11.2 of Annex I to the present Convention; ~~and~~

6.4 the North Sea Emission Control Area as defined in regulation 1.14.6 of Annex V to the present Convention.; and

6.5 the Norwegian Sea as defined in regulation 13.9.4 of Annex II of the present Convention."

Regulation 14

Paragraphs 3.4 and 3.5 are amended, and a new paragraph 3.6 is added after paragraph 3.5, as follows:

> "3.4 the United States Caribbean Sea Emission Control Area, which means the area described by the coordinates provided in appendix VII to this Annex; ~~and~~
>
> 3.5 the Mediterranean Sea Emission Control Area, which means the area described by the coordinates provided in appendix VII to this Annex.; and
>
> 3.6 the Norwegian Sea as defined in regulation 13.9.4 of Annex II to the present Convention."

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ANNEX 2

REPORT

Information and evidence in support of Norway's application for an Emission Control Area in Norwegian waters north of 62° N

Norwegian Maritime Authority

Report No.: 2022-0233, Rev. 1
Document No.:
Date: 2023-11-30

Project name: Report
Report title: Information and evidence in support of Norway's application for an Emission Control Area in Norwegian waters north of 62° N
Customer: Norwegian Maritime Authority
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Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
0	2023-03-30	First issue	AMJ	MASTE	TSV

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1 SUMMARY

The information in this report provides the basis for the Norwegian proposal for the designation of an ECA area in the Norwegian Economic Zone north of 62 degrees latitude to prevent, reduce and control emissions of nitrogen oxides (NOx), sulphur oxides (SOx) and particulate matters (PM) from ships. The proposed ECA area, referred to as the Norwegian Sea, is enclosed by geodesic lines connecting the coordinates, as shown in chapter 3 of this report. The area definition is in line with the Norwegian Sea area as specified in MARPOL Annex II Reg. 13.9.4 “Control of discharges of residues of Noxious Liquid Substances”.

Our approach

Figure 1-1 shows the overall approach and steps used in the assessment, which respond to the criteria for designation of an ECA as set out in Appendix III to MARPOL Annex VI.

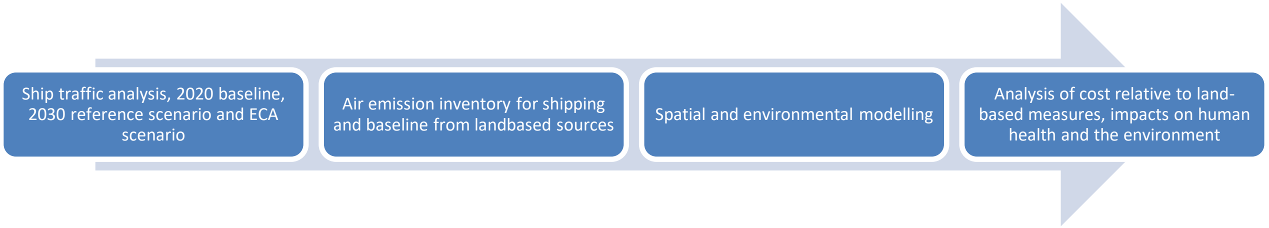

Figure 1-1 Illustration of the analysis approach

The framework for ship traffic analysis and modelling of ship emissions and reduction potentials is centered around the DNV’s *MASTER* model (Mapping of Ship Tracks, Emissions and Reduction potentials), which uses ship movement data from the Automatic Identification System (AIS), detailed ship specific information from IHS Fairplay and supporting data tables to estimate the energy demand, fuel consumption and emissions of the individual ship while sailing and when in port. Through the AIS ship activity-based modelling, the current 2020 baseline emission inventory for the proposed ECA area is estimated, as well as the likely future 2030 reference scenarios both with and without an ECA designation.

The AIS based modelling includes calculated total amount of NOx, SOx and PM emissions from shipping in the proposed ECA area, covering all types and size categories of ships identified by the AIS system. The quantification of ship emissions and reduction potentials are firstly done on a tabular level, organised by ship types and size categories, and by fuel types. Secondly, the estimated ship emissions and reduction potentials are gridded on a 0.1°×0.1° resolution for further analysis of impacts.

Dispersion and deposition of various atmospheric components have been calculated with the EMEP model, for the proposed ECA area. The EMEP model is a Eulerian model in which the atmosphere is divided into grid boxes. The EMEP atmospheric chemistry and dispersion model has been applied on a 0.1°×0.1° horizontal grid resolution to calculate the dispersion, chemistry and deposition of nitrogen, sulphur, and PM and hence to quantify the impact of ships and the future effect of an ECA regulation. Although the study area is limited to the Norwegian Sea, the total model domain covered most of Europe and the Arctic in order to properly account for the effects of any neighboring areas. 2019 meteorological data was generated by the Integrated Forecast System (IFS) model of the European Centre for Medium-Range Weather Forecasts (ECMWF), provided by the Norwegian Meteorological Institute. Gridded ship emissions for the Norwegian Sea were based on the ship emission inventories developed using the MASTER model, described above. For all other emission categories, the model used EMEP 2019 emission inventories from the 13-sector GNFR system (EMEP, 2021). The EMEP model was used to calculate concentrations and depositions of numerous atmospheric species, including trace gases in the NOx-VOC-O_3 tropospheric chemistry cycle, SOx and PM.

The estimated economic costs of introducing an ECA include operational and installation costs necessary for the ships to operate in compliance with the ECA requirements. The economic benefits associated with the effects of reduced pollution due to the ECA designation are estimated using two different approaches.

In the first approach, we estimate the benefits from reduced emission due to an ECA designation using costs per tonne NOx, SOx an PM emission set out by the Norwegian Coastal Administration for economic analyses of policies and projects. The input in this analysis is emission reductions due to the ECA designation from the ship traffic analysis. This approach uses average emission costs given the population in the affected area. The emission costs reflect human health impacts and environmental damage on nature and/or animal life. However, this approach does not consider how emissions can be spread through atmospheric circulation and how the health effects can vary with demographics.

The second approach focuses solely on the health effects of an ECA designation, and not on the environmental impact. Health impacts accounts for the majority of benefits related to regulations of the air pollutants subject to ECA designation, (Roy & Braaten, 2017). This is a more detailed approach, which uses annual average concentrations of NOx, SOx and PM from the EMEP model, in combination with concentration-response functions to estimate health impacts from ECA designation. We combine these data with granular population data sorted by municipality to estimate effects from prevented lung cancer and cardiovascular diseases.

Main findings

The Norwegian Sea has a long coastline with deep fjords, several major ports, and a vast number of small port locations. The larger ports act as central shipping hubs for the transport of goods, the shipping of minerals, fishing, aquaculture, military services and oil and gas transport. In 2020, a total of 3,450 unique ships registered with an IMO number were identified operating in the Norwegian Sea. These ships travelled a total distance of 23 million nautical miles (43 million kilometres). The general cargo ships, passenger ships and fishing vessels accounts for more than 60 % of the sailed distance in the proposed ECA area, and they mostly consist of relatively small ships less than 5,000 gross tonnes.

About 1.4 million of the inhabitants in Norway lives in communities in the vicinity of the proposed ECA area. With a population of close to 200,000 inhabitants, Trondheim is the biggest city in the area followed by Ålesund with 55,000, Bodø 43,000 and Tromsø with 42,000 inhabitants. The cities are all major national and international shipping ports.

The proposed ECA includes both areas in the mid-latitudes and as well as within the polar regions. The general atmospheric circulation in the area is characterized by low pressure weather systems (cyclones) migrating from west and towards east. The average wind speed is generally high. This means that dispersion of pollutants is effective, although topography may modify the wind pattern. The northern part of the ECA is within the atmospheric Polar Dome. The climate effect of PM emitted within the polar region is larger than the effect of particles emitted further south. The proposed ECA area constitutes widely different environments, from the deep seas to the continental slope and shelf, to the coastal zone with several small islands and fjords. The Vega Archipelago as well as the Geirangerfjord area lie in the proposed ECA area and both are on the World Heritage List. The diversity of the proposed ECA area is unique for Europe. The Norwegian Sea constitutes of particularly valuable and vulnerable areas (SVO) that are extra important for biodiversity and biological production. This is an area that contains one or more particularly significant occurrences of environmental values, valued according to the proportion of regional, national, and international stock, as well as stock status, restitution capacity, and red list status. The status as an SVO signals the importance of showing particular care in these areas even though it places no restrictions on commercial activity.

The Norwegian Sea has a high biological production and houses a very large biomass of organisms. This large biomass contains key species that serve as food for the fish stocks important for our fisheries. Lofoten, Vesterålen, and Senja are the spawning grounds of the world's largest stock of cod, which is crucial for both the ecosystems in the sea and us humans. It is also home to the world's largest cold-water coral reef and mainland Europe's largest seabird colony. 70 % of all fish caught in the Norwegian Sea and the Barents Sea visit these areas at least once in their lifetime.

The designation of an ECA in order to prevent, reduce and control emissions of NOx, SOx and PM from ships in the Norwegian Sea will have different timelines of effectiveness depending on the emission components. In this study, the designation of the ECA is anticipated to take effect in 2030.The SOx emissions are directly linked to the sulphur content in the fuels, and the SOx emissions will be reduced either by switching to sulphur-compliant fuels or by using exhaust gas cleaning systems. Consequently, the SOx emissions in the 2030 ECA scenario will be reduced by **2,910 tonnes/year,** which is a reduction of 37% following an ECA implementation.

As the PM emissions are closely linked to the fuel quality and sulphur content, the PM emissions are assumed to be reduced with the reduced sulphur content in the fuel (IMO, 2020). Similarly, the use of exhaust gas cleaning systems to reduce SOx emissions will also reduce the PM emissions when in operation. As a result, the PM_{10} and $PM_{2.5}$ emissions are estimated to be reduced in the 2030 ECA scenario by **1,300 tonnes/year** and **1,190 tonnes/year** respectively, which for both is 58% reduction following an ECA implementation.

The introduction of a NOx emission control area will result in a more gradual phasing-in of ships that meet NOx ECA requirements, as only new ships or new engine installations/major engine conversions will be subjected to the ECA regulation. The NOx emission reductions depend solely on the rate at which newbuilds or ships with modified engines operate in the area. To estimate the future effects of introducing the ECA requirements, the estimated NOx emissions follow a hypothetical full implementation called the Maximum Feasible NOx Reduction Scenario (MFNR). The basis for the MFNR scenario is that the fleet would be renewed over a 20-year period and that all ships are NOx Tier III compliant. As a result, using a linear projection, the fleet exchange could result in a gradual reduction of the NOx emissions by **1,500 tonnes/year** from 2030 and onwards. This will reduce the total NOx emissions in the Norwegian Sea from 46,180 tonnes/year in 2030 to 16,500 tonnes/year in 2050, which is a 65% reduction from the 2030 Reference scenario.

As far as air quality is concerned, the contribution from ships is found to be relatively small. High concentrations of NO_2 and PM in urban areas within the proposed ECA area are mainly linked to local sources such as wood burning and road traffic. The general SO_2 concentrations in Norwegian cities are low, except for in the vicinity of specific industrial facilities. The total contribution from ship emissions to ground level concentrations of NOx is less than 0.5 µg/m3 for NO and less than 4 µg/m3 for NO_2. The calculated maximum reduction in ground level SO_2 due to ECA regulations is 0.6 $\mu g/m^3$. For PM, the emissions from ships are mainly in the $PM_{2.5}$ fraction given that the particles mostly originate from engines. In general, the reduction in the ground level concentrations due to an ECA regulation is small, i.e. less than 0.5 µg/m3. The most important reduction is seen in specific areas like the Geiranger fjord and for the shipping lanes to and from Narvik, Trondheim and Tromsø. However, the effects of elevated emissions in ports will be poorly resolved in the dispersion calculations, and the effects there are likely to be higher than the average values shown in this study.

The annual mean concentrations of $PM_{2.5}$ in cities along the coast (Ålesund, Trondheim, Mo i Rana, Narvik, Harstad, Tromsø and Hammerfest[1]) are typically 4-6 $\mu g/m^3$, which are below the existing Norwegian air quality threshold value and criteria. However, the WHO recommended value is 5 $\mu g/m^3$ for annual mean $PM_{2.5}$ concentration. The Norwegian authorities are preparing a proposal for new threshold values and air quality criteria for a range of pollutants, including PM_{10} and $PM_{2.5}$. These new threshold values will be introduced in 2030. A number of cities and urban areas in Norway show concentrations of PM_{10} and $PM_{2.5}$ above these future threshold values.

As far as the impact of ship emissions on ecosystems is concerned, deposition of sulphur (S) and deposition of nitrogen (N) are the main pathways. Excess sulphur and nitrogen contribute to both acidification and eutrophication. Emissions from ships contribute up to 20-25 % of the total deposition of sulphur and nitrogen in a few relevant areas (like the Helgeland area). Northern Norway is an area with a generally low depositions of sulphur and nitrogen. In that respect the ECA regulation will reduce the environmental load.

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[1] https://luftkvalitet.nilu.no/overskridelse https://luftkvalitet.nilu.no/overskridelse

This study projects that, as a result of the ECA implementation, switching from VLSFO with a sulphur content of 0.5% to 0.1% or using scrubber technology, would increase fleetwide yearly operational costs (OPEX) with about USD 30 million. Assuming a gradual implementation of NOx ECA compliant technologies in the fleet from 2030 and onwards and full implementation within 20 years (MFNR scenario), an annual average NOx reduction of 1,500 tonnes is estimated to take place. The subsequent annual cost of the NOx reductions amounts to about USD 2.5 mill per year as a result of the ECA implementation. No additional costs are assumed for the PM reductions as it is directly related to the reduction of SOx emissions. The total annual cost of the ECA implementation is therefore around USD 33 mill per year. The consequent reduction in SOx and PM emissions will be 2,910 tonnes per year and 1,190 tonnes per year respectively, leading to a unit cost of about USD 10,300 per tonne SOx or USD 23,100 per tonne PM. The unit cost for the NOx emission reduction is estimated to be about USD 1,670 per tonne NOx. There are several factors varying both over time and with geography that make it difficult to directly compare the abatement costs from this ECA designation with land-based control measures. Still, the figures indicate that the abatement cost of an ECA implementation is comparable to other land-based control measures.

The authors of this study have not managed to identify any Norwegian studies that map out abatement costs related to land-based air pollution control measures. However, the North American ECA application provides a range of costs for various land-based controls, with PM10 abatement costs ranging from USD 16,000 to USD 23,200 per tonne for engine applications and USD 5,800 to USD 66,700 per tonne for stationary diesel engines. Costs for locomotives and harbour crafts vary widely, and SOx abatement costs for stationary sources range from USD 400 to USD 8,700 per tonne, with on-road costs estimated at USD 9,300 per tonne for heavy-duty diesel engines and USD 9,600 per tonne for light-duty engines.

The abatement cost of ECA designation at USD 10,300 per tonne for SOx is only marginally higher than the costs for land-based controls listed in the North American ECA application. The PM abatement cost with ECA designation is within the lower part of the interval for land-based controls, and the unit cost for NOx emission reduction is estimated at USD 1,670 per tonne. While it is challenging to directly compare abatement costs due to variations over time and geography, the figures suggest that the costs of ECA designation are comparable to those of other land-based control measures.

The benefit is the difference in economic cost of emissions in the 2030 ECA scenario compared to the 2030 Reference scenario. Using Approach 1 we estimate the yearly benefits of total reduced emissions to USD 6.9 million from 2030 and onwards. The reduction in PM_{10} amounts to about one third of the benefits. The estimated annual NOx reductions represent slightly less than two thirds, while SOx emission is only a small share of the total, about 2%. Focusing solely on the health impacts from an ECA designation in the second approach, the total annual health impact of the reduced exposure to emissions is a reduction in mortality of almost 2 lives. The confidence intervals are relatively large, with a 95% confidence interval of about 1 and 3 lives. The total change in mortality adds up to USD 8.5 million. The uncertainty in the mortality estimates translates into a 95% confidence interval of USD 4.2 million and USD 13 million. However, the cost of air pollutants subject to ECA designation is not only related to health effects alone. NO_x and SO_x can impact both the built environment, animal and plant health and ecological systems.

Conclusions

The designation of the Norwegian Sea as an ECA will reduce the SOx and PM emissions at the date when the requirements take effect, while the reduction of NOx will come more gradually. By introducing an ECA for the Norwegian Sea, the estimated SOx, PM_{10} and $PM_{2.5}$ emissions from ships will be reduced by 37%, 58% and 58% respectively from 2030 and onwards. Assuming a gradual implementation of NOx ECA compliant technologies in the fleet and full implementation within 20 years, an annual average NOx reduction of 1,500 tonnes is estimated. The future (2050) NOx emission for the proposed ECA area can be reduced to 16,500 tonnes per year, which in 2050 is a reduction of 65% from the 2030 reference scenario. The introduction of an ECA in the Norwegian Sea will therefore contribute to a significant reductions of ship emissions. Although more than 50% of the ship NOx emissions take place far out to sea, there is still a proportion that impacts human health and contributes to increased deposition of nitrogen and sulphur along the coast.

Several Norwegian cities and urban areas in the proposed ECA area have challenges with air quality, and the concentrations in several city centres exceed the Norwegian air quality criteria for PM_{10} in particular, but also NO_2. Further, the Norwegian authorities are in a process of proposing new threshold values for NO_2, PM_{10} and $PM_{2.5}$ from 2030 and onwards. Several cities and urban areas in Norway show concentrations of $PM_{2.5}$ above these future threshold values. The concentrations of pollutants in many coastal cities must be reduced to comply with the new air quality criteria, and in that respect reduced emissions from ships will have a positive impact.

Ship emissions of NOx impact human health in some areas also in the northern Norway, but the levels are generally low. The overall findings concerning health impact of SO_2 emissions from ships is that the contribution is generally small. Concerning health impacts of particulate matter, smaller particles (PM_1 and $PM_{2.5}$) have a relatively more significant effect than the larger particles (PM_{10}). However, the maximum $PM_{2.5}$ contribution from shipping of 0.2 $\mu g/m^3$ to the existing levels is considered small. It should be noted that the effects of elevated emissions in ports and city centres will be poorly resolved in the conducted dispersion calculations, and local effects are likely to be higher than shown in this study. Ozone production in remote areas is typically limited by available NOx. Any additional nitrogen, like NOx emitted from ships, will therefore contribute to extra ozone formation. Emission reductions due to implementation of ECA regulations will therefore have an impact on human health and the environment and give reduced ozone production in northern areas.

The proposed ECA area constitutes widely different environments and constitutes particularly valuable and vulnerable areas that are important for biodiversity and biological production. The area has high biological production and houses a large biomass of organisms that serve as food for the fish stocks instrumental for the fisheries. It is also spawning grounds of the world's largest stock of cod, which is crucial for both the ecosystems in the sea and us humans. Eutrophication constitutes a major threat to biodiversity, and any extra nitrogen, like nitrogen emitted to air from ships, will add extra nitrogen to the aquatic and terrestrial systems and consequently contribute to increased nitrogen levels and possible eutrophication. The ECA implementation for the Norwegian Sea will therefore significantly contribute to securing future low levels of eutrophication in the region.

The modelled annual concentrations of pollutants are distributed within a relative coarse grid of 0.1°x0.1° while there in practice will be local variation within each grid cell. This represents an uncertainty for the benefit analysis, especially in areas of denser human populations, local ship emission coincides with other land-based sources and stationary weather systems. This indicates that the estimated benefits to human health and the environment is likely to be locally underestimated. Nevertheless, based on the estimations made, the annual costs of an ECA designation of USD 33 million per year are estimated to be comparable to the cost of equivalent emission reduction measures carried out by land-based control measures.

An adoption of the proposed emission control area will result in significant ship emission reductions and improved ambient levels of air pollution in the Norwegian Sea and in the Kingdom of Norway which will lead to benefits to human health and the environment.

2 INTRODUCTION

The information in this report provides the basis for the Norwegian proposal for the designation of an ECA area in the Norwegian Economic Zone north of 62 degrees latitude to prevent, reduce and control emissions of nitrogen oxides (NOx), sulphur oxides (SOx) and particulate matters (PM) from ships, pursuant to Regulation 13, Regulation 14 and Appendix III to MARPOL Annex VI.

2.1 Criteria for designation of an ECA

Pursuant to MARPOL Annex VI, an ECA may be considered for adoption by the Organization if supported by a demonstrated need to prevent, reduce and control air pollution from ships. Section 3 of Appendix III to MARPOL Annex VI sets out the criteria for designation of an ECA, and the proposal shall include:

> *3.1.1 a clear delineation of the proposed area of application, along with a reference chart on which the area is marked,*
>
> *3.1.2 the type or types of emission(s) that is or are being proposed for control (i.e. NOx or SOx and particulate matter or all three types of emissions);*
>
> *3.1.3 a description of the human populations and environmental areas at risk from the impacts of ship emissions,*
>
> *3.1.4 an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts 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,*
>
> *3.1.5 relevant information, pertaining to the meteorological conditions in the proposed area of application, to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts,*
>
> *3.1.6 the nature of the ship traffic in the proposed emission control area, including the patterns and density of such traffic,*
>
> *3.1.7 a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NOx, SOx 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; and*
>
> *3.1.8 the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade.*

Each of the criteria is addressed individually in sections 3 – 10 of this annex.

3 AREA PROPOSED FOR ECA DESIGNATION

This section presents information that addresses criterion 3.1.1 of Appendix III to MARPOL Annex VI, as quoted: **“The proposal shall include a clear delineation of the proposed area of application, along with a reference chart on which the area is marked”.**

3.1 Area outline

The area proposed for ECA designation is formally defined as the Norwegian Exclusive Economic Zone north of 62 degrees latitude, hereafter referred to as the Norwegian Sea. The proposed ECA area is shown in Figure 3-1, and includes Norwegian fjords and waters adjacent to the Norwegian coast which extends up to 200 nautical miles from the baseline[2] of the maritime territory around mainland Norway, except that it does not extend into marine areas subject to the sovereignty or jurisdiction of other States. The Norwegian Sea is enclosed by geodesic lines connecting the coordinates, as shown in Appendix A. The area definition is in line with the Norwegian Sea area as specified in MARPOL Annex II Reg. 13.9.4 “Control of discharges of residues of Noxious Liquid Substances”.

The Norwegian Exclusive Economic Zone (EEZ) south of 62 degrees latitude is already designated under MARPOL Annex VI as an ECA for SOx with effect from 22 November 2006, and NOx with effect from 1 January 2021. The designation of the Norwegian Sea as an ECA will make the entire Norwegian Exclusive Economic Zone an ECA area pursuant to Regulation 13 and Regulation 14 of MARPOL Annex VI.

The Norwegian Sea has a water sea surface area of about 776,200 km^2 with an average water depth close to 1,000 meters, which gives a total water volume of about 770,000 km^3. Along the Norwegian coast, a continental shelf of varying width and depth forms part of the Norwegian Sea. The continental shelf is typically between 200 and 400 meters deep and particularly wide off Nordland and narrow off Vesterålen. Outside the continental shelf there are water depths varying between 1,000 and 3,300 meters, where the deepest waters are found in the Norwegian Basin. The upper water layers of the Norwegian Sea are characterised by comparatively high salinity (above 35 ‰) and relative warm sea temperatures (8 –12 °C). An extension of the North Atlantic current keeps coastal sea areas free of sea ice. In the Norwegian Sea, the water temperature has risen as a result of the ongoing climate change, and consequent changes in ocean circulation, and acidification will have to be expected.

The Barents Sea has water depths varying between 200 and 500 meters. The average depth in the Barents Sea is approximately 230 meters and the maximum depth in the Norwegian trench reaches 513 meters. The main climate-forming factors are latitudinal changes in the incidence of solar radiation and the influence of the warm Atlantic water masses, entering the Barents Sea in the west. The main feature of the winter air temperature distribution is the so-called warmth pole in the ice-free southwestern Barents[3] Sea, where the average sea temperature in January is close to 0°C. In the eastern part of the region, the severity of the winter regime in the southeastern Barents Sea increases sharply.

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[2] https://lovdata.no/dokument/LTI/forskrift/2002-06-14-625

[3] http://www.barentsinfo.org/barents-region/Nature/Barents-Sea/Physical-characteristics

Figure 3-1   Area proposed for ECA designation, the Norwegian Sea

4 DESCRIPTION OF EMISSIONS PROPOSED FOR CONTROL

This section presents information that addresses criterion 3.1.2 of Appendix III to MARPOL Annex VI, as quoted: **“The proposal shall include the type or types of emission(s) that is or are being proposed for control (i.e. NOx or SOx and particulate matter or all three types of emissions”**.

4.1 Type of emissions proposed for control

This proposal supports designation of an ECA to control emissions of NOx, SOx and PM emissions from ships in the Norwegian Sea north of 62 degrees latitude, as outlined in chapter 3.1.

4.2 Nitrogen oxides

Nitrogen oxides (NOx) are the generic term for a group of highly reactive gases, which all contain nitrogen and oxygen in varying amounts. Nitrogen oxides from combustion and after chemical transformation in the atmosphere can exist in the following main forms: NO, NO_2, HNO_3, N_2O_5 and acyl peroxy nitrates. For diesel engine emissions, NOx covers only NO and NO_2, and NO typically accounts for 95% of the total NOx. Most nitrogen oxides are colourless and odourless. NOx is emitted by many types of sources where combustion is taking place, such as road vehicles, ships, power plants, chemical plants and refineries. NOx 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 NOx formed depends on the operation of the ship (engine load, engine speed -RPM, engine temperature, etc.). The most significant environmental and health impacts of NOx occur through particulate matter formation (NOx contributes to secondary PM), contribution to NO_2 concentrations, contribution to ozone formation, nitrogen deposition, and eutrophication and nitrogen contribution to acidification.

NOx is often referred to as an ozone precursor together with volatile organic compounds promoting a cycle in which ground-level ozone is produced and destroyed in a set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days, creating a relatively stagnant atmosphere, ozone and its precursors can build up and result in increased levels of ozone than typically would occur on a single high-temperature day. 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. It is highly beneficial, from a public health perspective to control ozone because exposure to ozone can trigger a variety of health problems including chest pain, coughing, throat irritation, and congestion. It can worsen bronchitis, emphysema, and asthma.

4.3 Sulphur oxides

Sulphur oxides or SOx emission are compounds formed by the reaction of sulphur with oxygen during combustion of sulphur-containing fuels. SO_2 is the component of greatest concern and is used as the indicator for the larger group of sulphur oxides. The SOx emissions are harmful to human health, causing respiratory, cardiovascular and lung disease. Once released in the atmosphere, SOx emissions can lead to accidies rain, which will impact crops, forests and aquatic species and contributes to the acidification of the oceans.

SOx emissions from ship exhaust contribute to the formation of sulphate (SO_4) aerosols, which are small particles. Small sulphate aerosol particles, along with other PM species, can penetrate deep into the lungs of living organisms, including humans, contributing to increased lung cancer and cardiovascular disease mortality and asthma morbidity. In addition, deposition of SO_4 particles contribute to increased acidification of surface waters and terrestrial systems, which is deleterious to the environment. The exhaust gas containing sulphur oxides emitted by the combustion of marine fuel will further oxidise and in presence of catalyst like NO_2, will form sulphuric acid which is a major cause of acid rain.

4.4 Particulate matter

Particulate matter (PM) includes a broad class of chemically and physically diverse substances that form either liquid or solid particles. PM_{10} refers to particles less than or equal to 10 micrometres (μm) in aerodynamic diameter. $PM_{2.5}$ refers to fine particles less than or equal to 2.5 μm in aerodynamic diameter. Inhalable (or ‘thoracic’) coarse particles refer to those particles greater than 2.5 μm but less than or equal to 10 μm in aerodynamic diameter. Ultrafine PM refers to particles less than 100 nanometres (0.1 μm) in aerodynamic diameter. Ambient fine PM is composed of primary $PM_{2.5}$ (directly emitted particles) and secondary $PM_{2.5}$ (particles formed through chemical and physical interactions of precursor pollutants).

The NOx and SO_2 emissions from shipping contribute to the formation of secondary PM where in the case of NOx alone, the formation of ammonium nitrate is the most relevant. Thus, by reducing NOx emissions, the ambient air concentrations of PM will also be reduced.

5 POPULATION AND ENVIRONMENT AT RISK FROM EXPOSURE TO SHIP EMISSIONS

This section presents information that addresses criterion 3.1.3 of Appendix III to MARPOL Annex VI, as quoted: **"*The proposal shall include a description of the human populations and environmental areas at risk from the impacts of ship emissions*".**

5.1 Population and urban areas at risk

The national population of Norway by 2022 is about 5.4 million persons, and there is an expected growth of 12-13% in population throughout this century. About 1.4 million of the inhabitants live in communities surrounding the proposed ECA area. With a population of close to 200,000 inhabitants, Trondheim is the major city in the area followed by Ålesund at 55,000, Bodø 43,000 and Tromsø with 42,000 inhabitants. The cities are all major shipping ports being central for costal and international shipping.

Several Norwegian cities and urban areas have problems with air quality and the concentrations in city centers do exceed the Norwegian air quality criteria for PM_{10} in particular, but sometimes also NO_2 (e.g., Ålesund, Trondheim). Adverse air quality in cities is especially due to emissions from wood burning and road traffic (both studded tyres and exhaust). In general, the contribution from ships is small. An overview of source categories and source contribution for 12 Norwegian coastal cities/municipalities[4] shows that ships have negligible contributions to PM_{10} concentrations. For NOx/NO_2 the contribution from ship is maximum a few percent, except for Ålesund (10 %), Tromsø (8 %), and Hammerfest (9 %). However, all these cities have concentrations well below the threshold values for NO_2. The annual mean concentration of NO_2 in Tromsø was above the threshold value in 2007 but has been below since then. Monitoring results from coastal cities like Ålesund, Harstad and Tromsø show hourly mean concentrations of NO_2 above the air quality criteria for hourly mean concentration (100 µg/m3) but the monitoring stations are designed to monitor air quality in the vicinity of roads, and the elevated concentrations cannot be attributed to ship emissions.

5.1.1 2030 reference scenario

The trends in ship traffic and appurtenant ship emissions are assessed towards 2030. This provides the basis for establishing the 2030 reference scenario for ship emissions. The estimated trends in ship traffic and emissions are based on:

- Historical developments and projection of ship traffic
- implications of short-term regulative implications, fleet technology and alternative fuel uptake.

Historical development and projection of ship traffic

The economic activity is the main activity driver of maritime transport, and the statistical office of European Union provide data on transport of goods that gives an overview of the historical developments in maritime transport on a national and down to port level. Data form Eurostat[5] shows that the gross weight of goods transported to and from main ports in Norway

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[4] From S to N; Ålesund, Molde, Aukra, Trondheim, Levanger, Mo i Rana, Bodø, Narvik, Harstad, Tromsø, Hammerfest, Nordkapp, all north of 62°N. Source: Norwegian Environment Agency – Fagbrukertjeneste for luftkvalitet (https://www.miljodirektoratet.no/tjenester/fagbrukertjeneste-for-luftkvalitet/), in Norwegian only

[5] https://ec.europa.eu/eurostat

has increased by 10% over the last decade towards 2021, indicating a historical increase in the annual traffic for cargo carrying ships of 1% in Norwegian waters. This corresponds well with the AIS modelled fuel consumption for cargo carrying ships in this period, which shows an annual growth close to 1% in the Norwegian waters and for the Norwegian Sea. The AIS modelled fuel consumption shows an annual increase in the period 2015-2019, followed by a significant drop for cruise and passenger ships in 2020-2021 due to the COVID-19 pandemic.

The report Energy Transition Norway 2022 forecast the Norwegian GHG emissions, energy demand and energy supply through to 2050 (DNV, 2022b). The report also includes a forecast of the GDP development for Norway, where sectoral analysis forms the foundation of the GDP development. The GDP developments for Norway is expected to have a growth of 1.5% per year in the period 2020-2030, including the effects of 2020 Covid-19 outbreak (DNV, 2022b). As there is a strong link between GDP and ship traffic developments for cargo carrying ships, also shown in the Maritime forecast to 2050, 2018 edition (DNV, 2018b) and by Nektarios (2020), the GDP developments for Norway can be used to indicate growth in the ship traffic for cargo carrying ships. The Norwegian Coastal Administration (NCA) has established prognosis for the Norwegian coastal ship traffic for the period 2018-2050 (NCA, 2018). The prognosis shows an overall reduction for the cargo carrying ships for the period 2019-2030, indicating an annual reduction of 0.5% for wet-/dry bulk ships and an annual increase in of 0.4% for general cargo ships.

For the **projection of ship traffic** for the 2030 reference scenario, this study has considered the historical developments in Norwegian ship traffic 2015-2022, the Norwegian GDP projections towards 2050 and the prognosis for the Norwegian coastal ship traffic 2018-2050. In addition, historical data for cargo flow for Norway, reported by Eurostat 2011-2020 is considered. Based on this, we have assumed that the projection of ship traffic for wet-/dry bulk ships remains flat in the period 2020-2030 (NCA 2018, DNV 2022b). It is also assumed an annual growth in the ship traffic of 1% for general cargo ships, 1.5% for cruise ships, 0.5% for passenger ships and 0.2% for other ships (NCA 2018, DNV 2022b, TØI 2019). A reduction in the ship traffic of 1.7% for the offshore ships and 0.5% for the fishing vessels (NCA 2018). It is recognised that such estimate will include uncertainties. A challenge to provided growth estimates based on the literature is that the methods and assumptions is different, as well as most recent projections for cargo ships goes back to 2017/2018.

Short-term regulative implications, expected fleet technology and alternative fuel uptake

The maritime sector is facing a growing pressure to decarbonise and operate in a more environmentally sustainable way. The expected tightening of regulations in the years to come is driving decarbonisation as shipowners must plan for lifecycle compliance. The global regulator for shipping is the IMO, with its concrete ambitions of at least halving absolute GHG emissions by 2050 compared with in 2008, in addition to reducing carbon intensity by 70%. Regional and national regulators are also entering the scene increasingly. With the ongoing greenhouse gas emission reductions in shipping providing further momentum, shipping is expected to become more energy effective, to change its fuel mix and use new technology and ship designs, and operational adjustments to cut its carbon and environmental footprint. The expected fleet technology and alt fuel uptake in the fleet involve several aspects such as energy efficiency, new energy converters (such as fuel cells, batteries, etc.) which influence the NOx, SOx and PM emissions from ships.

Extensive new CO_2 regulations applying to existing ships were adopted in June 2021. Amongst these are the Energy Efficiency Existing Ship Index (EEXI), the Carbon Intensity Indicator (CII) rating scheme, and the enhanced Ship Energy Efficiency Management Plan (SEEMP). These measures, along with already existing Energy Efficiency Design Index (EEDI), are all designed to meet the target of achieving a 40% reduction in carbon intensity for shipping by 2030 relative to 2008. The CII requirements will take effect for all cargo, RoPax and cruise vessels 5,000 gross tonnage and above. The 2021 guidelines on the operational carbon intensity reduction factors (resolution MEPC.338(76)), requires the operational CII of specific ship types to reduce by 5% in 2023 relative to the 2019 reference line, and thereafter 2 % annually to 2026. The CII requirements for the years of 2027 to 2030 is to be further strengthened and developed considering the review of the short-term measure.

Beyond the IMO requirements, the EU has imposed influential emission reduction initiatives. The EU ambition is to reduce the Union's total sector-independent emissions by 55% by 2030, relative to 1990, and to become climate-neutral by 2050. In July 2021, the EU presented its 'Fit for 55' legislative package. Preliminary agreement is to include shipping in the EU's Emission Trading System from 2024, where the ships presently reporting emissions under the EU MRV regulation required to purchase CO_2 emission credits. All intra-EU emissions will be included, but only 50% of the emissions for voyages when arriving in or departing from the EU. There will also be a phase-in period starting with 40% coverage in 2024 and increasing to 100% in 2026. The FuelEU Maritime Regulation is a new regulation coming into effect in 2025, imposing life cycle GHG footprint requirements on the energy used on board ships. It will apply to the same ships that are covered by the EU MRV regulation and will, in addition to CO_2, cover methane and nitrous oxide, all in a well-to-wake perspective. The GHG intensity of the energy used will be required to improve by 2% in 2025 relative to 2020, ramping up to 75% by 2050.

Norway has communicated a Nationally Determined Contribution (NDC) under the Paris Agreement to reduce greenhouse gas emissions by at least 50% and towards 55% by 2030 compared to 1990. This is a crucial step on the path towards Norway's target of being a low-emission society by 2050 (Meld. St. 13 (2020-2021)). In addition, the Norwegian legislation on public procurement places obligations on central government, municipality, and county authorities to «organise their procurement practice such that it helps reduce harmful impact on the environment and encourages climate friendly solutions when relevant», (LOV-2016-06-17-73). AS a result of this, the Norwegian Public Roads Administration (NPRA) and several Norwegian county municipals has contracted fully electric battery powered car ferries in the domestic ferry sector. The NPRA has also introduced the use of natural gas (LNG) in the maritime sector, introduced the world's first hydrogen ferry in 2021 and contracted the operation of hydrogen ferries[6] between Bodø and Lofoten from 2025.

The fuel oil consumption data submitted to the IMO Ship Fuel Oil Consumption Database in GISIS, reporting year 2020[7], gives the status of fuel types used by international shipping of 5,000 GT and above. The aggregated annual amount of each type of fuel oil shows that the main usage is heavy fuel oil, light fuel oil and diesel/gas oil, and that only 0.05% of the total reported fuel consumption is other fuels such as ethane, used cooking oil, biofuel and LBG. The Norwegian Directorate of the Environment has proposed to introduce a new sales requirement[8] for advanced biofuel used for shipping. The proposed sales requirements specify that traders of liquid fuel and liquid fuels for vessels and aquaculture facilities shall ensure that at least 4% by volume of the total amount of liquid fuel and liquid fuels sold per year consists of advanced biofuel and advanced liquid biofuel. From 1 January 2024 the proposed requirement is 6% by volume. A prognosis of the uptake of alternative fuels and an emission forecast for Norwegian domestic ship traffic for the period 2026-2060 has been made on behalf of the NCA (DNV, 2022a). The prognosis includes evaluation of market, political and regulative drivers, technology developments and costs for the uptake of alternative fuels. The forecast indicates that the ship traffic in Norwegian waters from 2019 to 2030 will have an uptake of about 5% biofuel (HVO), 5% electric powered ships and 5% LNG, resulting in a total of 11.5% reduction in CO_2 emissions.

For the short-term regulative implications, fleet technology and alternative fuel uptake for the 2030 reference scenario, this study has considered the IMO and EU regulative drivers for emission reductions and alternative fuel usage for ships being 5,000 gross tonnes and above. For ships being below 5,000 gross tonnes, typically domestic ship traffic, the forecast of alternative fuel uptake for Norwegian waters forms the basis for the 2030 fuel and emission estimates. For the wet-/dry bulk ships, general cargo ships, passenger ships, cruise ships, offshore ships, fishing vessels and other ships the respective fuel consumption is about 94%, 35%, 56%, 98%, 66%, 2% and 40% for ships being 5,000 gross tonnes and above. For these ships, and annual reduction of 2% are estimated covering fleet technology and alternative fuel uptake. The reduction is in line with the IMO requirements and supported by the EU MRV regulations for ships. As a result, the estimated reductions for wet-/dry bulk ships, general cargo ships, passenger ships, cruise ships, offshore ships, fishing

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[6] https://www.vegvesen.no/en/fag/trafikk/ferje/hydrogen-ferries-to-lofoten/

[7] https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC%2077-6-1%20-%202020%20report%20of%20fuel%20oil%20consumption%20data%20submitted%20to%20the%20IMO%20Ship%20Fuel%20Oil%20Consumption%20Database%20in%20GISIS.pdf

[8] https://www.miljodirektoratet.no/aktuelt/fagmeldinger/2023/januar-2023/hoyring-av-omsetningskrav-for-biodrivstoff-til-sjofart/

vessels and other ships being 5,000 gross tonnes or above are 19%, 7%, 11%, 20%, 13%, 0% and 8% respectively. For ships being below 5,000 gross tonnes, the uptake of alternative fuels is mainly made on domestic operated passenger ships and offshore ships. For these ships, and annual reduction of 2% are estimated for the passenger ships and 0.5% for the offshore ships covering fleet technology and alternative fuel uptake. The passenger ships and offshore ships below 5,000 gross tonnes consume about 44% and 34% of their totals, hence the estimated reductions in fuel consumption for the passenger ships and the offshore ships in 2030 are 9% and 2% respectively (DNV, 2022a). For fishing vessels and other ships, the fleet technology and alternative fuel uptake is for this study set to 0%**.**

Effects on SOx emissions for the 2030 reference scenario

Based on estimated fuel consumption from the AIS analysis, it is estimated that about 55% of the total fuel consumption in the Norwegian Sea are of low- or zero sulphur fuels such as marine gas oil and LNG, while the remaining 45% are typically heavy fuel oils or light fuel oils containing maximum 0.5% S. This means that more than half of the fuel consumed in the area is likely to already be compliant with the SOx emission control area requirements. Regardless of the introduction of ECA in the Norwegian Sea, there will be other regulations and trends affecting future SOx emissions in the coming years. Essentially, there will be two important changes that affect the SOX emissions:

- Reduced SOx emissions as a result of lower fuel consumption through energy optimization of ships and technology uptake
- Reduced SOx emissions as a result of the phasing in of alternative fuels that do not contain sulphur (such as LNG, biofuels, hydrogen/ammonia, electric drive, etc.)

The estimated effects on SOx emissions for the 2030 reference scenario is in this study estimated to follow the reduction in fuel consumption. However, it is recognised that the IMO, EU MRV and National regulations in the future will require uptake of alternative fuels at larger extent affecting the SOx emission. The uptake of alternative fuels is in 2020 for ships of 5,000 gross tonnes and above is low (0.005%), and for the 2030 reference scenario the effect on SOx emissions from uptake of alternative fuels is estimated to remain low.

Effects on NOx emissions for the 2030 reference scenario

The introduction of a NOx emission control area will mean a gradual phasing-in of ships that meet NOx Tier III requirements, as only new ships or new engine installations/major engine conversions will be subject to the regulations. Existing ships can operate with unchanged NOx emissions until they are phased out or major engine conversions are made.

In the context of NOx, it is important to distinguish between domestic ship traffic and international/transit ship traffic. Emissions from domestic ships ship traffic, defined as ships sailing between Norwegian ports, is subject to the Norwegian NOx tax, where the Norwegian NOx-Fund[9] administrates the NOx Agreement between business organisations and the Ministry of Climate and the Environment, running to and including year 2027. Under the NOx-Fund regime (practically covering all domestic NOx-taxable ship emissions), ships are exempted from the regular NOx-tax, and instead pay a lower tax into the NOx-Fund. In return, significant emission reduction levels agreed with the Government must be met. The NOx-Fund also covers NOx-emissions from oil and gas installations, drilling rigs and major parts of land-based industry. The NOx-Fund's financial capital is used to support investments (up to 70% of the CapEx) in various NOx-reducing technologies on ships and other business sectors, where the reduction effect is verified after actual implementation. According to the NOx-Fund's figures, the Norwegian domestic ship emissions amounted to approximately 38,000 tonnes in 2019. According to the NOx-Fund, it is assumed that domestic NOx emissions from shipping, covered by the NOx

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[9] https://www.noxfondet.no/

agreement, will see a reduction from 38,000 tonnes down to 25,000 – 30,000 tonnes in 2027. This is also supported by recent observed emission trends, the effect of the NOx-Fund's verified projects from 2019 and so far in 2022, and the NOx-Fund's further portfolio of planned NOx reduction measures. Regardless of planned operation inside or outside the Nort Sea ECA in Norway, the NOx-Fund today regards Tier III technology as standard equipment for new buildings, which does not actually represent any voluntarily added CapEx – hence not eligible for NOx-Fund support. Hence, the NOx-Fund offers financial support to stimulate the building of new ships (with required use of Tier III) that may potentially accelerate the replacement of old ships with high emissions.

This study assumes that the regulation-driven phase in of ships technically equipped for tier III towards 2030 follows the NOx-Fund projections for domestic ship traffic. For the remaining ship traffic, the NOx reduction is anticipated to come as a gradual phasing-inn of Tier III compliant technologies after the implementation of the ECA regulation. Through the AIS analysis of ship traffic in Norwegian waters, approximately 45% of the ship fuel consumption and emissions from shipping is anticipated to relate to domestic ship traffic. The NOx emission reduction of 20% towards 2030 is estimated for passenger ships, offshore ships, fishing vessels and other ships representing about 40% of the total NOx emissions in the area.

Results for the 2030 reference scenario

The results for the 2030 reference scenario are shown in Table 5-1. The results include fleet developments, technology and alternative fuel uptake and the uptake of NOx reduction technologies in the Norwegian domestic ship traffic. The results from the 2030 reference scenario are geographically distributed using AIS data as input for the environmental modelling and further analysis of health and environmental impacts.

Table 5-1 2030 reference scenario

Ship type	Fleet development 2020 – 2030 (%)	Fleet technology and alternative fuel uptake 2020 – 2030 (%)	Effect of NOx-Fund emission reductions 2020 – 2030 (% for NOx)	Fuel estimate 2030 (tonnes)	Estimated ship emissions in 2030 (tonnes)			
					NOx	SOx*	PM_{10}	$PM_{2,5}$
1-Wet-/dry bulk ships	0 %	-19 %		386,000	16,440	1,730	1,330	1,210
2-General cargo ships	10 %	-7 %		163,000	7,350	860	430	400
3-Passenger ships	5 %	-20 %	-20%	146,000	5,900	510	310	280
4-Cruise ships	15 %	-20 %		75,000	4,840	670	410	370
5-Offshore ships	-17 %	-13%	-20%	83,000	2,460	220	160	150
6-Fishing vessels	-5 %	0%	-20%	169,000	5,720	310	260	250
7-Other ships	2 %	-8%	-20%	108,000	3,470	300	200	180
Total	**-**	**-**	**-**	**1,130,000**	**46,180**	**4,600**	**3,100**	**2,840**

5.2 Description of the proposed ECA, the Norwegian Sea

A short description of the environmental conditions and resources in the Norwegian Sea is presented in the following subchapters. The information is gathered from web resources, such as Barentswatch, the Institute of Marine Research, and ICES, including previous reports delivered by DNV.

5.2.1 Biogeography

The Norwegian Sea is a part of the geographical bioregion "Temperate Northern Atlantic". In this report, the Norwegian Sea refers to the part of the Norwegian Sea covered by Norway's exclusive economic zone (EEZ) and a part of the Barents Sea (Figure 3). The Norwegian Sea borders the Barents Sea in the north and the North Sea in the south. It constitutes widely different environments – from the deep seas to the continental slope and shelf, to the coastal zone with several small islands and fjords. The geological diversity makes it unique for Europe. There are large annual and seasonal variations in climate in the Norwegian Sea due to the large temperature differences between the warm air in the south and cold air over the polar regions in the north.

5.2.2 Bottom topography, estuaries, fjords and wetlands

The Norwegian Sea constitutes of two deep basins (between 3,000 and 3,500 m deep), the Norwegian Basin and the Lofoten Basin, separated by the Vøring Plateau (between 1,000 and 3,000 m deep). In the deep ocean, the bottom is mostly covered by large plains with mud, created by the remains of plankton and algae. It also constitutes volcanic mountains, as well as deposits from masses from the continental slope, like outside of Storegga. The continental slope is covered by sediments of clay, although in areas with stronger currents, like in the steep hills, only sand and gravel remain. This creates a suitable environment for the cold-water corals often found in this area.

During the ice age, the masses excavated by the glaciers were deposited on the continental shelf. The sediment on the continental shelf is mostly dominated by sand and gravel, with the clay accumulating in the areas of slow currents. There are also coral reefs on the continental shelf, such as the Sula reef (Sularevet). Pockmarks are also created on the continental shelf when gas sieves up from the bedrock. The pockmarks, which are pits in the sediments, can be kilometers long and up to 30 m deep. They are important habitats for bacteria and species living of the gas.

The coastal zone constitutes of several small islands, deep fjords, sheer cliffs, and high mountains, which are the remains of a former higher landscape. It varies in depth from 40 m below to 40 m above sea level, with some exceptions. The seabed consists of an alternation between islands and channels where the seabed varies from clay and silt to stone and gravel. In the transition zone between weak and strong currents, large accumulations of shell sand are also formed. The shallow water provides good light conditions, and the rocks and stones provide a hard substrate for the kelp forests. This change in bottom types provides an enormous species richness of fish and shellfish.

Many estuaries and fjords open into the Norwegian Sea. The fjords usually have a shallow sill at the mouth, with considerable depth in the inner part, which makes them deeper than the coastal waters. The steep mountain slopes often merge into a flat bottom of clay and silt. In the transition between the bottom of the fjord and the sides of the fjord, there are often avalanche fans from mountain and snow avalanches and spalls, or gravel and sand deposits from rivers and streams. Where the valleys open into the fjords there is a larger gravel and sand delta from the rivers that flow into the fjord. In many of the fjords, there are moraine ridges formed during the ice melt that creates local thresholds. The Tautra ridge in the Trondheim fjord is such a moraine ridge.

5.2.3 Hydrology

There are mainly three bodies of water in both the Norwegian Sea and the Barents Sea: Atlantic waters, Arctic waters, and coastal waters. The water circulation of the European shelf seas is dominated by tidal and wind-generated currents. In the Norwegian Sea the ocean circulation is dominated by the Norwegian Atlantic Current, which is a poleward extension of the Gulf Stream, and the Norwegian Coastal Current (Figure 4-2). The Atlantic current goes further out from the coast and is warmer and saltier than the coastal current originating from Skagerrak. Every second, around 8 million tonnes of warm and salty water flows into the Norwegian Sea from the northern Atlantic Ocean. That is eight times the sum of all the rivers in the whole world. The inflowing water gives off heat to the atmosphere, which is crucial for the mild climate in Norway before it is transported to the Barents Sea and the Arctic Ocean. The mix of water bodies with different temperatures and salinity in the Norwegian Sea is of great importance for the distribution of plankton and fish in the area. Since 2016, the water flowing into the Norwegian Sea from the south has been colder and fresher. Still, the overall cooling has been limited due to the increased strength of westerly winds bringing in warmer air.

Fjords can be naturally prone to anoxia, a condition exacerbated by eutrophication, due to the bathymetry preventing full circulation of the deeper water masses. Estuarine habitats, marshes, and coastal wetlands may also suffer from drainage and the accumulation of particles and eutrophication.

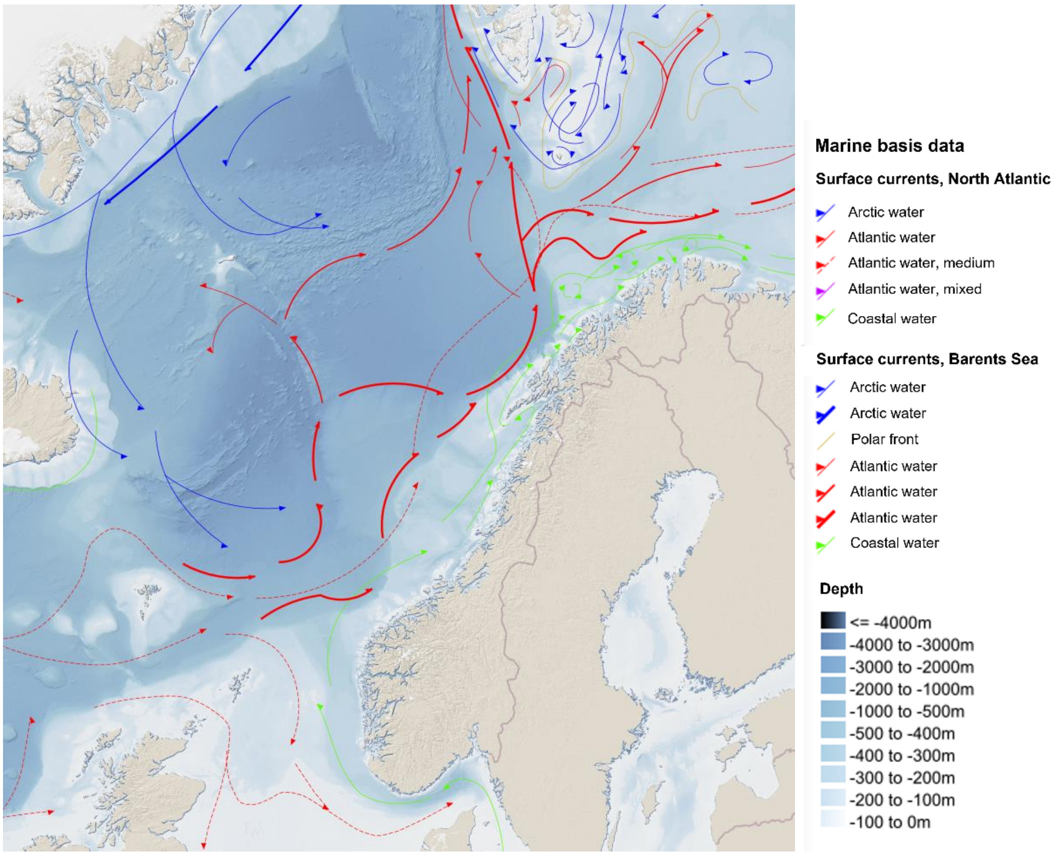


Figure 5-1 The surface currents in the Norwegian Sea and Barents Sea, including ocean depth. Retrieved from www.barentswatch.no/en.

5.2.4 Ecological characteristics

The ecosystem in the Norwegian Sea has relatively low biodiversity and a relatively simple food chain, but the dominant life forms are very abundant. The Norwegian Sea has a high biological production and houses a very large biomass of organisms, approx. 200 million tonnes. Almost 75% of this large biomass comprises zooplankton, mainly small crustaceans such as *Calanus finmarchicus* and krill. *Calanus finmarchicus* is a key species in the ecosystem and stays in the depth of the Norwegian Sea during the winter. These organisms serve as food for the fish stocks important for our fisheries, such as Norwegian spring-spawning herring (*Clupea harengus*), blue whiting (*Micromesistius poutassou*), and mackerel (*Scomber scombrus*). These fish species migrate to the Norwegian sea in the summer but have had a declining biomass in recent years. Pollock (*Gadus chalcogrammus*) and cod (*Gadus morhua*) are also important commercial fish stocks (Figure 5-2) Other species that are a large part of the total Norwegian catch in the Norwegian Sea are haddock (*Melanogrammus aeglefinus*), cusk (*Brosme Brosme*), Atlantic redfish (*Sebastes norvegicus*), common ling (*Molva Molva*).

After the mid-2000s, the zooplankton biomass in the Norwegian Sea declined, but the annual primary production by phytoplankton increased, possibly due to the increased inflow of cold and fresh Arctic water containing elevated concentrations of nutrients.

Key marine mammals in the Norwegian Sea are harbor porpoises (*Phocoena phocoena*), white-beaked dolphins (*Lagenorhynchus albirostris*), pilot whales (Globicephala melas), Atlantic white-sided dolphins (*Lagenorhynchus acutus*), killer whale (*Orcinus orca*), humpback whales (*Megaptera novaeangliae*), and minke whales (*Balaenoptera acutorostrata*), as they dominate in abundance. Grey seals (*Halichoerus grypus*) and harbor seals (*Phoca vitulina*) are also distributed along the Norwegian coast and create colonies of high density in the Norwegian Sea (Figure 4-4). However, they are largely stationary and spend much of their time close to shore and on land. A long-term shift in summer distribution from the Norwegian Sea to the Barents Sea has occurred for marine mammals in recent years. Additionally, for hooded seal (*Cystophora cristata*), grey seal, and harp seal (*Pagophilus groenlandicus*), pup production is at a low level or declining.

The Norwegian Sea has several ecological functions and is therefore important for many of the large seabird populations in the northeast Atlantic. Northern parts are grazing areas for populations that breed further north and east. Many species stay in the Norwegian Sea for large parts of the year, while most use it as a migration and wintering area. Seabirds are wholly or partly dependent on the sea for food. While the coastal species have a limited radius of action, the pelagic species (including most auks, terns, and northern fulmar) can move tens of kilometers from their nesting colonies, especially in summer.

Over the past 30 years, the population of several seabird species that nest and feed along the Norwegian coast has declined. This especially applies to the populations of the common murre (*Uria aalge*), which has been reduced by 99%, the Atlantic puffin (*Fratercula arctica*), which has been reduced by 71%, and the black-legged kittiwake (*Rissa tridactyla*), which has been reduced by 86%. The reasons for the changes are not fully understood.

Benthic fauna and flora in the Norwegian Sea are varied due to large depth variations and other geological, physical, and chemical conditions. The large deep-sea basins have flat areas with limited but varied deep-sea fauna. The shallow bank areas are characterised by both benthic fauna and flora with high biological production. Through the MAREANO mapping program, a number of new discoveries have been made of coral reefs, coral forests, sea feathers, and sponges. Many deposits of coral have also been discovered on the shelf areas in the Norwegian Sea in connection with seabed surveys when planning other petroleum activities. In the same way as for corals, there is also a belt with a high density of both sponges and hard bottom sponges along Eggakanten in the transition zone to deeper seas. The areas at The Halten Bank also house several dense deposits of sponges and hard bottom sponges. Coral reefs of *Desmophyllum pertusum* (formerly known av *Lophelia pertusa*), which is the most important reef-building coral in Norwegian waters, are shown in Figure 4-5. The coral reefs inhabit a range of biological life and are nursing areas for many of the important commercial fish species.

Lofoten, Vesterålen, and Senja are the spawning grounds of the world's largest stock of cod, which is crucial for both the ecosystems in the sea and us humans. It is also home to the world's largest cold-water coral reef and mainland Europe's largest seabird colony. 70 % of all fish caught in the Norwegian Sea and the Barents Sea visit these areas at least once in their lifetime.

The four most important pressures on the Norwegian Sea ecoregion, excluding climate change, are abrasion, underwater noise, selective extraction of species, and introduction of contaminating compounds. While contaminating compounds are mainly introduced from sources outside the Norwegian Sea, the other pressures are linked to human activities in the region (fishing, maritime transport, and oil and gas production).

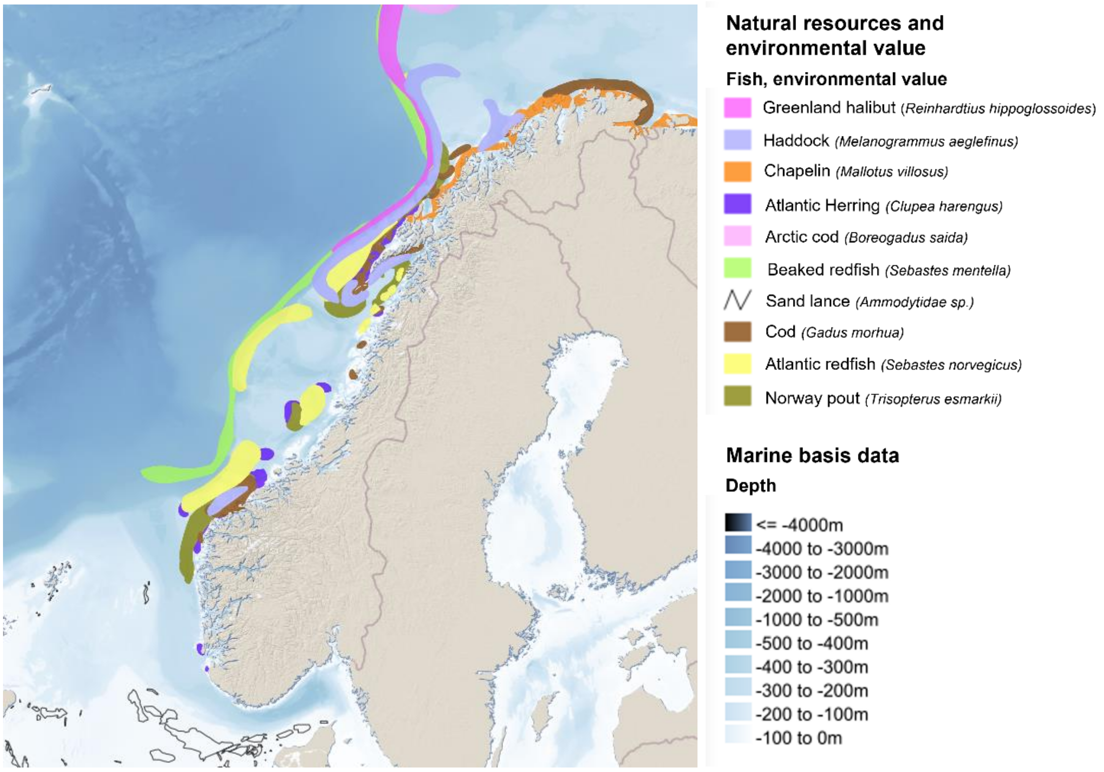


Figure 5-2 Areas in which certain commercial fish species have a high environmental value. Retrieved from www.barentswatch.no/en.

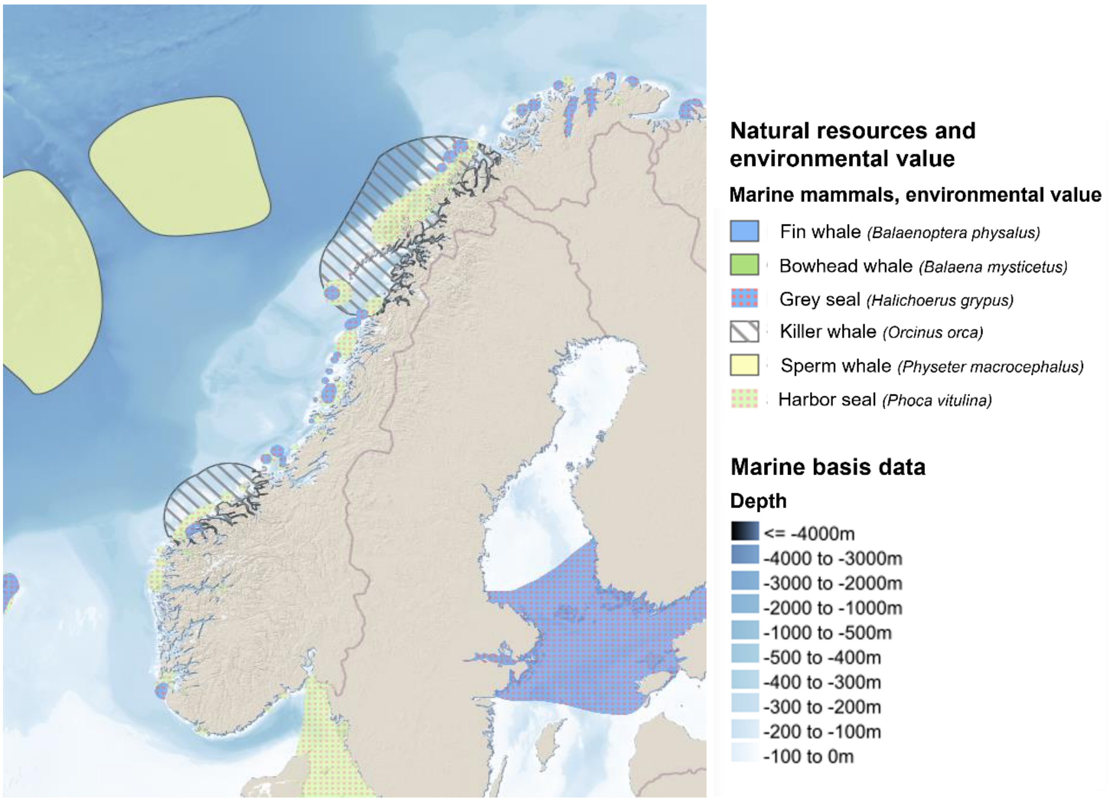


Figure 5-3 Areas in which certain marine mammals have a high environmental value. Retrieved from www.barentswatch.no/en. Retrieved from www.barentswatch.no/en.

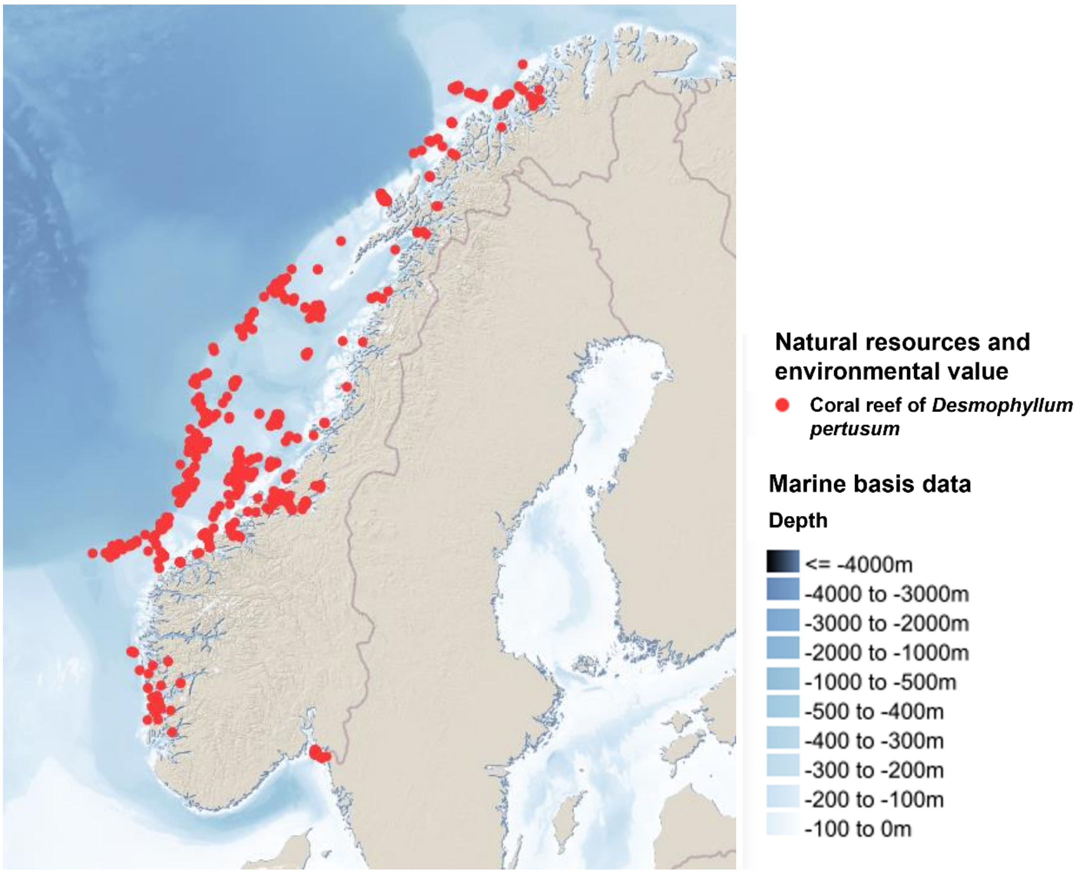


Figure 5-4 Areas with coral reefs of *Desmophyllum pertusum* (formerly known as *Lophelia Pertusa*), which have a high environmental value. Retrieved from www.barentswatch.no/en.

5.2.5 Marine protected areas and SVO

The first national marine protected areas were Tauterryggen in Nord-Trøndelag, and Saltstraumen in Nordland, which was established in 2013. Today there are more such areas, but they only make up 1 % of the total sea area. Norway also has four marine national parks, and they are all located in the south of Norway.

Particularly valuable and vulnerable areas (SVO) are sea areas that are extra important for biodiversity and biological production. They are geographically defined areas that contain one or more particularly significant occurrences of environmental values, valued according to the proportion of regional, national, and international stock, as well as stock status, restitution capacity, and red list status. The status as an SVO signals the importance of showing particular care in these areas but places no restrictions on commercial activity. The national marine protected areas and SVOs are shown in Figure 5-5.

Along the coast of Trøndelag, and Nordland, the SVO Coastal Zone of the Norwegian Sea stretches. This area houses several different habitats that are important for several groups of species, for example, kelp forests and coral deposits that facilitate grazing and rearing areas for both pollock and herring. The areas are also important for wintering, rearing, spawning, and feeding for coastal seabirds and marine mammals.

The seabed deeper than 1,000 m is protected against fishing influence through the Marine Resources Act to take care of vulnerable species and habitats on the seabed. The same applies to shallower areas in the northern Barents Sea and coral reefs along the coast.

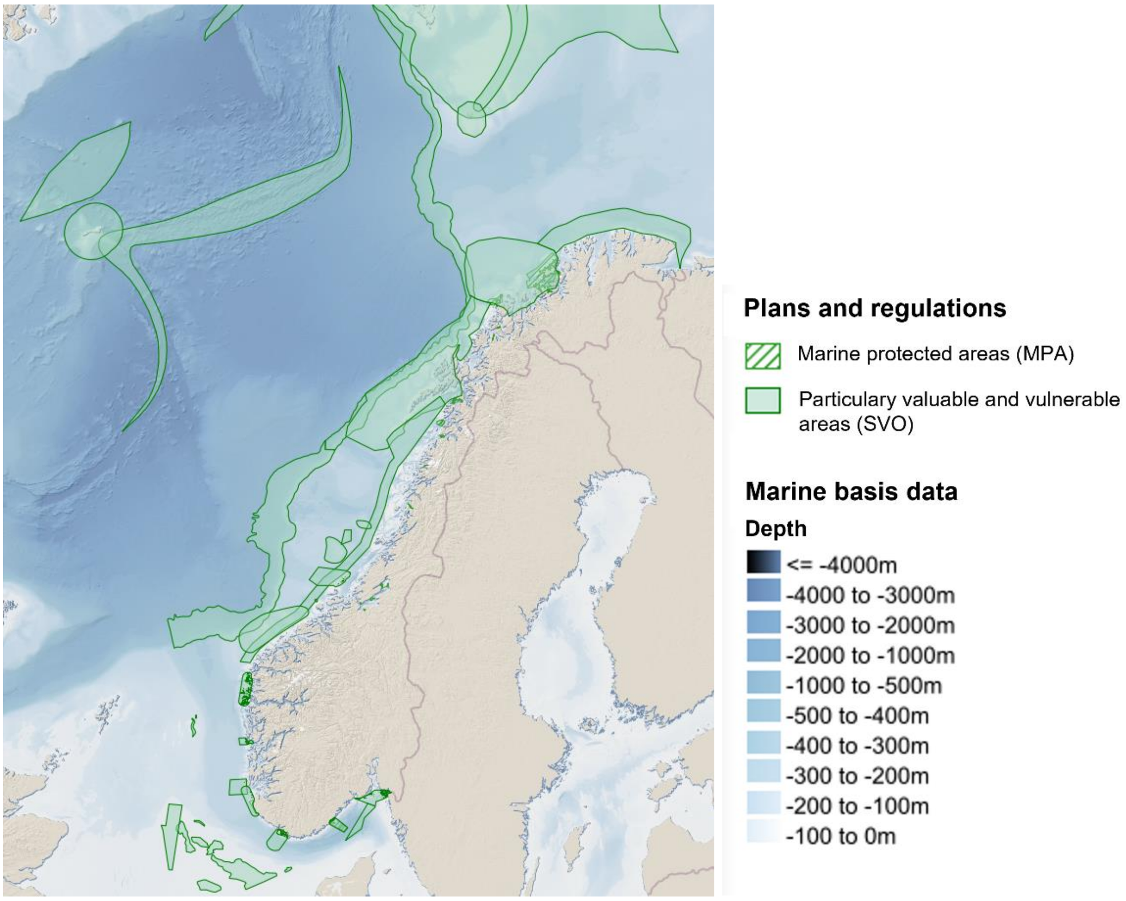


Figure 5-5 National marine protected areas and particularly valuable and vulnerable areas (SVO). Retrieved from www.barentswatch.no/en.

6 LOCAL CONDITIONS INFLUENCING AIR POLLUTION

This section presents information that addresses criterion 3.1.5 of Appendix III to MARPOL Annex VI, as quoted: **“The proposal shall include 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”**.

6.1 Meteorological conditions

The proposed area extends from 62 degrees latitude to approximately 74 degrees latitude, see Figure 3-1, and includes both areas in the mid-latitudes and polar regions. The general atmospheric circulation in the area is characterised by low pressure weather systems (cyclones) migrating from west and towards east. In a low-pressure system/cyclone in the Northern Hemisphere the wind blows in a counterclockwise pattern and hence the wind direction varies as the cyclones pass. Figure 6-1 shows the wind direction and wind speed for two locations, Goliat FPSO (71.30°N, 22.30°E) located in the arctic region and Norne (66°N 8°E) located in the Norwegian Sea.

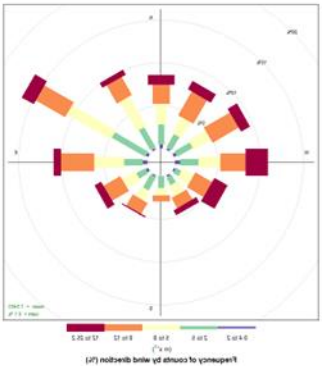
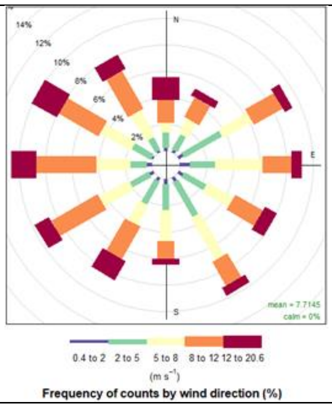
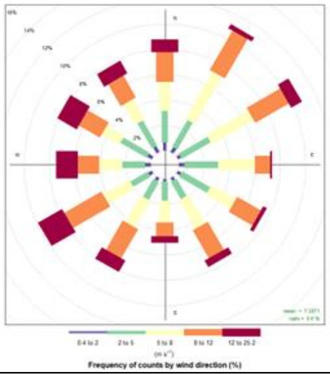
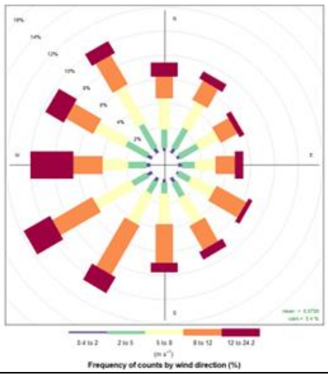
Goliat 2019	**Goliat 2020**
	
Norne 2019	**Norne 2020**
	

Figure 6-1 Wind rose for Goliat (71.30°N, 22.30°E) and Norne (66°N 8°E) Norwegian weather stations for 2019 and 2020. The wind rose shows where the wind comes from, give an a %-share sorted by wind speed 0.4 – 2 m/s (blue), 2-5 m/s (light green), 5-8 m/s (light yellow), 8-12 m/s (orange) and above 12 m/s (dark red). Calm conditions, i.e. wind speed below 0.4 m/s occur in 0-0.6% of the time only.

The wind data shows that the wind is evenly distributed with regard to wind direction, although with a slight larger share of westerly winds. Calm conditions with no wind rarely occur, this means that it is “always windy” in the study area. Average yearly wind speed is 7-8 m/s while maximum wind speed is 24-25 m/s, equivalent to level 10 Storm on the Beaufort scale.

The polar front is the atmospheric boundary between cold, polar air and warmer air from the mid-latitudes. The location of the polar front will vary considerably throughout the year. In wintertime the polar front shifts southwards and may be as far south as 40–50°N. In summer the polar front is often located at +/-70°N. In summertime continental northern Europe is influenced by high pressure systems giving warm air also in the North. Mid-latitude extratropical cyclones (“low pressure weather systems” described above) often occurs along the polar front, giving strong winds and unstable atmospheric conditions.

The wind along the coast is modified by topography which means that the wind direction will be modified by islets and islands, fjords and mountains. In addition, rough topography will slow down strong winds so that wind speed close to the coast is lower than at open sea. Nevertheless, the wind is usually strong along the coast so that dispersion of pollutants emitted will be effective. However, there are some areas inland, e.g. in fjords, where wind conditions are calm and where inversion and stable conditions may occur during the cold season or during nighttime. In these areas, special measures should be taken to avoid excessive levels of pollutants. Long fjords with a large number of cruise ships are an obvious example (e.g. Geiranger).

6.2 Arctic Polar Dome

The arctic atmosphere is special in the sense that isentropic surfaces, i.e. surfaces of constant potential temperature[10], form a closed domes over the Arctic. These isentropic layers and hence this dome acts as a transport barrier that isolates the Arctic lower troposphere from the rest of the atmosphere. Air masses and pollution transported northwards will typically “slide” on these isentropic surfaces and will not reach the ground. For pollution to reach the surface, it must originate from a source region that has the same low potential temperatures as the Arctic Haze layers (Stohl et al., 2007). This also implies that pollution from low and middle latitudes will not reach the Arctic surface since these source regions are too warm, i.e. too high potential temperature. Hence northern Eurasia is the main source region for pollution in the Arctic. However, pollution transport from Eurasia is highly episodic. *Blocking events* are important mechanisms that affect the transport into the Arctic, especially during winter. Stable high-pressure systems (anticyclones) over N-Russia / Siberia block the migrating low-pressure systems (cyclones) in the North Atlantic and set up a flow of air masses from N-European source regions and into the Arctic.

As a consequence of this Arctic Polar Dome and the stratified atmospheric layers, emissions at high latitudes are more likely to be transported into to lower arctic atmosphere than pollutants emitted further south. In addition, the atmospheric lifetime / residence time is longer in polar regions due to less solar radiation during winter, slow transport, less precipitation/wet removal and weak vertical mixing than further south. Hence the radiative effect of pollutants emitted in polar areas is larger compared to the radiative effect of pollutants emitted further south.

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[10] Potential temperature θ is the temperature that an unsaturated parcel of dry air would have if brought adiabatically (with no exchange of heat or mass) and reversibly from its initial state to a standard (surface) pressure p_0

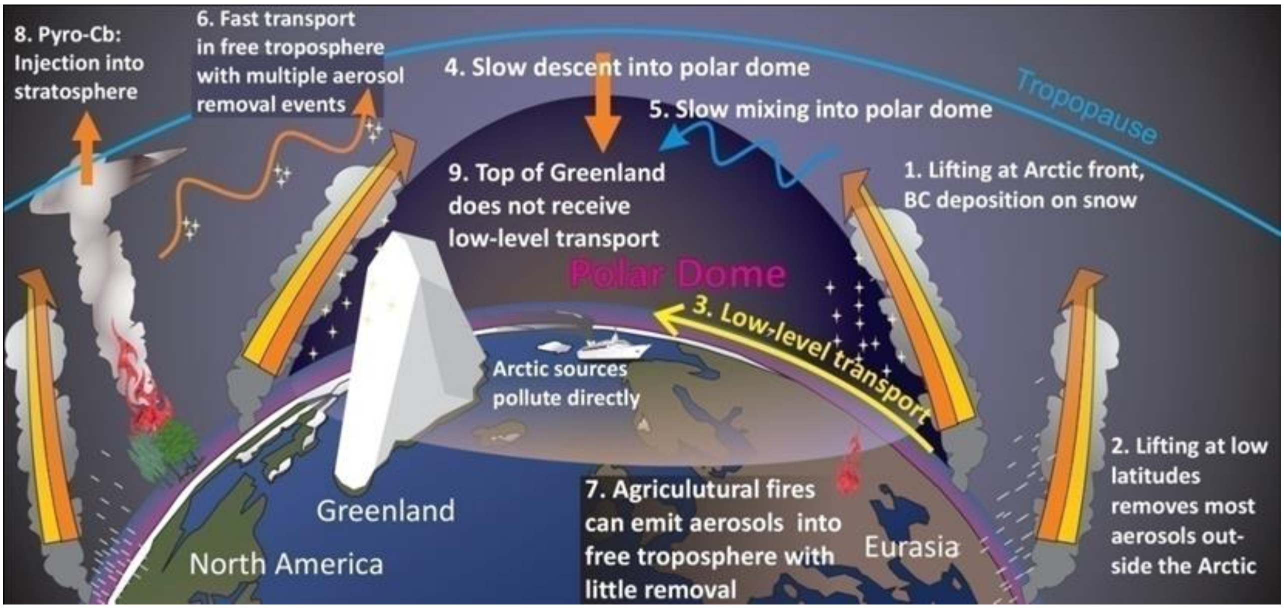

Figure 6-2 Schematic illustration of the Arctic Polar Dome and transport to and within the Arctic region (Stohl, 2006; AMAP, 2011). The Arctic Dome is larger during winter and smaller during summer.

To summarise, the study area is characterised by low-pressure weather systems / cyclones ("fronts") giving evenly distributed strong winds. With regard to dispersion and dilution of emissions from ship traffic, the strong wind / high wind speed gives effective dilution and dispersion of the emissions from ships. Hence the meteorological conditions in the proposed area reduce the probability for high ambient concentrations of air pollution or any adverse environmental impact. However, in the Arctic region, the phenomenon of Arctic Polar Dome inhibits atmospheric transport and creates a strongly stratified atmosphere. Pollutants emitted far north show a greater radiative impact than pollutants emitted further south.

7 IMPACT ASSESSMENT OF AIR POLLUTION AND OTHER PROBLEMS CAUSED BY SHIP EMISSIONS

> This section presents information that addresses criterion 3.1.4 of Appendix III to MARPOL Annex VI, as quoted: ***"The proposal shall include*** **an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts 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".**

This chapter provides a description of the basic data used in the analysis and the AIS-based method for quantifying emissions of NOx, SOx and PM from ships operating in the Norwegian Sea. The analysis includes all types and size categories of ships identified by the AIS system to estimate the total emission contributions from shipping in the area. The impact of the ECA requirements will form the basis for understanding the need for special regulations in the proposed ECA area.

Figure 7-1Figure 7-1 shows the overall approach and steps used in the assessment. Through the AIS ship activity-based modelling, the current 2020 baseline emission inventory for the proposed ECA area is estimated, as well as the likely future 2030 reference scenarios both with and without an ECA designation. The emission contribution of NOx, SOx and PM to the impact areas are included in environmental impact modelling, which results in an analysis of impacts on human health and the environment.

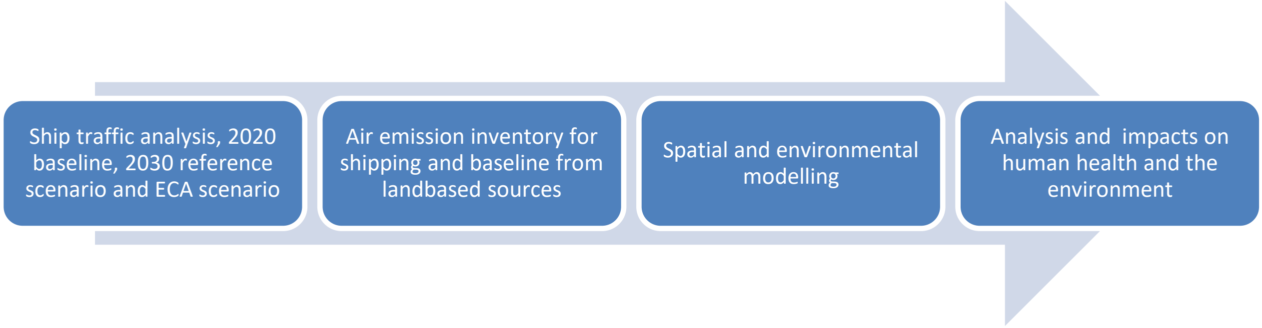

Figure 7-1 Illustration of the analysis approach

7.1 Ship traffic analysis

7.1.1 Method for projection of ship traffic and emissions towards 2030

The objective of this analysis is to quantify the ship emission reductions caused by the introduction of an NOx-, SOx- and PM emission control area in the Norwegian Sea north of 62 degrees latitude, and to make the difference in emissions available in both a tabular and a geographically gridded format for further analysis of environmental and health impacts. The quantification of emission reduction is done firstly on a tabular level, organised on ship types, size categories and on ship fuel types. The regulation will impact the ships operating in the area differently, from no impact to considerable impact. Lastly, the estimated emission reductions are gridded for further analysis of impacts.

The applied principle of the emission scenario developments is shown in Figure 7-2, and further described below.

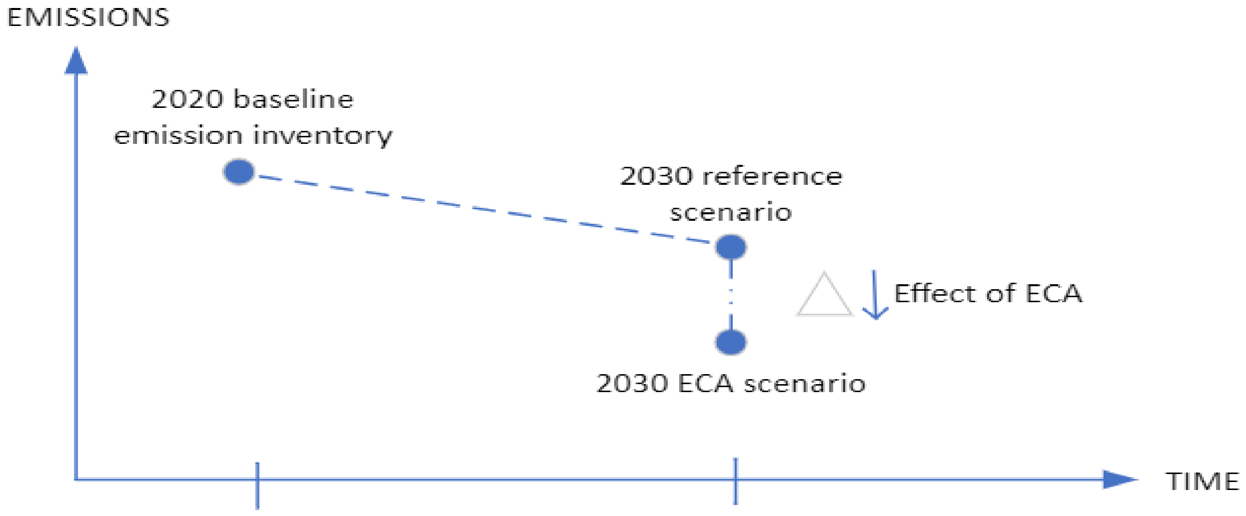

Figure 7-2 Principle for emission scenario developments

The emission reduction potentials of introducing an NOx-, SOx- and PM emission control area in the Norwegian Sea are found based on the 2019 ship activity and emission baseline, and then adjusted in three steps:

1) **Establish the 2020 baseline emission inventory**. The baseline emission inventory applies AIS ship activity data for 2019 as a starting point due to the 2020/21 activity being less representative because of the COVID-19 pandemic. In addition, the 2019 emission inventory is adjusted for the 2020 sulphur cap as specified under MARPOL Annex VI with a subsequent reduction in SOx and PM emissions.
2) **Establish the 2030 reference scenario.** Covering ship emissions without ECA requirements. The reference scenario incorporates expected changes in the future fleet activity levels, and changes in uptake of fuels, technologies, and ship operations. This is based on currently implemented national and international drivers and regulations. These drivers and regulations include, but are not limited to:
    - International carbon intensity regulations, such as EEDI, EEXI, EU-ETS and CII requirements
    - National policies and incentives, such as the NOx-Fund, and the ongoing electrification of ferries
    - Development in ship traffic
3) **Establish the 2030 ECA scenario**. The 2030 ECA scenario is built on adjusting the uptake of fuels, technologies and operational changes assumed in the 2030 reference scenario, to account for the expected impacts of new ECA regulations. The difference between 2030 reference scenario and the 2030 ECA scenario is used for further analysis of impacts.

The framework for ship traffic analysis and modelling of ship emissions and reduction potentials is centered around the DNV's *MASTER* model (Mapping of Ship Tracks, Emissions and Reduction potentials). The MASTER model (DNV (2008), Mjelde, Martinsen, & Endresen (2014) and DNV GL (2018a)) uses ship movement data from the Automatic Identification System (AIS), detailed ship specific information from IHS Fairplay and supporting data tables to estimate the energy demand, fuel consumption and emissions of the individual ship while sailing and when in port. The AIS system provides a detailed and high-resolution overview of all ship movements, where sailing speeds, operating patterns, sailed distances (nautical miles) and time spent in various areas are identifiable for each ship having the AIS system installed[11]. AIS is mandatory for ships of 300GT and upwards engaged in international voyages and for all cargo ships of 500 GT or more. In addition, AIS is also used by many smaller ships on voluntary basis so that the results will include the majority of ships

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[11] Carriage requirements for shipborne navigational systems and equipment, https://www.imo.org/en/OurWork/Safety/Pages/AIS.aspx

operating in the area. The information from the AIS system is merged with technical databases for detailed information on the individual ship, such as installed power on main and auxiliary engines, boilers, machinery configurations, ship design speed, main fuel type, specific fuel consumption, Engine International Air Pollution Prevention certificates, tonnage, etc.

The AIS data enriched with ship register data, provides the basis for modelling the propulsion power demand for the individual AIS registered ship position. Translating the propulsion energy demand into fuel consumption, will also require input from the supply side (i.e., number of engines in operation, load on the engines, mechanical/diesel electric configurations, technologies, fuel types, etc.). Additional data and methods are needed when estimating the onboard auxiliary and boiler demands. This varies from ship to ship (i.e., transporting cargo, transporting passengers, service missions, etc.), ranging from providing a safe support for onboard systems to ensuring hotel facilities for crew and passengers. The auxiliary and boiler demands will also depend on operation mode, and for some ship type increase in port mode (i.e., under loading and unloading of cargo, crane operations, etc.). This allows for aggregation of individual ship fuel consumption and emissions, as well as on ship type and size categories, geographical areas, and for detailed voyage analysis.

7.1.2 2020 baseline emission inventory

Approximately 3450 unique ships (with IMO numbers) have been identified operating in the proposed ECA area. Table 7-1 presents the key performance characteristics for these ships, presented as the 2020 baseline emission inventory which contribute to ambient concentrations of air pollution or to adverse environmental impacts in the Norwegian Sea. The modelling of ship traffic, fuel consumption and emissions shows that the fleet in the 2020 baseline inventory consume about 1.3 million tonnes of marine fuels (Mtoe) contributing to the emission of 58 kilo-tonnes of NOx, 5.2 kilo-tonnes of SOx, 3.6 kilo-tonnes of PM_{10} and 3.3 kilo-tonnes of $PM_{2.5}$.

The wet/dry bulk segment is dominating in terms of fuel consumption, this consisting of relatively large ships being 10,000 gross tonnage or more. The larger wet-/dry bulk ships mostly operate in the IMO-approved traffic separation system[12] situated about 20 nautical miles or more from the Norwegian coast, as indicated in Figure 8-3. Amongst the wet-/dry bulk ships, the bulk ships and crude oil tankers are the largest contributors to NOx, SOx and particle emissions. However, the LNG tankers are by far the largest energy users in the Wet/dry bulk segment, but since most of the LNG ships have dual fuel engines or turbines using boil-off gas, their contribution to NOx, SOx and particle emissions are relatively low.

Table 7-1 2020 baseline emission inventory for the Norwegian Sea of application

Ship type	No of ships	Sailed distance (nautical miles)	AIS observed time (hours)	Fuel consumption (tonnes)	Ship emissions (tonnes)			
					NOx	**SOx**	**PM_{10}**	**$PM_{2.5}$**
1-Wet-/dry bulk ships	950	3,667,000	526,600	475,600	20,250	2,130	1,640	1,490
2-General cargo ships	830	5,086,000	1,042,000	157,900	7,120	830	420	390
3-Passenger ships	260	5,663,000	1,810,000	172,300	8,710	600	360	330
4-Cruise ships	110	369,000	70,000	78,800	5,090	700	430	390
5-Offshore ships	220	760,000	435,000	121,300	4,490	320	240	220
6-Fishing vessels	630	4,712,000	2,389,000	178,800	7,570	330	270	260
7-Other ships	450	2,456,000	1,388,000	114,900	4,620	320	210	190
Grand Total	**3,450**	**22,713,000**	**7,660,600**	**1,299,600**	**57,850**	**5,230**	**3,570**	**3,270**

The ship fuel consumption split on ship type and size segments are shown in Table 7-2. The table shows that about 38% of the fuel consumption is related to operation of relatively small ships, below 5,000 gross tonnes. These ships typically consume distillate fuels.

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[12] https://kystverket.no/en/navigation-and-monitoring/vts---vessel-traffic-service/sailing-rules/

Table 7-2 Distribution of fuel consumption on ship type and size segments

Ship type \ Size segment	< 1,000 GT	1,000 – 4,999 GT	5,000 – 9,999 GT	10,000 – 24,999 GT	25,000 – 49,999 GT	50,000 – 99,999 GT	>= 100,000 GT	Grand Total
1-Wet-/dry bulk ships	0.3 %	1.7 %	1.4 %	4.2 %	5.6 %	6.5 %	16.8 %	36.6 %
2-General cargo ships	0.5 %	7.5 %	2.9 %	1.0 %	0.2 %	0.0 %	0.1 %	12.1 %
3-Passenger ships	2.8 %	3.1 %	1.3 %	6.1 %	0.0 %	0.0 %	0.0 %	13.3 %
4-Cruise ships	0.0 %	0.0 %	0.5 %	0.7 %	1.3 %	2.2 %	1.3 %	6.1 %
5-Offshore ships	0.1 %	3.1 %	3.3 %	1.2 %	0.2 %	1.2 %	0.2 %	9.3 %
6-Fishing vessels	3.6 %	9.8 %	0.3 %	0.0 %	0.0 %	0.0 %	0.0 %	13.8 %
7-Other ships	1.7 %	3.7 %	0.7 %	1.3 %	1.4 %	0.1 %	0.0 %	8.8 %
Grand Total	**9.0 %**	**28.9 %**	**10.5 %**	**14.5 %**	**8.8 %**	**9.9 %**	**18.4 %**	**100.0 %**

The total fuel consumption for the ships operating in the Norwegian Sea has been split on main types of fuel consumed and on engine types. Table 7-3 shows that more than 50% of the fuel consumption are of MDO/MGO quality, LNG or boil of gas, regarded as SOx ECA compliant fuels. Less than 20% of the fuel is consumed by 2-stroke engines typically being large and efficient slow-speed engines which have higher NOx emissions than medium or high-speed 4-stroke engines. This is accounted for in the modelling of NOx, SOx and particulate matter emissions.

Table 7-3 Distribution of fuel consumption of type of fuel and engine configuration (2 or 4 stroke)

Ship type / Engines	2-stroke	4-stroke	Not identified	Totals
MDO/MGO	3 %	31 %	1 %	34 %
LNG/BOG	3 %	17 %	1 %	21 %
Residual fuels ULSFO	1 %	16 %	0 %	18 %
Residual fuels VLSFO	14 %	13 %	0 %	27 %
Grand Total	**21 %**	**76 %**	**3 %**	**100 %**

Table 7-4, Table 7-5 and Table 7-6 shows the percentage distribution in emissions of NOx, SOx and particles respectively, between the different ship type and size categories. As can be seen from the tables, the wet/dry bulk ship category accounts for around a third of the total NOx emissions in the analysis area and over 40% of the SOx and particle emissions. This category consists of ships that are typically 10,000 gross tonnes or more.

Table 7-4 Distribution of NOx emission on ship type and size segments

Ship type \ Size segment	< 1,000 GT	1,000 – 4,999 GT	5,000 – 9,999 GT	10,000 – 24,999 GT	25,000 – 49,999 GT	50,000 – 99,999 GT	>= 100,000 GT	Grand Total
1-Wet-/dry bulk ships	0.3 %	1.5 %	1.4 %	6.1 %	9.6 %	9.8 %	6.4 %	35.0 %
2-General cargo ships	0.5 %	7.0 %	2.9 %	1.6 %	0.3 %	0.0 %	0.1 %	12.3 %
3-Passenger ships	2.8 %	2.9 %	0.2 %	9.1 %	0.0 %	0.0 %	0.0 %	15.1 %
4-Cruise ships	0.0 %	0.0 %	0.5 %	0.8 %	1.9 %	3.4 %	2.2 %	8.8 %
5-Offshore ships	0.1 %	3.0 %	2.5 %	1.1 %	0.2 %	0.6 %	0.2 %	7.8 %
6-Fishing vessels	3.3 %	9.5 %	0.3 %	0.0 %	0.0 %	0.0 %	0.0 %	13.1 %
7-Other ships	1.7 %	3.4 %	0.6 %	1.0 %	1.2 %	0.1 %	0.1 %	8.0 %
Grand Total	**8.7 %**	**27.2 %**	**8.4 %**	**19.6 %**	**13.3 %**	**13.9 %**	**9.0 %**	**100.0 %**

Table 7-5 Distribution of SOx emission on ship type and size segments

Ship type \ Size segment	< 1,000 GT	1,000 – 4,999 GT	5,000 – 9,999 GT	10,000 – 24,999 GT	25,000 – 49,999 GT	50,000 – 99,999 GT	>= 100,000 GT	Grand Total
1-Wet-/dry bulk ships	0.1 %	1.8 %	2.1 %	8.8 %	13.9 %	12.2 %	1.6 %	40.6 %
2-General cargo ships	0.2 %	9.6 %	3.9 %	1.5 %	0.5 %	0.0 %	0.1 %	15.8 %
3-Passenger ships	1.2 %	1.3 %	0.2 %	8.7 %	0.1 %	0.0 %	0.0 %	11.5 %
4-Cruise ships	0.0 %	0.0 %	0.5 %	1.7 %	3.2 %	4.7 %	3.3 %	13.3 %
5-Offshore ships	0.1 %	1.4 %	1.1 %	1.0 %	0.2 %	1.8 %	0.6 %	6.2 %
6-Fishing vessels	1.6 %	4.5 %	0.3 %	0.0 %	0.0 %	0.0 %	0.0 %	6.4 %
7-Other ships	0.8 %	1.5 %	0.7 %	1.5 %	1.5 %	0.1 %	0.1 %	6.1 %
Grand Total	**4.0 %**	**20.1 %**	**8.7 %**	**23.2 %**	**19.4 %**	**18.9 %**	**5.8 %**	**100.0 %**

Table 7-6 Distribution of PM (PM_{10} & $PM_{2.5}$) emission on ship type and size segments

Ship type \ Size segment	< 1,000 GT	1,000 – 4,999 GT	5,000 – 9,999 GT	10,000 – 24,999 GT	25,000 – 49,999 GT	50,000 – 99,999 GT	>= 100,000 GT	Grand Total
1-Wet-/dry bulk ships	0.2 %	1.4 %	1.6 %	8.3 %	12.6 %	11.6 %	10.3 %	45.9 %
2-General cargo ships	0.3 %	6.9 %	3.0 %	1.1 %	0.4 %	0.0 %	0.1 %	11.9 %
3-Passenger ships	1.5 %	1.7 %	0.7 %	6.1 %	0.1 %	0.0 %	0.0 %	10.1 %
4-Cruise ships	0.0 %	0.0 %	0.3 %	1.5 %	2.9 %	4.3 %	3.0 %	12.0 %
5-Offshore ships	0.1 %	1.8 %	1.8 %	0.7 %	0.2 %	1.7 %	0.5 %	6.7 %
6-Fishing vessels	2.0 %	5.4 %	0.3 %	0.0 %	0.0 %	0.0 %	0.0 %	7.7 %
7-Other ships	0.9 %	2.0 %	0.7 %	1.1 %	0.8 %	0.1 %	0.1 %	5.7 %
Grand Total	**4.9 %**	**19.1 %**	**8.4 %**	**18.8 %**	**17.0 %**	**17.7 %**	**14.0 %**	**100.0 %**

7.1.3 2030 ECA scenario

The designation of an ECA to prevent, reduce and control emissions of NOx, SOx and PM from ships in the Norwegian Sea will have different timelines of effectiveness depending on the emission components. In this study, the ECA implementation is anticipated to take place in 2030.

Immediate effects caused by the ECA requirements

The SOx emission is directly linked to the sulphur content in the fuels, and the SOx emissions will be reduced either by switching to sulphur compliant fuels or by using exhaust gas cleaning systems. The share of residual fuels in the 2020 baseline was estimated to be about 44% of the total fuel consumption, and that this fuel contains 0.5% sulphur, ref. Table 7-3. The share of residual fuels in the 2030 ECA scenario is anticipated not to change significantly from the 2020 baseline scenario. As result, the SOx emission in the 2030 ECA scenario will be reduced from 4,600 tonnes/year to 1,690 tonnes/year by converting the sulphur content of the residual fuels from 0.5% to 0.1% sulphur.

As the PM emissions are closely linked to the fuel quality and sulphur content, the PM emissions are assumed to be reduced accordingly (IMO, 2020). Similarly, the use of exhaust gas cleaning systems to reduce SOx emissions will also reduce the PM emissions when in operation. The PM reductions are estimated using the same approach as for the SOx emissions and by applying the fuel- and sector-based emission factors for PM_{10} and $PM_{2.5}$ as provided by the EMEP/EEA guidebook 2019 (EMEP, 2019). As a result, the PM emissions will be reduced from 3,100 tonnes/year to 1,800 tonnes/year (PM_{10}) and 2,840 tonnes/year to 1,650 tonnes/year ($PM_{2.5}$).

Future effects caused by the ECA requirements

The introduction of a NOx emission control area will mean gradual phasing-in of ships that meet NOx Tier III requirements, as only new ships or new engine installations/major engine conversions will be subject to the regulations. The NOx emission reductions depend solely on the rate at which newbuilds or ships with modified engines operates in the area. The NOx reduction will therefore come gradually over the following years after the introduction of the NOx ECA (proposed 2030), and mainly follow the uptake of newbuilds or when major modifications on engine NOx critical components are made. The NOx control requirements of Annex VI apply to installed marine diesel engine of over 130 kW output power. The NOx emission for Tier III compliant engines is about 80% below the Tier I engines (ship construction date on or after 1 January 2000) and about 74–77% below the Tier II engines (ship construction date on or after 1 January 2016).

To estimate the future effects of introducing the NOx ECA, the estimated NOx emissions follow a hypothetical full implementation called the **Maximum Feasible NOx Reduction Scenario (MFNR)**. The basis for the MFNR scenario is that all ships in the area are NOx Tier III compliant. This means that the NOx emissions will be reduced by at least 75% for all ships not already being NOx Tier III compliant. NOx Tier III compliant ships are typically low-pressure natural gas powered (LNG) engines or ships fitted with NOx emission reduction technologies such as Selective Catalytic reduction (SCR), Exhaust Gas Recirculation (EGR), etc. under the NOx -Fund scheme.

From the 2020 baseline analysis, about 21% of the of the fuel consumption stems from Tier III compliant ships which are powered by low-pressure natural gas engines or gas turbines, ref. Table 7-3. The NOx emissions from these ships represent about 6% of total NOx emissions in the area. In addition, there are other domestic operated Tier III compliant ships using SCR or other NOx reduction technologies. Based on this, the 2030 reference scenario estimated that a total of 10% of the NOx emissions come from ships already being Tier III compliant.

The 2030 NOx emission is estimated to 46,180 tonnes/year, whereof 90% is assumed to come from ships not being Tier III compliant. In the MFNR scenario, all ships become Tier III compliant resulting in a minimum 75% reduction for all ships not already being Tier III compliant. The estimated total NOx emission for the MFNR scenario is 16,500 tonnes/year, which represents a total NOx reduction of 68%. The age distribution of the world merchant fleet varies by ship type, and the average age of all ships in the world merchant fleet 2022 was just over 20 years (Statista, 2023). Though there are many ships operating in the area being older than 20 years, it could be anticipated the majority of these would be renewed over a 20-year period. As a result, using a linear projection, the fleet exchange could result in a yearly NOx reduction of **1,500 tonnes/year** from 2030 and onwards.

Uptake of alternative fuels and technologies will also have an impact on SOx and PM likely resulting in an emission reduction. This is however not accounted for in the MFNR scenario.

Table 7-7 Emissions in the Norwegian Sea, 2020 baseline emission inventory, 2030 reference scenario, the 2030 ECA scenario and the MFNR scenario. MFNR reflecting estimated ship traffic emissions following a hypothetical full NOx Tier III implementation

Emission component	2020 baseline (tonnes/year)	2030 reference scenario (tonnes/year)	2030 ECA scenario (tonnes/year)	Maximum Feasible NOx Reduction scenario (tonnes/year)
NOx emissions (tonnes)	57,850	46,180	46,180	16,500
SOx emission (tonnes)	5,230	4,600	1,690	-
PM_{10} emissions (tonnes)	3,570	3,100	1,800	-
$PM_{2.5}$ emissions (tonnes)	3,270	2,840	1,650	-

7.2 Environmental modelling

7.2.1 The EMEP model

Dispersion and deposition of various atmospheric components have been calculated with the EMEP model rv4.45. This is an open-source chemistry transport model developed at the Norwegian Meteorological Institute (https://github.com/metno/emep-ctm). A detailed model description is available in Simpson et al. (2012). The EMEP model is a Eulerian model in which the atmosphere is divided into grid boxes. Although the study area was Norwegian Sea north of 62°N and the Barents Sea, the total model domain covered most of Europe and the Arctic. In model calculations it is crucial to have a large domain to avoid numerical errors at the edges of the model domain. In addition, the model captures long-range transport of pollutants, for example from Central Europe and the UK. For the model calculations presented here, the domain had a grid size equal to 0.1° × 0.1° throughout the entire model domain. This corresponds to a grid box size of 3.8 km W-E × 11.1 km N-S at 70°N.

As input data to the model, meteorology for 2019 was applied. The meteorological data were generated by the Integrated Forecast System (IFS) model of the European Centre for Medium-Range Weather Forecasts (ECMWF), provided by the Norwegian Meteorological Institute. Gridded ship emissions for the Norwegian Sea were based on the ship traffic analysis described in chapter 7.1. For all other emission categories, the model used EMEP 2019 emission inventories from the 13-sector GNFR system (EMEP, 2021). The EMEP model was used to calculate concentrations of numerous atmospheric species, including trace gases in the NOx -VOC-O_3 tropospheric chemistry cycle, SOx and particulate matter (PM).

The EMEP model was run for three different emission inventories for a full year:

- 2030 Reference scenario
- 2030 ECA scenario
- No ship emission scenario

The difference between 2030 Reference scenario and 2030 ECA scenario will quantify the effects of the ECA regulation.

7.2.2 Nitrogen oxides

Nitrogen oxides (NO and NO_2) emitted from combustion of fuels under high temperature originate from the nitrogen (N_2) and oxygen (O_2) in air. NOx emitted from ships are mostly in the form of NO (90-95 %). In the NOx emission inventory, there is no immediate emission reduction from implementation of the NOx ECA regulation as only new ships or new engine installations/major engine conversions will be subject to the regulations. The lifetime of NOx in the atmosphere is typically of the order of one day. Figure 7-3 NOx emissions from ships for the 2030 reference scenario, EMEP model input. Unit: mg/m2 shows the NOx emissions in the Norwegian Sea for the 2030 reference scenario gridded with a resolution of 0.1x0.1 degree.

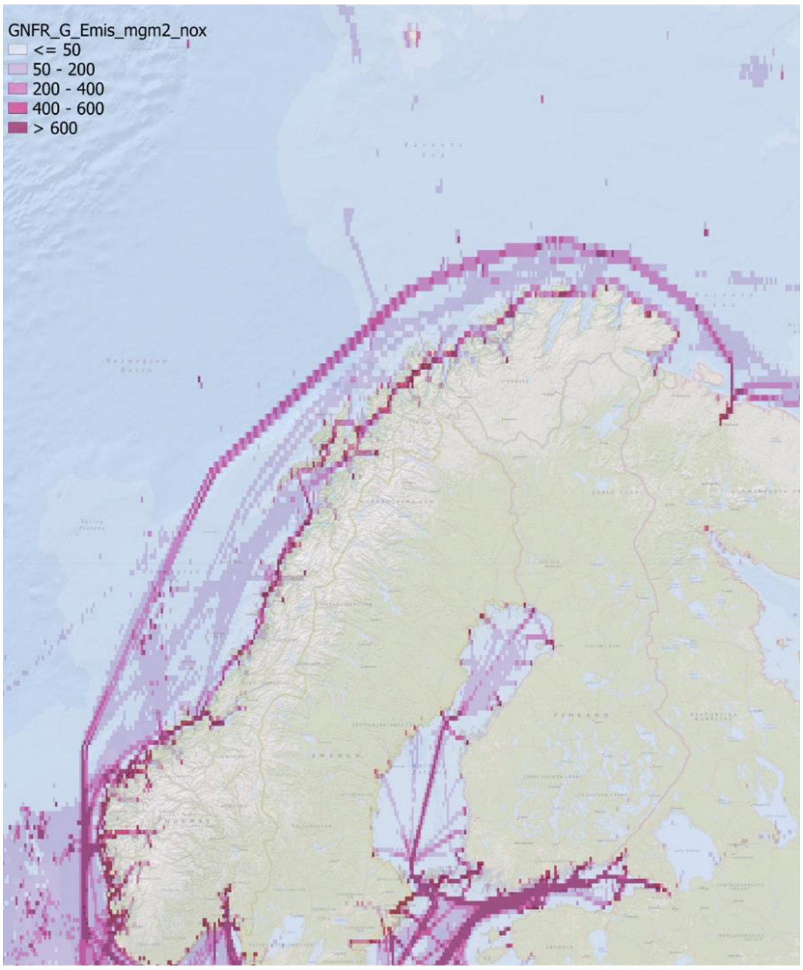

Figure 7-3 NOx emissions from ships for the 2030 reference scenario, EMEP model input. Unit: mg/m^2

The ground level concentrations of NOx are shown in Figure 7-4. Elevated concentrations are found in urban and industrial areas, whereas rural areas and Northern Norway generally show low values. The sources areas for ships are clearly visible for NO (Figure 7-4 left panel). As already stated, 90–95% of NOx is emitted as NO giving high NO concentrations along ship tracks. In general, the ground level concentrations in the ECA area north of 62°N are lower than EU/Norwegian threshold values and also below Norwegian air quality criteria.

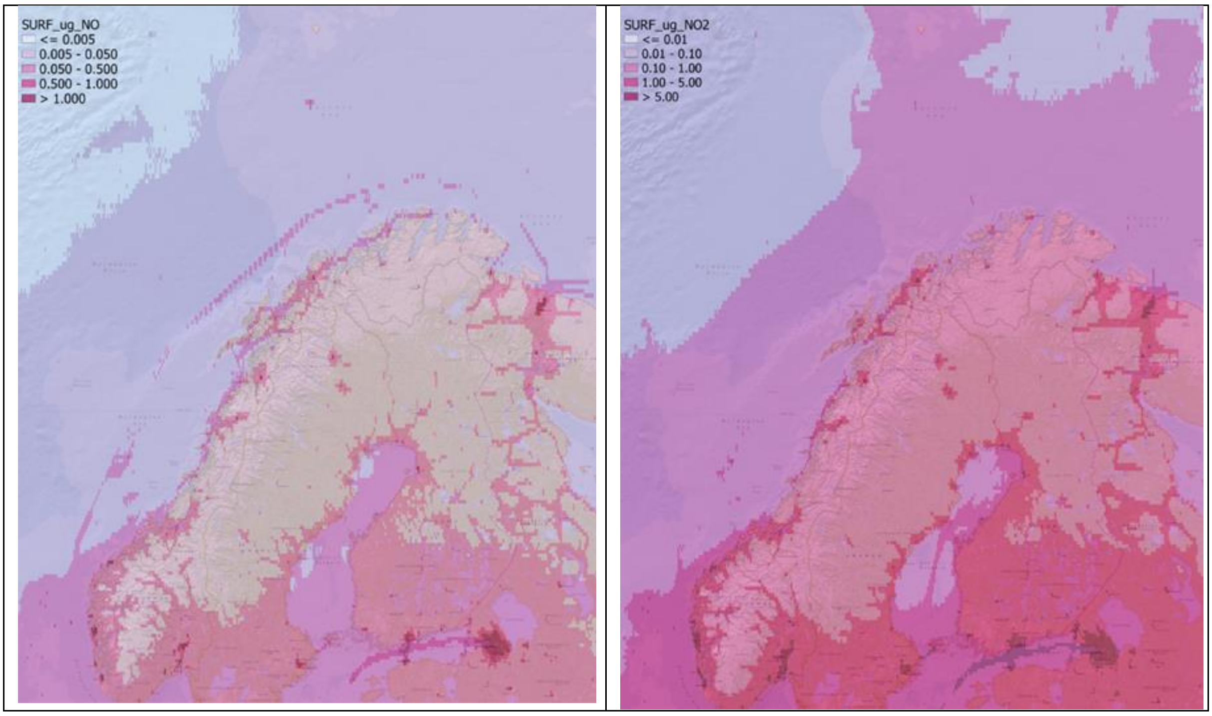

Figure 7-4 Ground level concentrations of NOx, NO (left panel) and NO_2 (right panel), all sources included. The maps show concentrations for the Nordic countries, W Russia and Baltic countries, but this study focus on the areas north of 62°N merely. Please note different scales in the two plots. Unit: µg/m^3.

Dry and wet deposition of nitrogen

Nitrogen contributes to eutrophication of rivers/lakes and the terrestrial environment, i.e. excess nitrogen that acts as a fertilizer. Nitrogen enters the aquatic and terrestrial environment through deposition. Dry deposition, i.e. deposition of nitrogen onto surfaces, and wet deposition, i.e. uptake in droplets and rainout by precipitation are two different processes. Dry deposition is dependent upon the surface concentration of the NO/NO_2, surface properties and deposition velocities of NO/NO_2. Wet deposition is dependent upon solubility of the gas and rainfall pattern. Hence the results for dry and wet deposition show very different geographical patterns (Figure 7-5).

The deposition of nitrogen in Northern Norway is generally low and the soil and flora are adapted to low levels of nitrogen. Eutrophication, excess levels of nitrogen, may alter the plant flora in the way that robust plants that tolerate high levels of nitrogen will dominate over plants that are adapted to nitrogen-poor environment. Eutrophication constitutes a threat to the environment and levels of nitrogen in the environment have increased over the past decades. Any reduction of nitrogen, also from ships, will be beneficial for the terrestrial environment (both rivers, lakes and soil) with regard to eutrophication.

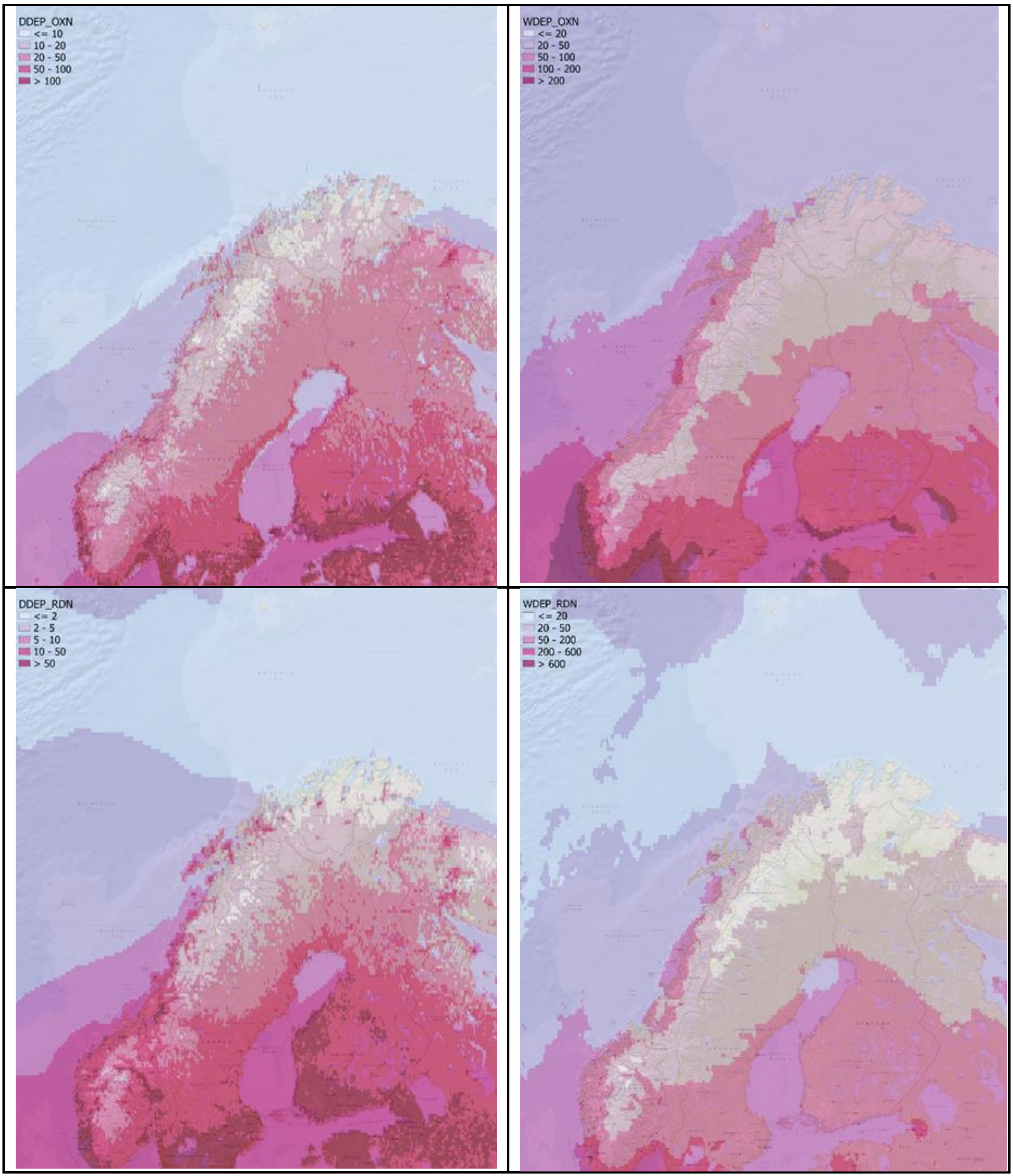

Figure 7-5 Total dry deposition of oxidized nitrogen (upper left panel), reduced nitrogen[13] (lower left panel), and wet deposition of oxidized nitrogen (upper right panel), and reduced nitrogen (lower right panel), 2030 Reference scenario. Please note the difference in scale in the different plots. Unit: mg(N)/m^2.

The **Maximum Feasible NOx Reduction Scenario (MFNR)** follow a hypothetical full NOx Tier III implementation in 2030. This reduces the NOx emissions from shipping from 46,180 tonnes per year to 16,100 tonnes per year, ref. Table 7-7. This means a reduction by 2/3. Concerning ground level concentrations and air quality, especially in urban areas, such

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[13] In plants, nitrogen is found in different oxidation states ranging from nitrate (NO_3-, the most oxidized form) to ammonia (NH_4-, the most reduced form). Reduced nitrogen, like e.g. ammonia and ammonium, is most available for plant uptake and hence play an important role in plant growth.

reduction will only have a minor impact. However, concerning deposition of nitrogen, where emission from ships can add up to a 10 % contribution, a reduction according to MFNR will have an effect in certain areas.

7.2.3 Sulphur oxides

The term SO_x in this study includes mainly sulphur dioxide (SO_2), but there will also be a few percent of oxidized sulphur like SO_3 and SO_4 in the flue gas emitted from ships. In the atmosphere SO_2 is oxidized to sulphate (SO_4^{2-}) in the gas phase by OH, and in the aqueous phase by e.g. H_2O_2, O_3, HO_2NO_2 and catalytic metals (Berglen et al., 2004). The lifetime of SO_2 is typically one day, the lifetime of sulphate depends upon concentration, precipitation and the wet removal rate, but is typically of the order of days (again Berglen et al., 2004).

The SO_x emissions applied in the model runs are shown in Figure 7-6, i.e. emissions for all sectors 2030 Reference scenario. In the ECA domain, there are two main source regions for ship emissions; a) along the coast and b) the major ship tracks 20 – 60 nautical miles offshore. The emissions from oil and gas production units are also clearly visible, seen as colored “dots” in the figure. The emission inventory for all sectors also includes SO_2 emissions from smelter activity in N-W Russia, close to the Norwegian border. Note that the smelter in Nikel (Ru) closed down in December 2020, also the emissions from smelter activity in Monchegorsk (Ru) south of Murmansk have been reduced. Hence the background impact from these land-based sources in the Arctic has decreased.

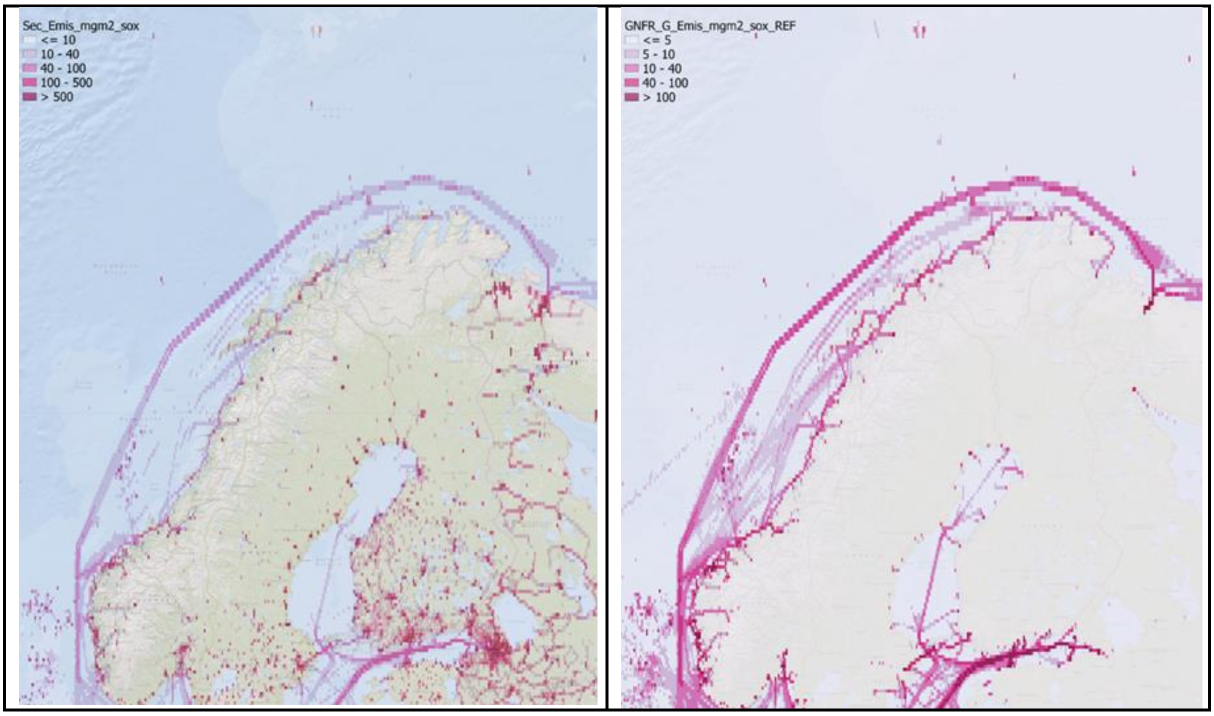

Figure 7-6 Annual SOx emissions applied in the EMEP model calculations, all sectors (left panel) and 2030 Reference ship emissions (right panel). Please note different scale in the two plots. Unit: mg/m^2.

The ground level concentrations of SO_2 and sulphate are shown in Figure 7-7. The levels of sulphur reflect to a large extent the emission pattern with high values over source regions like the Kola Peninsula (Ru), St Petersburg (Ru) and specific urban and industrial areas.

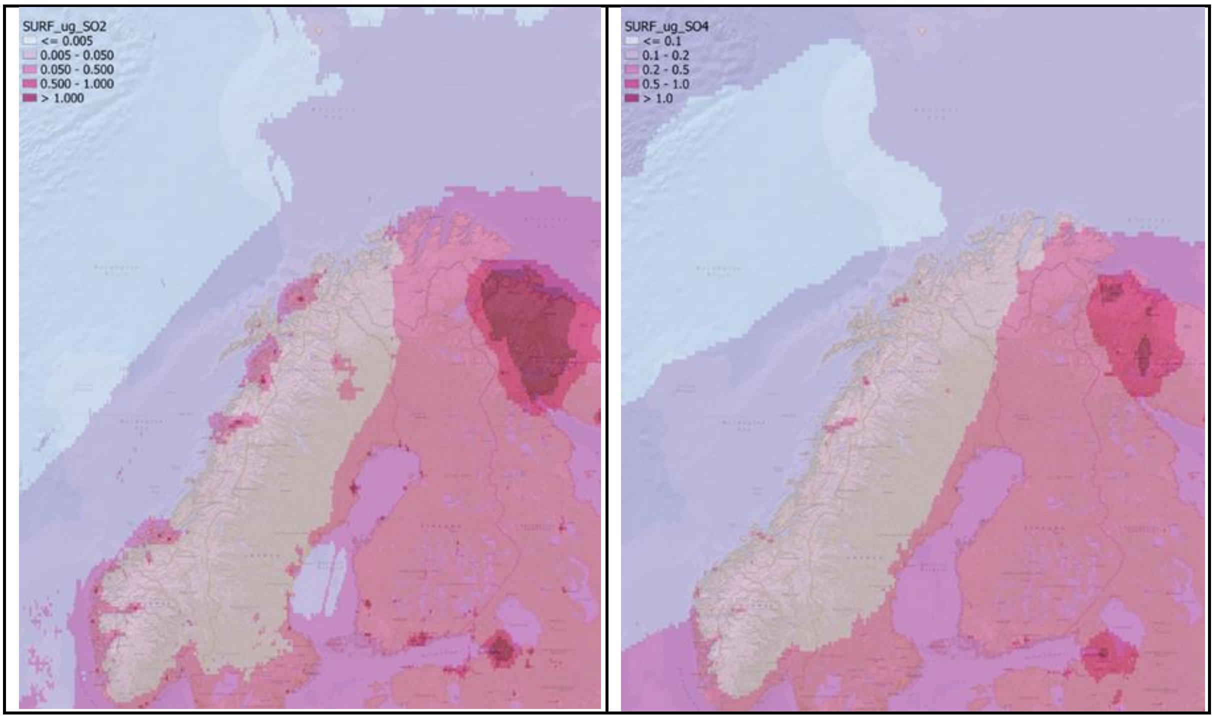

Figure 7-7 Total ground level concentration of SO_2 (left panel) and sulphate (right panel). Unit: µg/m^3.

To show the impact from ECA regulations, the differences concerning SO_2 and sulphate concentrations between the Reference 2030 and the ECA 2030 inventories are shown in Figure 7-8. The only difference between the two model calculations is the SOx emission inventory north of 62°N. Given that the lifetime of SO_2 is approximately a day, sulphur a few days, the reduced concentrations occur mainly within the ECA domain. Sulphate is mostly a secondary component and the areas with a visible reduction are larger than for SO_2, see Figure 7-8 left panel showing SO_2 vs. Figure 7-8 right panel showing sulphate. The most important reductions occur in the Møre coastal areas (62–63°N) including the Geiranger fjord, but also the Trondheim area (64°N), ship tracks to and from Narvik, and Tromsø show a certain reduction in surface concentrations of sulphur. Maximum calculated reduction in ground level SO_2 is 0.6 µg/m^3. This is a very small reduction in absolute numbers. It must be noted however that the concentration of SO_2 generally is low in cities in Norway.

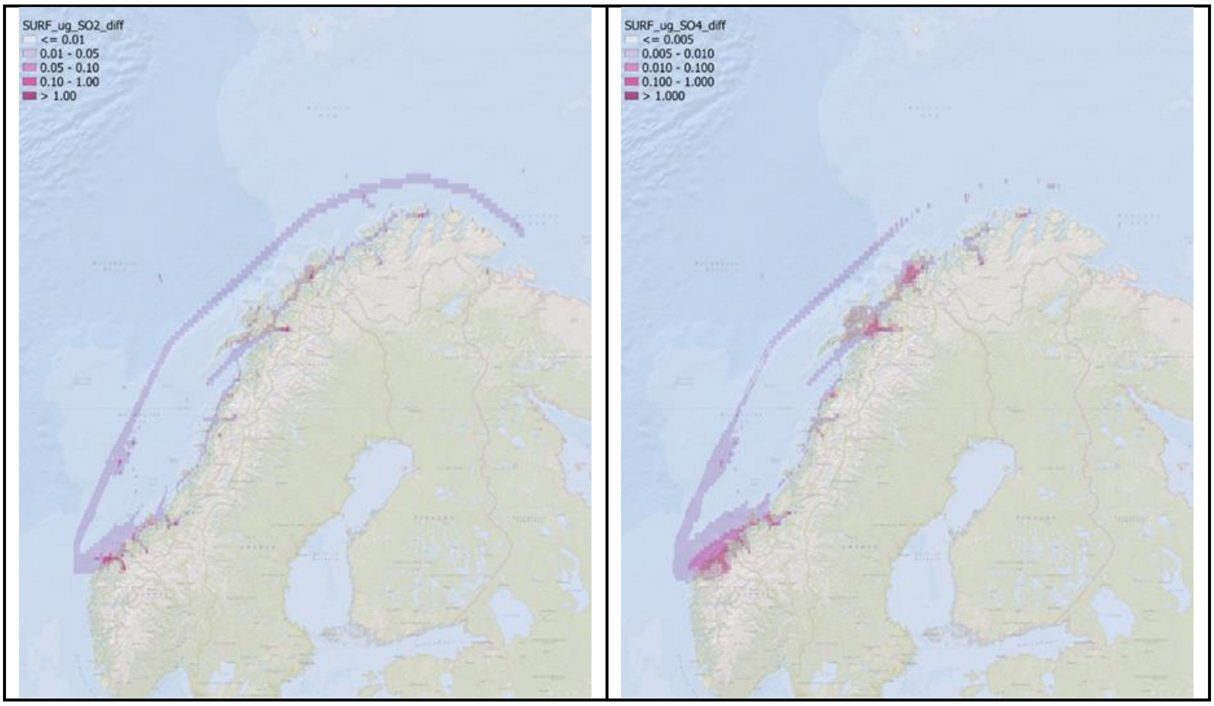

Figure 7-8 Reduction in annual mean concentrations of SO_2 (left panel) and sulphate (right panel) due to implementation of ECA regulations, i.e. difference between Reference 2030 and ECA 2030 inventories. Unit: $\mu g/m^3$.

Dry and wet deposition of sulphur

Sulphur contributes to acidification of rivers/lakes and the terrestrial environment. Sulphur enters the aquatic and terrestrial environment both through dry and wet deposition. Dry deposition, i.e. deposition of sulphur onto surfaces, and wet deposition, i.e. uptake in droplets and rainout by precipitation are two different processes. Hence the results for dry and wet deposition show very different geographical pattern, Figure 7-9. In the ECA domain, dry deposition of sulphur is more important than wet deposition (Figure 7-9, left panel vs. right panel).

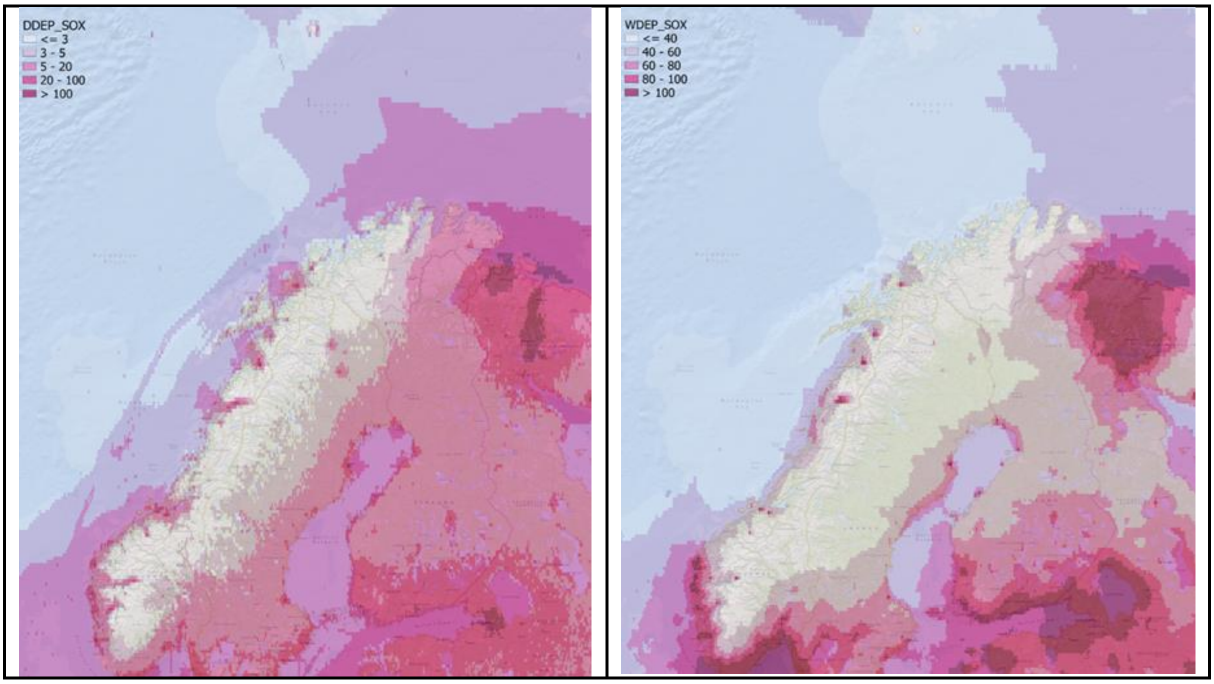

Figure 7-9 Total dry deposition of sulphur (left panel) and wet deposition (right panel). Please note the difference in scale in the different plots. Unit: mg(S)/m^2.

The reduction of sulphur deposition due to ECA regulations occur close to the ship tracks, as shown in Figure 7-10. The most important reductions are seen along the major ship track offshore, as well as in the Møre coastal areas (62–63°N) including the Geiranger fjord, the Trondheim area (64°N), ship tracks to and from Narvik, and Tromsø. These are the same areas that show reduced ground level concentrations. There is hardly any reduction of sulphur deposition inland due to ECA regulations, Figure 7-10.

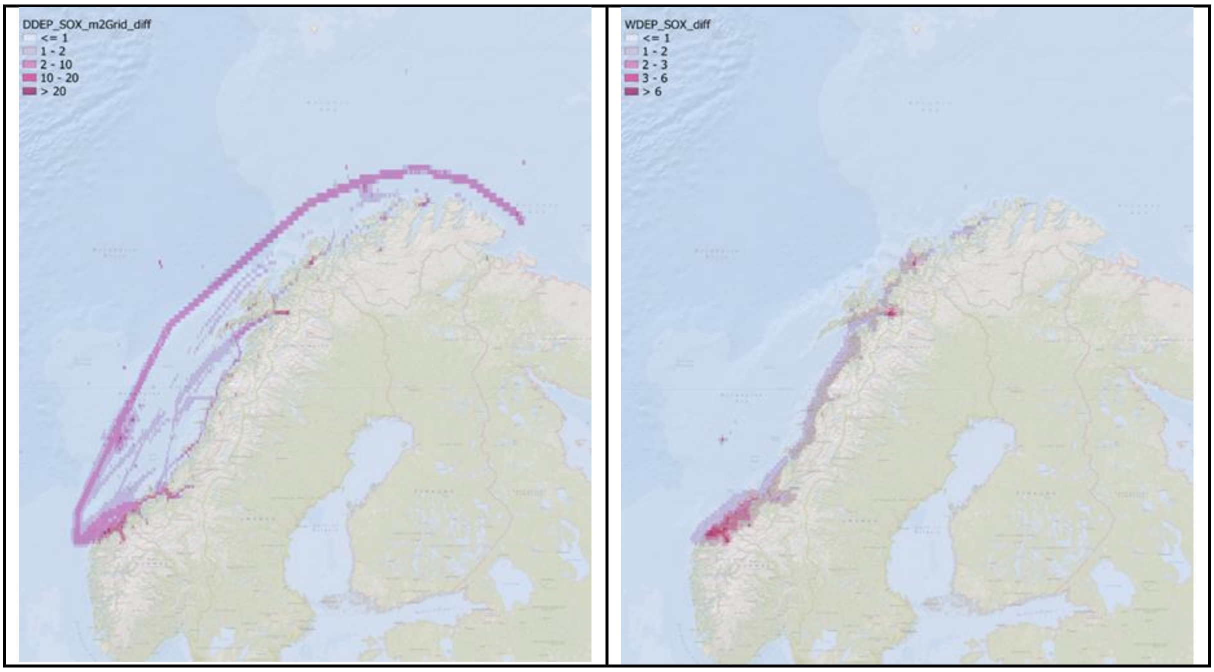

Figure 7-10 Reduction in dry deposition (left panel) and wet deposition (right panel) due to implementation of ECA regulations, i.e. difference between Reference 2030 and ECA 2030 inventories. Please note the difference in scale in the different plots. Unit: mg(S)/m^2

7.2.4 Particulate matter

Particulate matter (PM) is often categorised according to size. $PM_{2.5}$ is characterised as fine particles[14] while PM_{10} is categorised as coarse particles. In some studies, concerning e.g. health, also smaller size particles (PM_1) are taken into account, but this is beyond the scope of the application.

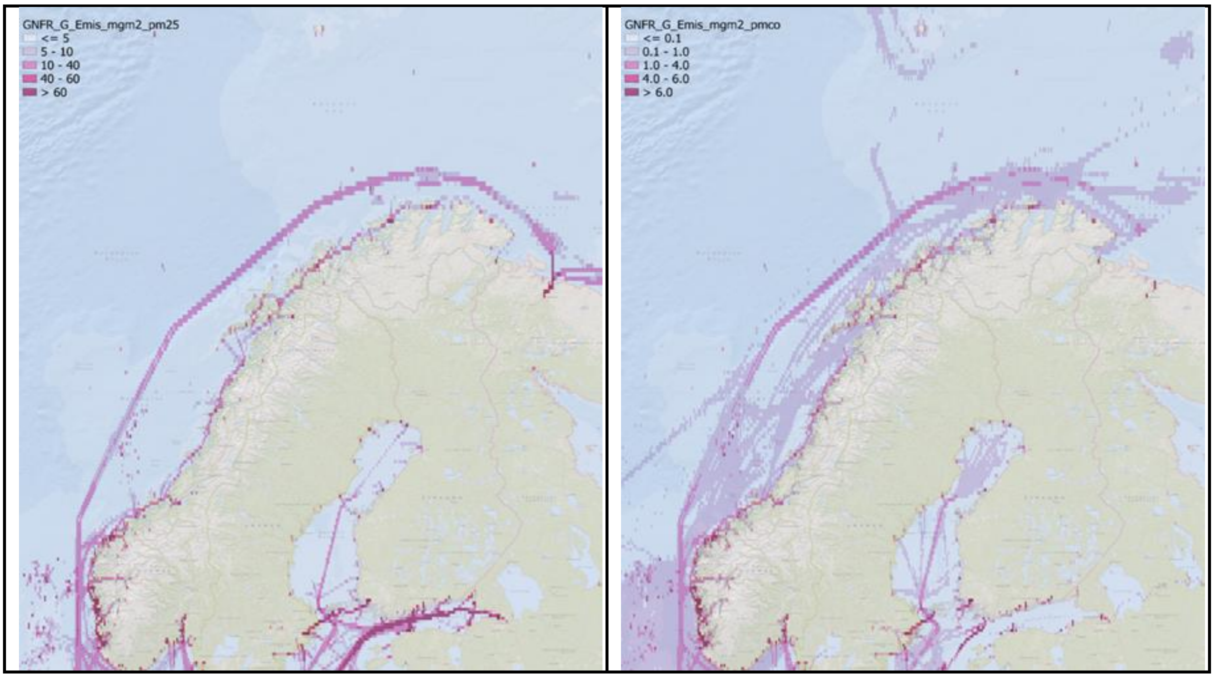

Figure 7-11 Annual ship emissions of $PM_{2.5}$ (left panel) and $PM_{2.5-10}$, i.e. particles with aerodynamical diameter between 2.5 and 10 µm (right panel) applied in the EMEP model runs. Please note different scale in the two plots. Unit: mg/m^2.

The size of the particles is very much dependent on the source. Fine particles ($PM_{2.5}$) is often a product of combustion, but also particle growth, e.g. organic particles that forms from gas phase oxidation, form a nuclei, then grow further by condensation and/or stick to other small particles. Coarse particles over ocean are mainly sea salt particles. Over land road traffic and industry and mining are significant anthropogenic sources of coarse particles. The distribution of ship PM emissions applied in this study are shown in Figure 7-11.

Calculated ground level concentrations of PM_{10} (coarse) and $PM_{2.5}$ (fine), all sources included, are given in Figure 7-12. For coarse particles the maximum values are seen over ocean. This is mainly sea salt particles generated by wind and waves. For fine particles ($PM_{2.5}$) there are also high concentrations over ocean at mid-latitudes, but urban and industrial areas are clearly visible in the plot (Figure 7-12 left panel).

The lifetime of particles in the atmosphere is typically of the order of days. The lifetime depends among other factors on particle size/mass (that determines gravitational settling) and hygroscopic properties (that determines uptake in cloud droplets and wet deposition loss). The concentrations in land areas important for the ECA application are generally low, i.e. maximum 3-4 µg/m^3, except for specific urban areas.

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[14] $PM_{2.5}$ are particles with aerodynamic diameter less than 2.5 µm. PM_{10} are particles with aerodynamic diameter less than 2.5 µm. Note that $PM_{2.5}$ is included in PM_{10}.

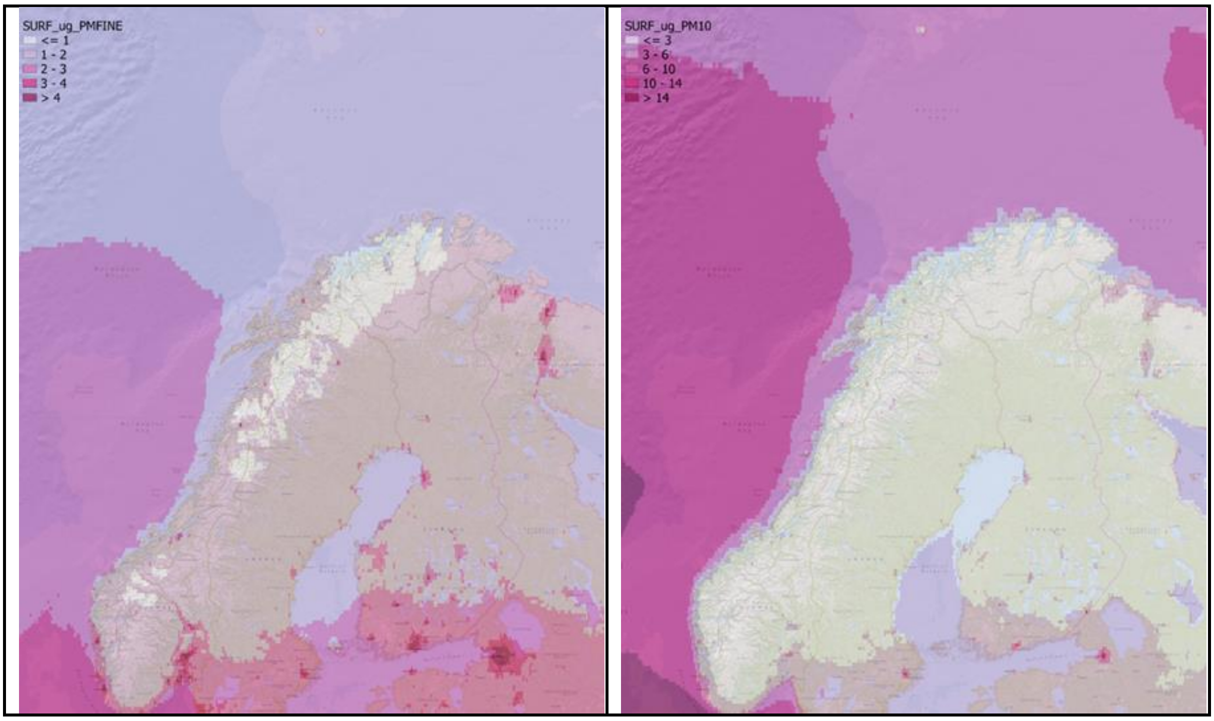

Figure 7-12 Ground level concentrations of $PM_{2.5}$ (fine, left panel) and PM_{10} (coarse, right panel) in the model, all sources included. Please note different scales in the two plots. Unit: µg/m^3.

The emissions from ships are mainly in the $PM_{2.5}$ fraction given that the particles originate from combustion mostly (see difference between the two panels in Figure 7-11). The impact from ECA regulation, i.e. difference between the Reference 2030 and ECA 2030 is shown in Figure 7-13. In general, the reduction in ground level concentrations is relatively small, i.e. less than 0.5 µg/m^3. The most important reduction is seen in specific areas like the Geiranger fjord, the ship track to and from Narvik and cities like Trondheim and Tromsø.

The annual mean concentrations of $PM_{2.5}$ in cities along the coast (Ålesund, Trondheim, Mo i Rana, Narvik, Harstad, Tromsø, Hammerfest[15]) is typically 4-6 µg/m^3. The values in background, rural areas are lower (Figure 7-12). In Norway the threshold value for $PM_{2.5}$ annual mean concentration is 10 µg/m^3. The Norwegian air quality criteria is 8 µg/m^3 for annual mean and 15 µg/m^3 for daily mean concentrations. This means that the air quality in Norwegian cities and ports in the ECA area along the coast is below the air quality threshold values and criteria.

However, the WHO recommended value is 5 µg/m^3 for annual mean concentration. In addition, EU and also Norwegian authorities (Norwegian Institute for Public Health, FHI and Norwegian Environment Agency) are in a process to propose new threshold values and air quality criteria for a range of pollutants, including PM_{10} and $PM_{2.5}$. These new threshold values will be introduced from 2030 and onwards. A number of cities and urban areas in Norway show concentrations of PM_{10} and $PM_{2.5}$ above these future threshold values.

The contribution from ships in Norwegian ports are minor compared to local sources like wood burning, car traffic (both studded tyres and exhaust), local industry and existing background values. The exhaust flue gas from ships in port is emitted at a certain height above ground with a certain vertical velocity and elevated outflow temperature. Hence the dispersion of pollutants emitted from ships are more effective than ground-based sources in coastal cities. Inversion is less frequent in areas close to the sea as compared to inland areas. Inversion is the phenomenon where atmospheric temperature increases with height giving very stable atmospheric conditions with slow vertical transport and hence slow dispersion.

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[15] https://luftkvalitet.nilu.no/overskridelse https://luftkvalitet.nilu.no/overskridelse

However, even though the contribution from ships is small, ship emissions will add to concentration levels that are just below or above future threshold values and present WHO recommendations. In that respect a reduction due to ECA regulations may contribute to improving air quality in coastal cities.

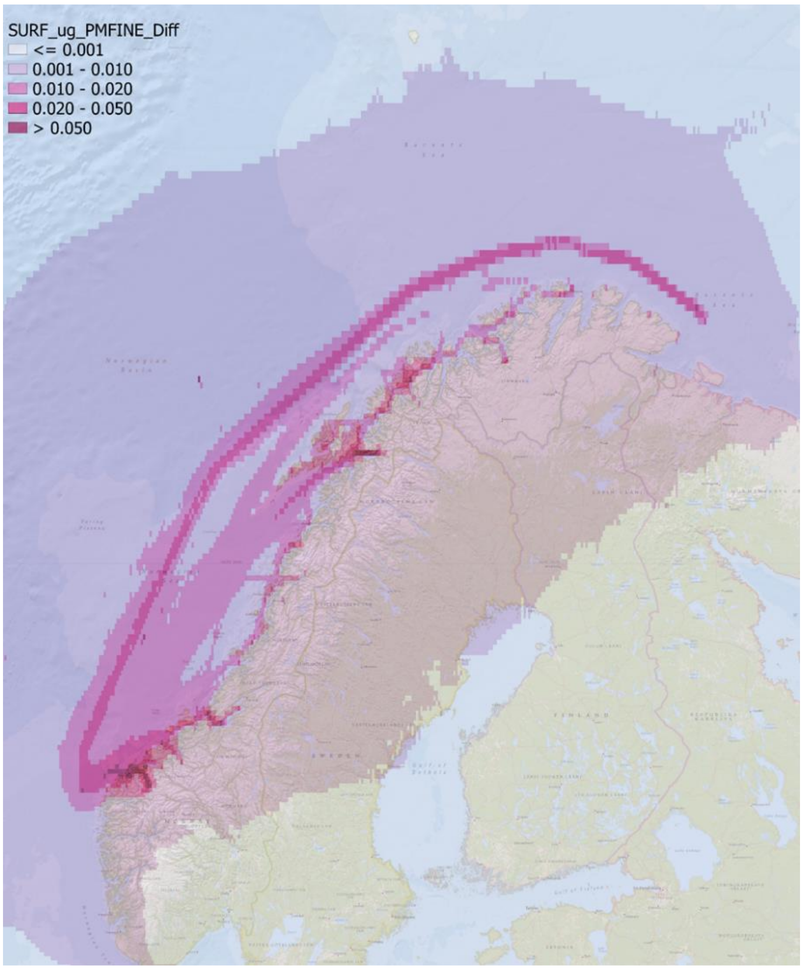


Figure 7-13 Reduction in $PM_{2.5}$ concentrations due to ECA regulations, i.e. difference between the 2030 reference scenario and 2030 ECA scenario. Unit: $\mu g/m^3$.

Black Carbon (BC)

Particulate Matter emitted from shipping is to a large extent Black carbon. Black Carbon aerosols absorb solar radiation, alter the earth's albedo and hence contribute to global warming. The role of BC is beyond the scope of this application. Nevertheless, reduction of particles emissions from shipping will be beneficial in the sense that the concentration of BC will be reduced. However, this effect is not studied or quantified further in this application.

Secondary Organic Aerosols due to NOx

NOx also contributes to formation of Secondary Organic Aerosols (SOA). This particle formation mechanisms have a significant effect on $PM_{2.5}$ levels in some regions like the Baltic Sea (Karl et al., 2019). The effect of NOx upon SOA formation in the ECA domain is not investigated further in this study. However, the effect of NOx upon SOA is expected to be weaker. The reason for this is that ECA is located further north and hence with lower solar angle and less active photochemistry, the NOx emissions are considerably lower, there is less background pollution, and the wind is stronger giving more effective dispersion.

7.3 Health impacts caused by emissions from international shipping

In order to quantify the health impact caused by ship emissions, the difference between a) a model run with all emission categories included and b) a model run without ship emissions have to be assessed. The model results concerning surface level concentrations are analyzed and discussed in chapter 7.3, while the model results concerning dry and wet deposition are shown in chapter 7.4.

7.3.1 Nitrogen oxides

The contribution to surface level concentrations of nitrogen is shown in Figure 7-14. Concerning the Nordic countries, the maximum effect is seen in the Baltic Sea and the North Sea (see Johnson et al., 2015 for details). For the ECA area north of 62°N, the maximum calculated contribution from total shipping is less than 0.5 µg/m^3 for NO and a less than 4 µg/m^3 for NO_2. The maxima occur in specific ports along the coast (e.g. Ålesund, Tromsø).

Concerning human health, NO_2 is the critical component and EU (and Norway) have established strict threshold values for both hourly mean concentrations and annual mean concentrations. The concentrations in Ålesund are well below these threshold values, the NO_2 concentrations in Tromsø were above the threshold value for annual mean concentration in 2007, but below since then. In rural areas along the coast, the NO_2 contribution from ship emissions may be in the order of a few µg/m^3. However, the levels are generally low (background values) and the threshold values are not exceeded. So, the conclusion concerning NOx and its impact on human health is that there is a certain contribution in some areas, but that the levels are generally low and well below the established threshold values.

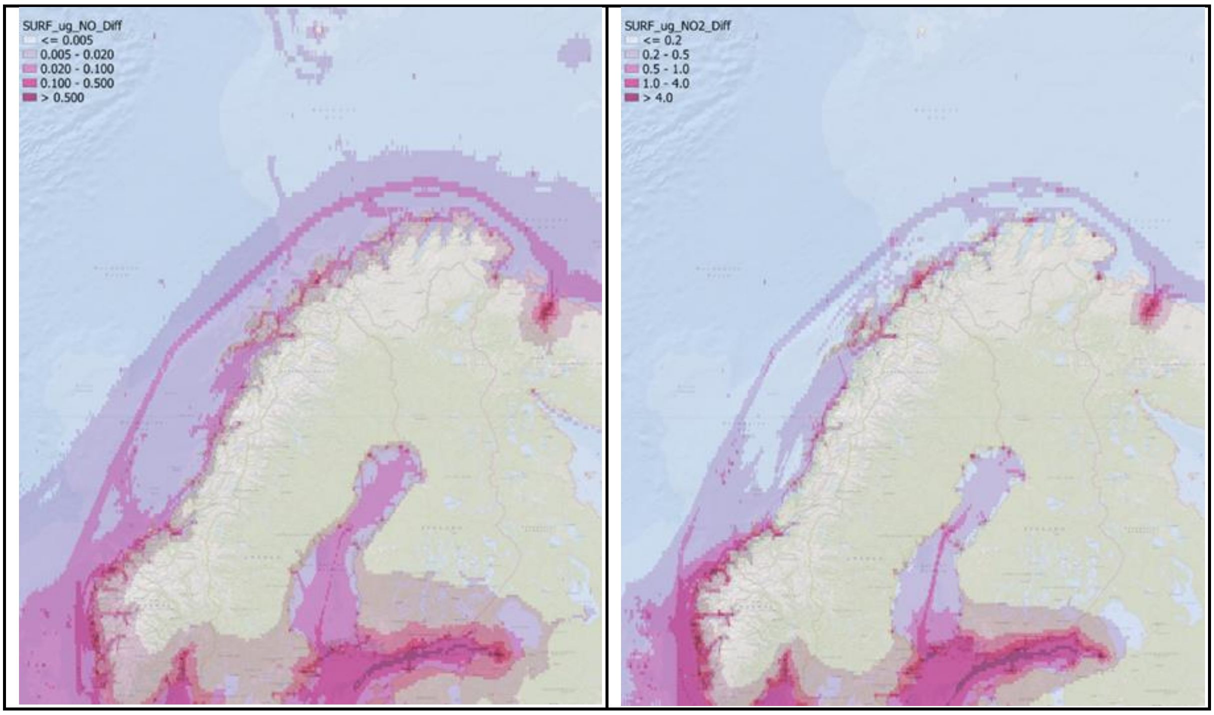


Figure 7-14 The contribution to nitrogen oxides (NO_x) from ship emissions, i.e. difference in annual mean surface level concentrations with and without ship emissions included. NO (left panel) and NO_2 (right panel). Please note different scales in the two plots. Unit: µg/m^3.

Ozone (O_3)

Ozone (O_3) is a secondary gas in the atmosphere, i.e. that it is not emitted directly. Ozone is formed through chemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight (UV). Ozone is a strong oxidant and a toxic gas that may harm both humans (their respiratory system) and vegetation (harm cells, e.g.

taken up by green leaves). Maximum concentrations in Norway occur in spring (April/May) due to long range transport of pollutants from Central Europe. However, emissions of nitrogen will enhance ozone production downwind of the sources/source regions on a local to regional scale. Ozone production in remote areas is typically limited by available NOx. This means that it is more than sufficient VOCs available for ozone production, the level of NOx is the crucial factor. Hence any additional nitrogen, like NOx emitted from ships, will contribute to extra ozone formation. In that regard, NO_x reductions due to implementation of ECA regulations will give reduced ozone production in northern areas. Reduction of ozone concentrations, although small, will have a positive impact on human health and the terrestrial environment.

7.3.2 Sulphur

The emissions of sulphur have been reduced substantially in Norway during the past decades and is now around 15,000 tonnes SO_2 annually. Except for a few industrial facilities, the concentrations are low, i.e. less than 1 µg/m^3. The contributions from ships are shown in Figure 7-15. Maximum contributions from ship emissions occur in the Baltic Sea and N-W Russia, but these areas are not included in this study. The calculated maximum increase in concentrations due to emissions of ships in the ECA are less than 1 µg/m^3 for SO_2 and less than 0.1 µg/m^3 for sulphate. These levels are low and mostly even lower than the detection limit for commonly used monitoring instruments.

The overall finding then concerning health impact of SO_2 from ships is that the contribution from shipping is generally small.

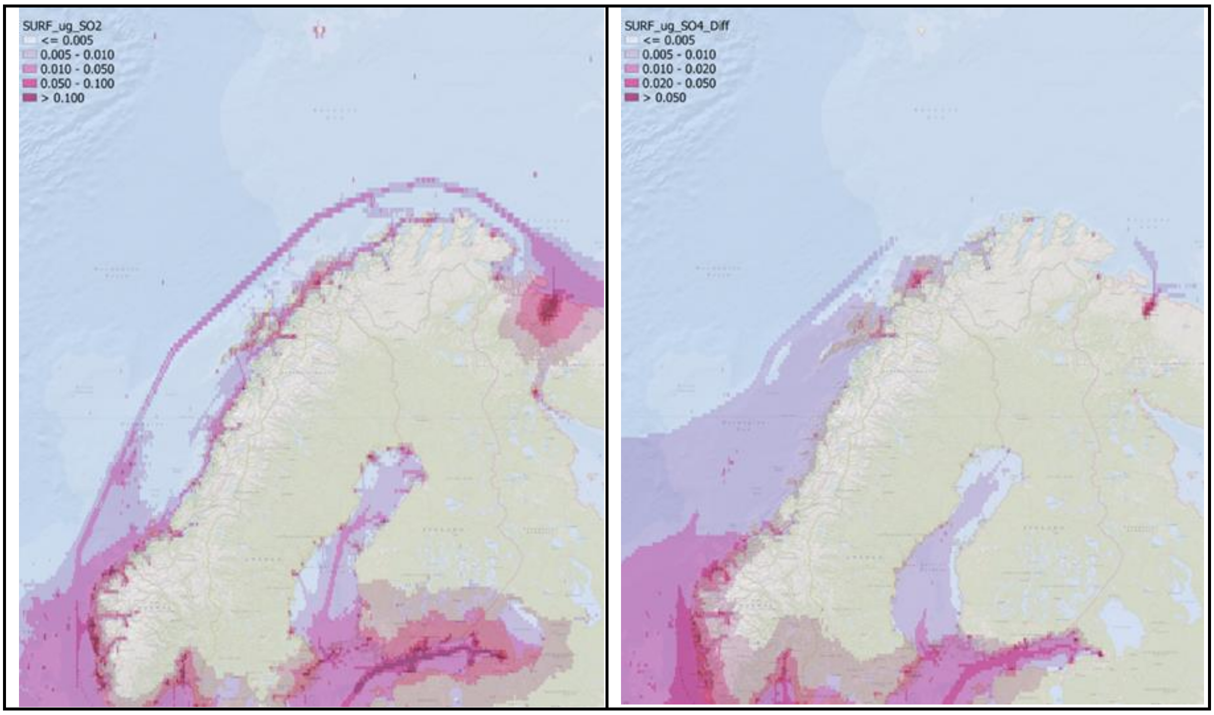


Figure 7-15 The contribution to sulphur components from ship emissions, i.e. difference in annual mean surface level concentrations with and without ship emissions included. SO_2 (left panel) and sulphate (SO_4, right panel). Unit: µg/m^3.

7.3.3 Particulate matter, i.e. $PM_{2.5}$

Concerning health effects of particulate matter, smaller particles (PM_1 and $PM_{2.5}$) have a more significant effect than larger particles (PM_{10}). The reason for this is that smaller particles may penetrate deeper into the lungs while larger particles tend to be trapped in the upper part of the human respiratory system.

The contribution to surface level concentrations of PM$_{2.5}$ is shown in Figure 7-16. As for NOx, the contribution from ship emissions within the ECA area north of 62°N is generally low. The calculated maximum contribution from ships is below 0.2 µg/m^3, and maximum contribution occur e.g. in ports along the Møre coastline (62°N / 63°N), but also ports like Tromsø and Nordkapp show maxima. There are few monitoring results for PM$_{2.5}$ in Norway, but the concentrations in rural areas are generally low. The annual mean concentrations in Tromsø are around 6 µg/m^3, well below the threshold value for annual mean concentrations. In that respect a maximum contribution of 0.2 µg/m^3 to the existing levels is considered small, and also smaller than the year-to-year variability.

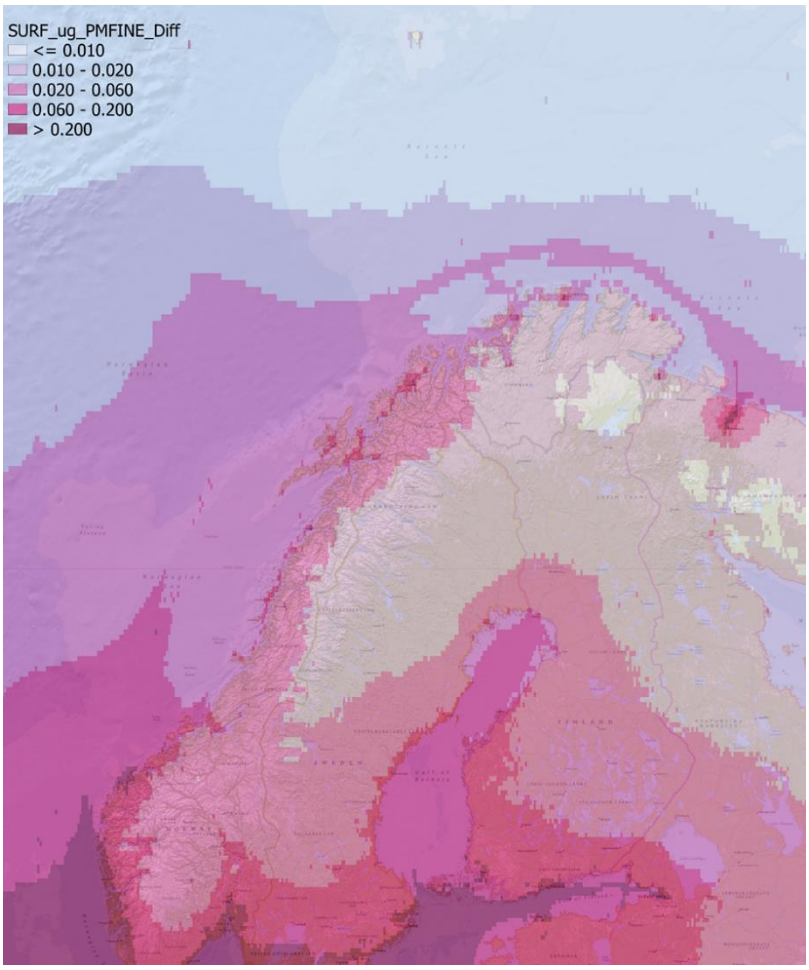


Figure 7-16 The contribution to PM$_{2.5}$ from ship emissions, i.e. difference in annual mean surface level concentrations with and without ship emissions included. Unit: µg/m^3.

7.4 Ecosystem impacts caused by emissions from international shipping

7.4.1 Deposition of nitrogen – eutrophication

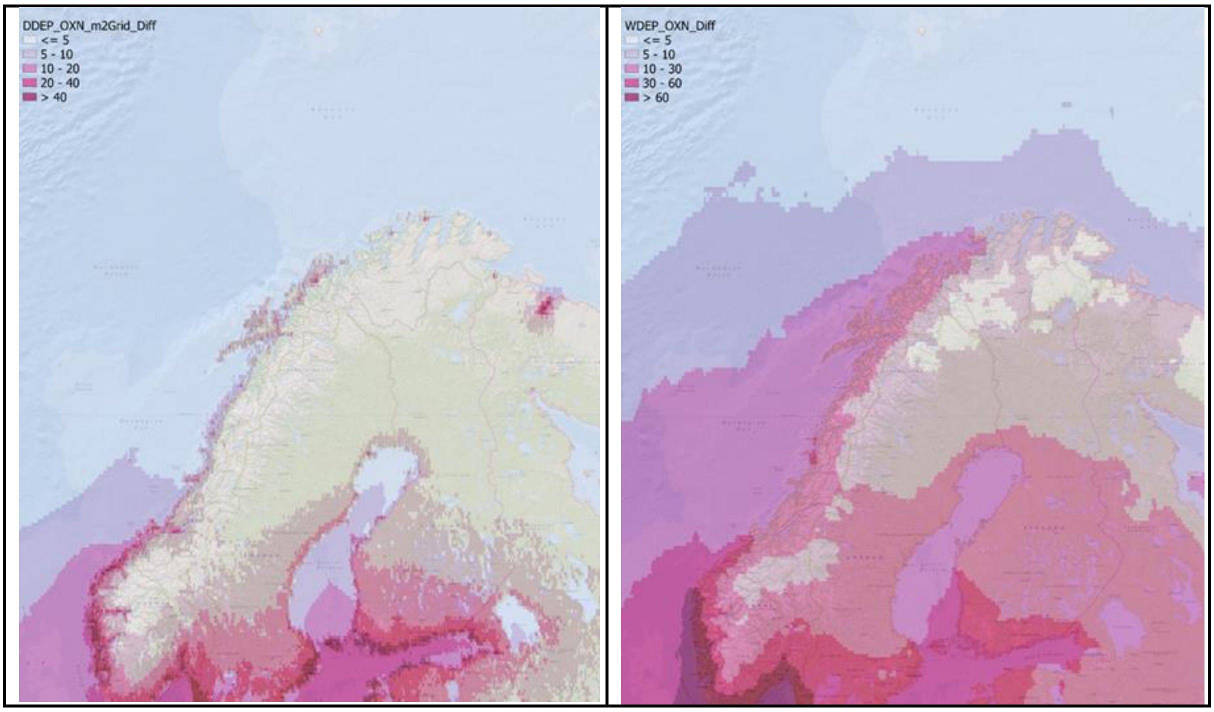
The contribution from ships to deposition of nitrogen is shown in Figure 7-17. The results are shown both for oxidized nitrogen and reduced nitrogen[16]. As for sulphur, dry deposition is most important close to the source, while wet deposition occurs further away.

The maximum calculated contribution to nitrogen deposition is just above 200 mg(N)/m^2 year and occurs in the region of Helgeland (65°N / 66°N). Background deposition of nitrogen in the area is typically up to 700-800 mg(N)/m^2 year. So, for some specific areas at the coast the contribution from ships constitutes nearly 25% of the total deposition of nitrogen. For areas inland, the deposition of nitrogen from ships is much smaller, i.e. less than 10-20 mg(N)/m^2 year. Nevertheless, nitrogen deposition in Northern Norway is low. The deposition ranges typically from below 100 mg(N)/m^2 up to 200-300 mg(N)/m^2 except for areas at Helgeland with high deposition (as already stated 700-800 mg(N)/m^2 year, see Aas et al., 2017 for details).

Eutrophication constitutes a major threat to biodiversity. Areas in Northern Norway including areas north of 62°N show relatively low deposition and vegetation is adapted to a low nitrogen regime. Any excess nitrogen may alter that and change the vegetation cover, i.e. suppress plants that are sensitive to nitrogen and favor the growth of plants that tolerate higher nitrogen levels.

Also note that the calculations presented here only account for nitrogen deposited through air and precipitation. This means that nitrogen from run-off from agriculture, sewage, and other sources are not accounted for. These additional sources will contribute further to possible excess nitrogen in the environment.

The main conclusion is then that any extra nitrogen, like nitrogen emitted to air from ships, will add extra nitrogen to the aquatic and terrestrial systems and hence contribute to increased nitrogen levels and possible eutrophication.



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[16] Again, in plants, nitrogen is found in different oxidation states ranging from nitrate (NO3-, the most oxidized form) to ammonia (NH4-, the most reduced form). Reduced nitrogen, like e.g. ammonia and ammonium, is most available for plant uptake and hence play an important role in plant growth.

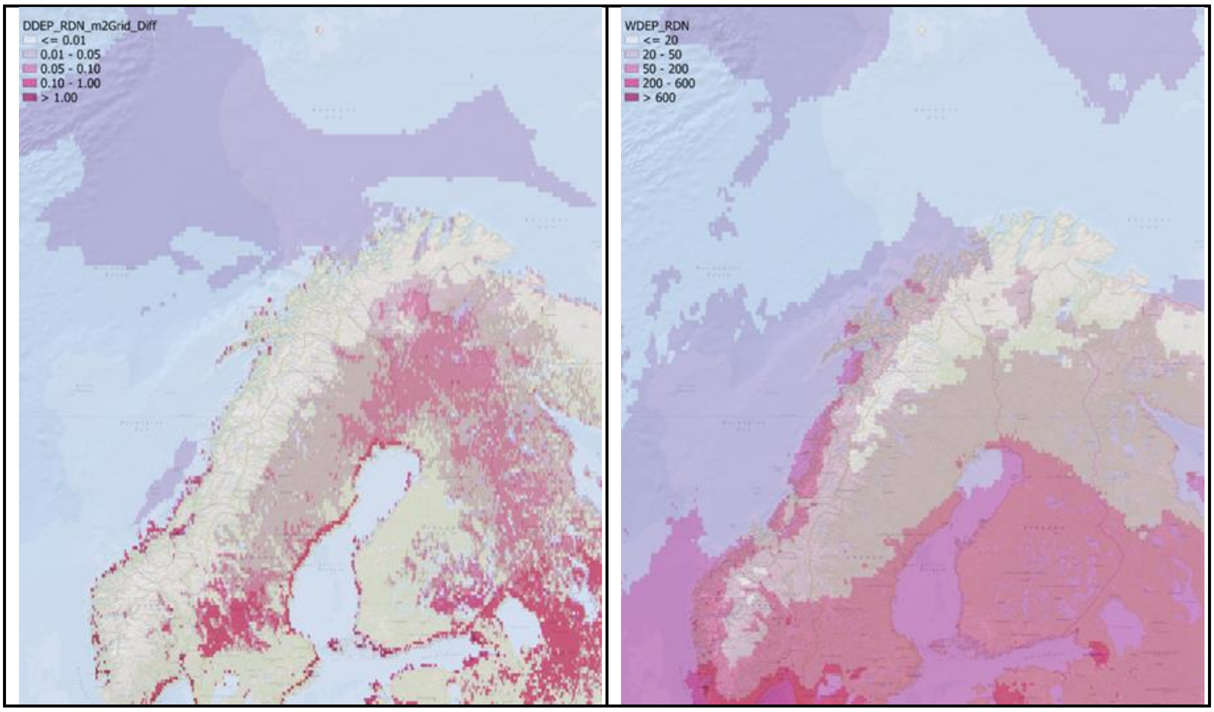

Figure 7-17 Total contribution to nitrogen deposition from ship emissions, i.e. difference in annual mean dry deposition of oxidized nitrogen (upper left panel), dry deposition of reduced nitrogen (lower left panel), wet deposition of oxidized nitrogen (upper right panel), and wet deposition of reduced nitrogen (lower right panel) with and without ship emissions included. Please note the difference in scale in the different plots. Unit: mg(N)/m^2.

7.4.2 Deposition of sulphur – acidification

The contribution from ships to deposition of sulphur is shown in Figure 7-18. Concerning dry deposition, the maximum impact is seen along the ship tracks (Figure 7-18 left panel). This is of course due to the fact that dry deposition is dependent on the surface concentration, in addition to deposition velocity. SO_2 from ships is emitted close to the surface and hence dry deposition will be important in the vicinity of these ships where SO_2 is emitted. Dry deposition of sulphur emitted from ships is hardly detectable on land.

Wet deposition (Figure 7-18 right panel) is dependent on the solubility of SO_2 and sulphate, precipitation amount and precipitation frequency. Maximum wet deposition of sulphur from ships then occurs mostly along the coastline due to orographic rain.

Total deposition of sulphur in the Norwegian Sea and in Northern Norway is typically up to 200 mg(S)/m^2 year (EMEP Report 1/2022, Aas et al., 2017). Compared to these values, a contribution of 2-3 mg(S)/m^2 year from ship emissions constitutes a few percent increase. As discussed elsewhere in this study, the emissions of sulphur have decreased during the past 20-30 years due to regulations and technology development. Hence sulphur is less of a problem than it was some years ago.

The pH of the ocean has dropped by 0.1 since pre-industrial times mainly due to anthropogenic emissions of CO_2. This drop in pH has an impact on marine ecosystems, especially organisms like oysters and corals. Any further acidification, although small, will add to the situation. In that respect it will be beneficial to reduce emissions of sulphur from sea transport.

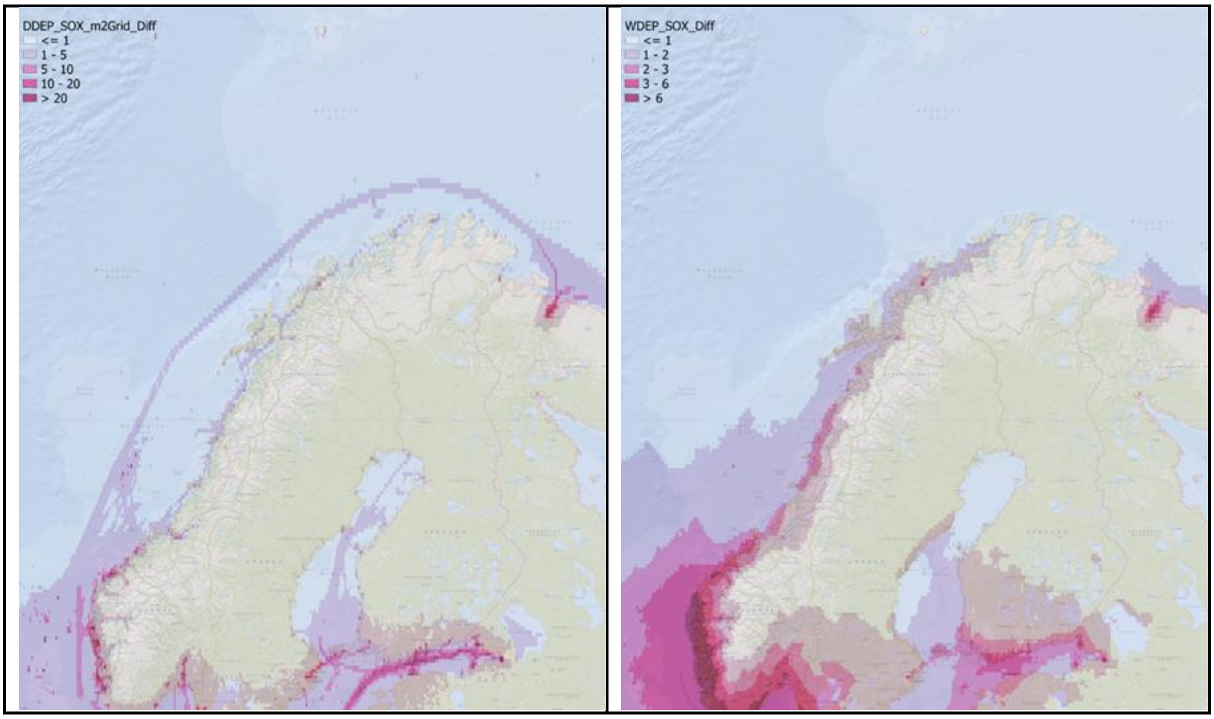

Figure 7-18 Total contribution to sulphur deposition from ship emissions, i.e. difference in annual mean dry deposition of sulphur (left panel) and wet deposition (right panel) with and without ship emissions included. Please note the difference in scale in the different plots. Unit: mg(S)/m^2.

8 THE NATURE OF THE SHIP TRAFFIC IN THE AREA

> This section presents information that addresses criterion 3.1.6 of Appendix III to MARPOL Annex VI, as quoted: **"The proposal shall include a description of the nature of the ship traffic in the proposed Emission Control Area, including the patterns and density of such traffic".**

This chapter provides an overview of the ship traffic and current traffic patterns for ships operating in proposed Emission Control Area, the Norwegian Sea. The basis for describing the nature of ship traffic is the AIS ship movement analysis presented in chapter 7.1.2.

8.1 Ship traffic in the Norwegian Sea

The Norwegian Sea has a very long coastline with deep fjords, many major ports, and a vast number of small port locations. The ports are all playing a major role as logistics centers and being important for maintaining and facilitating the local communities and industries. The large ports act as central shipping hubs for goods transport, shipping of minerals, fishing, aquaculture, military services and oil and gas transport. The Norwegian Sea is also important as a trade route for ship traffic between the north-eastern Arctic areas and Europe.

During 2019, a total number of 3,450 unique ships registered with an IMO number were identified as having operated in the Norwegian Sea. These ships travelled a total distance of 23 million nautical miles (43 million kilometres) as shown in Figure 8-1. The general cargo ships, passenger ships and fishing vessels accounts for more than 60 % of the sailed distance in the area, and they mostly consist of relatively small ships less than 5,000 gross tonnes. Apart from the fishing vessels, the passenger ships and the general cargo ships typically operate in costal and inshore traffic.

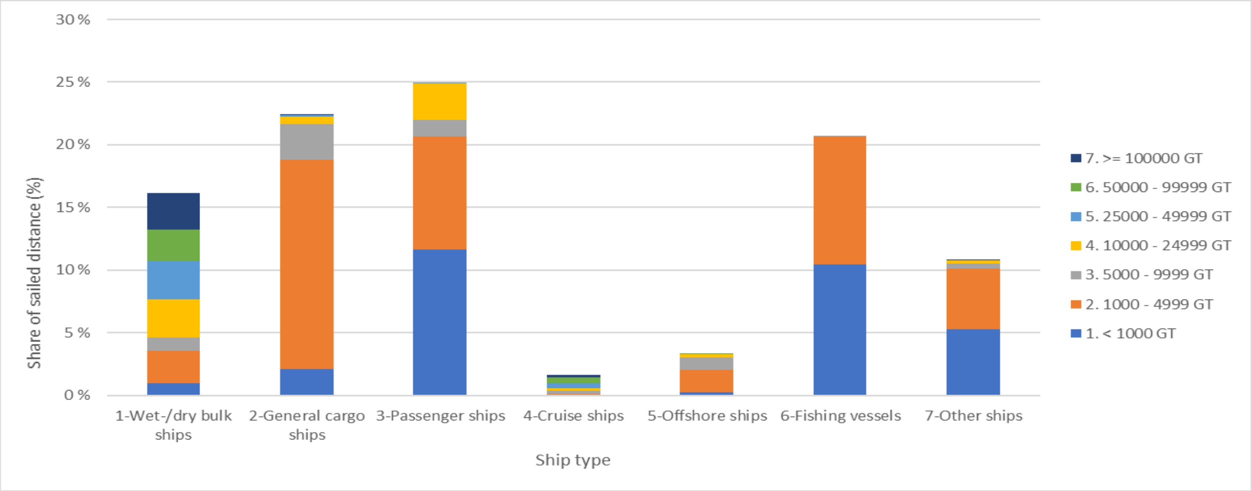

Figure 8-1 Sailed distance by ship type and size (gross tonnage)

Figure 8-2 shows the monthly distribution of fuel consumption in the Norwegian Sea sorted by ship types. For some ship categories, large variations in activity throughout the year are observed. The emission density will vary correspondingly between the months of the year. This is most prominent for the cruise vessels.

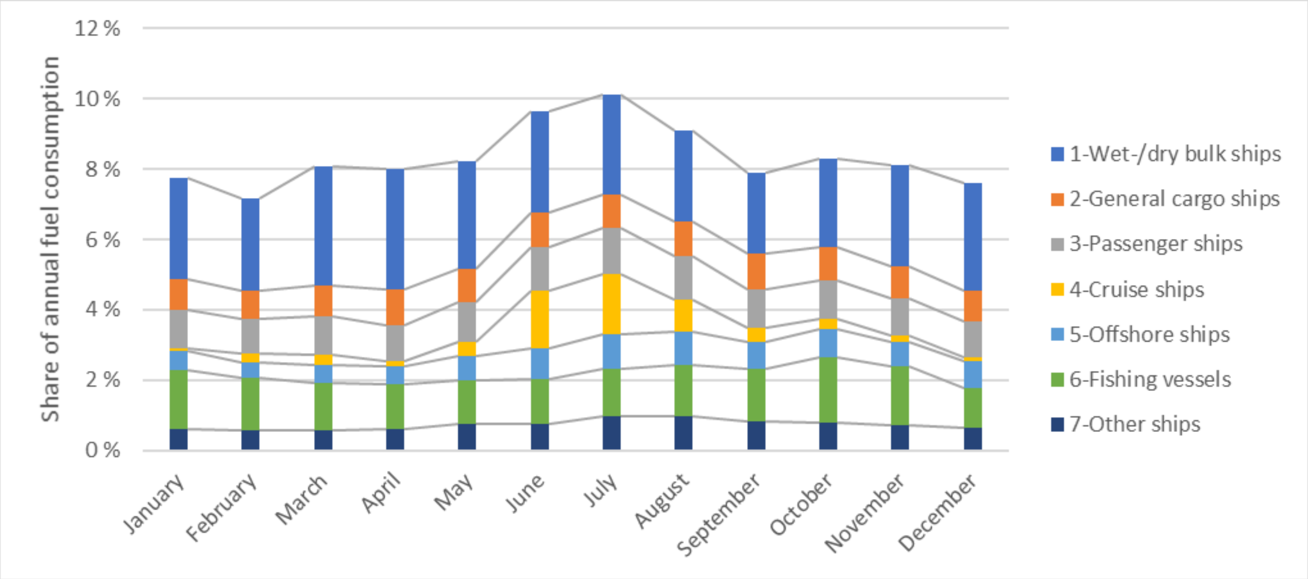

Figure 8-2 Monthly distribution of ship fuel consumption and appurtenant ship emissions

8.2 Operating patterns

The ship traffic patterns in the Norwegian Sea are shown in Figure 8-3. The map shows that the ship traffic is mainly concentrated in two flows along the coast. One is seen as coastal ship traffic well within 12 nautical miles from shore, and the other is in the traffic separation system (TSS) and associated recommended sailing routes further from Norwegian the coast.

The coastal and inshore ship traffic is close to populated areas, vulnerable nature, and landscape areas. The inshore ship traffic is dominated by passenger ships, car ferries and general cargo ships operating between Norwegian ports along the entire coastline. Fishing vessels are different from other types of traffic and operating over the entire area, also far out in the Norwegian Sea and Barents Sea. The coastal and inshore ship traffic and the TSS traffic each represent around half of the total fuel consumption in the Norwegian Sea.

Through the IMO, Norway has established route measures off the coast of Northern Norway on the Vardø–Træna section from 1 July 2007. These consist of a series of traffic separation systems connected to recommended routes. The system applies to tankers of all sizes and cargo ships of more than 5,000 gross tonnes in international traffic. The measures have since shaped the sailing pattern for a significant proportion of the ships that must plan their voyage in relation to the traffic separation system (as is clearly shown in Figure 8-3). Ships arriving from the North Sea on their way to the Barents Sea passes Stad near the coast and then typically head for the traffic separation system (TSS) at Træna.

As is illustrated in Figure 8-3, there is an even fuel consumption density between the coastal and the TSS traffic, this is slightly different for the different emission components. This is characterized by the fact that the ship composition is quite different between the two traffic flows. The larger ships that dominate in the TSS emit a somewhat higher proportion of NOx, due to the fact that a larger proportion of these ships have large two-stroke engines. Two-stroke engines are more energy efficient, thus having higher NOx emissions. This is even more prominent with SOx emissions, where a larger proportion of the ships in TSS use residual fuels with a sulfur content of up to 0.5%. However, this picture is offset by the fact that such a large proportion of emissions from the large ships originate from LNG tankers that use boil-off gas from the cargo and thus have very low NOx and PM emissions and no SOx emissions. Hence, roughly 50% of the emissions components are distributed within and outside the 12 nm limit. Furthermore, outside the two main shipping lanes, there is a considerable activity from supply and service vessels in connection with the petroleum activity, as well as fishing vessels.

In summary, this means the following:

- Fuel consumption is equally distributed between coastal and inshore traffic and the traffic in the traffic separation scheme (TSS) further out at sea.
- Traffic in the TSS zones will also be the traffic that will be most affected by the introduction of an SOx emission control area north of the 62nd parallel since the larger ships will use 0.5% sulphureous fuel to a greater extent.
- Coastal traffic within the 12 nm limit will be less affected by the introduction of an ECA since several of the smaller ships already use fuel with a low sulphur content and that newbuilds within the relevant categories will to a greater extent be expected to adapt to the strictest NOx requirements due to the special Norwegian NOx tax together with support for measures from the NOx-Fund.

It is also worth noting that the traffic hubs associated with the larger cities and towns, which appear as distinct hot spots for all emission components in the coastal traffic flow in Figure 8-3. The areas around Ålesund, Molde, Kristiansund, Tromsø, Hammerfest and Honningsvåg in particular appear to have an elevated concentration of emissions. These areas will have to be seen in the context of where it is seen that the concentration is already high due to other sources, and then it will have to be discussed together with the pollution situation and potential harmful effects in chapter 7. Here it is important to note that through Enova’s onshore power investment over the past 5 years, Norwegian ports have gradually gained an extensive network of shore power systems.

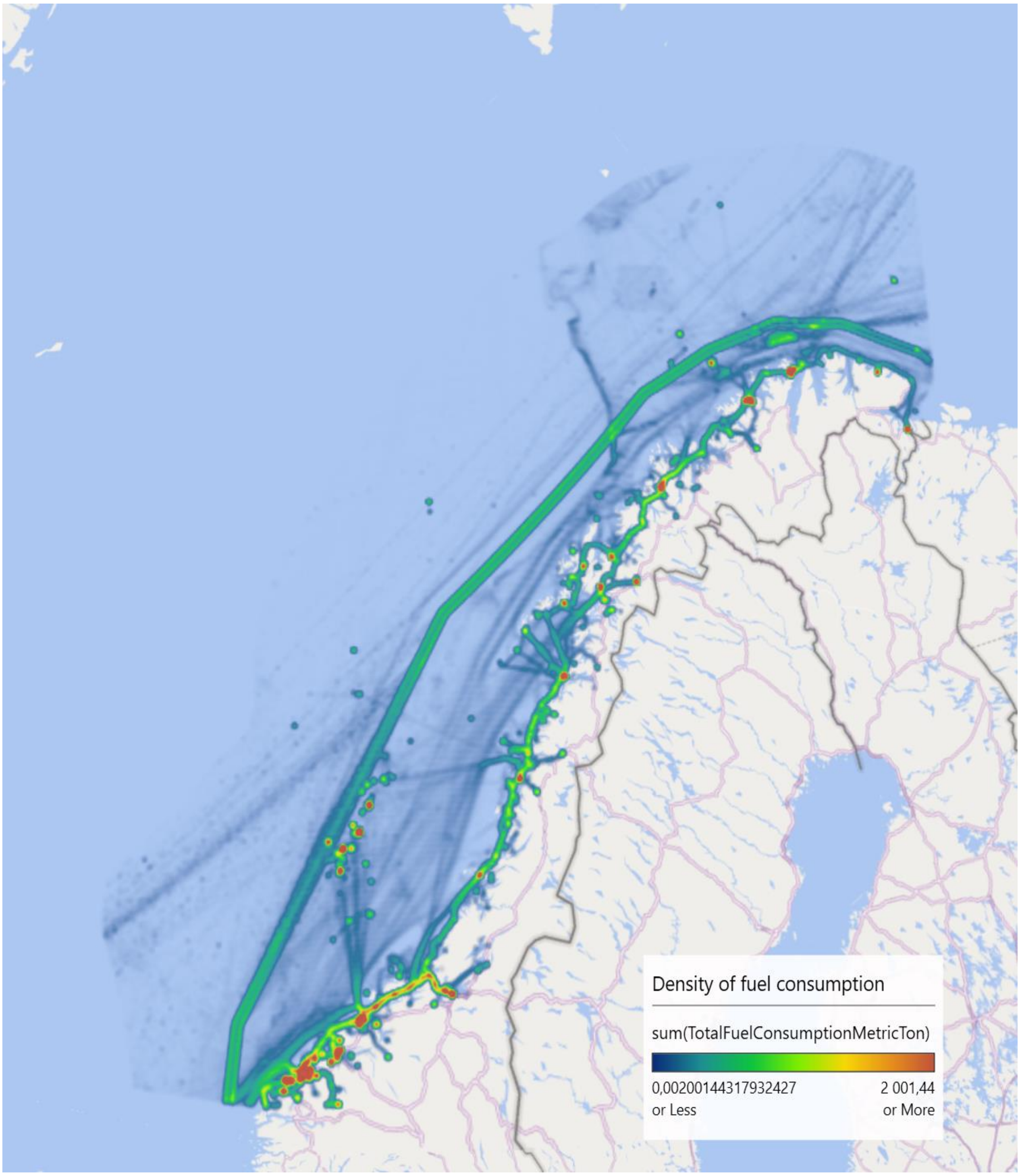

Figure 8-3 Density of fuel consumption by ships in the Norwegian Sea, 2020

9 LAND BASED CONTROL MEASURES

This section presents information that addresses criterion 3.1.7 of Appendix III to MARPOL Annex VI, as quoted: **“*The proposal shall include* a description of the control measures taken by the proposing Party or Parties addressing land-based sources of** NOx**, Sox 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”**.

This section presents information that addresses criterion 3.1.7 of Appendix III to MARPOL Annex VI, as quoted: **“*The proposal shall include* a description of the control measures taken by the proposing Party or Parties addressing land-based sources of** NOx**, Sox 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”**.

The emissions of pollutants from land-based sources have been reduced substantially during the past decades. The reductions are due to measures like technology implementation and development, regulations, economic factors, changes in behavior and others. The cost for the different measures is covered by several parties, ranging from the consumers/inhabitants, business enterprises and factories, municipalities, and the state government (budget).

Concerning greenhouse gases, although beyond the scope of this study, the emission intensity for greenhouse gases, i.e. tonnes CO_2-equivalents emitted per output in NOK have decreased by 54.5 % since 1990 – 2021[17]. Again, this emphasizes that emissions have decreased while economic activity has increased.

Nitrogen oxides NOx

The total reported emissions of NOx from all of Norway was 143,200 tonnes in 2021, ref. Figure 9-1. This is a 25 % reduction compared to 1990 (198,300 tonnes), although maximum emissions in the period 1990 – 2021 was 237,300 tonnes (1998). The most important sources (2021) are oil and gas production, costal navigation, passenger cars, and industrial activities.

The emissions from industry have been reduced through a combination of regulations, i.e. that the Environmental Authorities set up maximum permitted level of emissions and/or maximum permitted concentrations in the flue gas, followed by technology development and implementation of low NOx -technology. An example of this is the oil and gas production where the energy need has increased since 1990, but at the same time low- NOx technology has been implemented so that the total emissions from the oil and gas industry have not changed substantially from 2000 until 2021. Also, the emission from passenger cars have been reduced due to new improved engine technologies. The emissions of NO_2 increased around 2008 due to increased sale of diesel cars compared to gasoline cars (diesel cars have higher NO_2 emissions than comparable gasoline cars). In recent years, the number of electric cars has increased substantially, and hence the emissions of NOx from passenger cars have decreased even more. Till now, the Norwegian tax system makes it more advantageous to buy electric cars (i.e. lower prices) compared to diesel and gasoline cars.

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[17] https://www.ssb.no/en/natur-og-miljo/miljoregnskap/statistikk/utslipp-fra-norsk-okonomisk-aktivitet, March 2023 https://www.ssb.no/en/natur-og-miljo/miljoregnskap/statistikk/utslipp-fra-norsk-okonomisk-aktivitet, March 2023

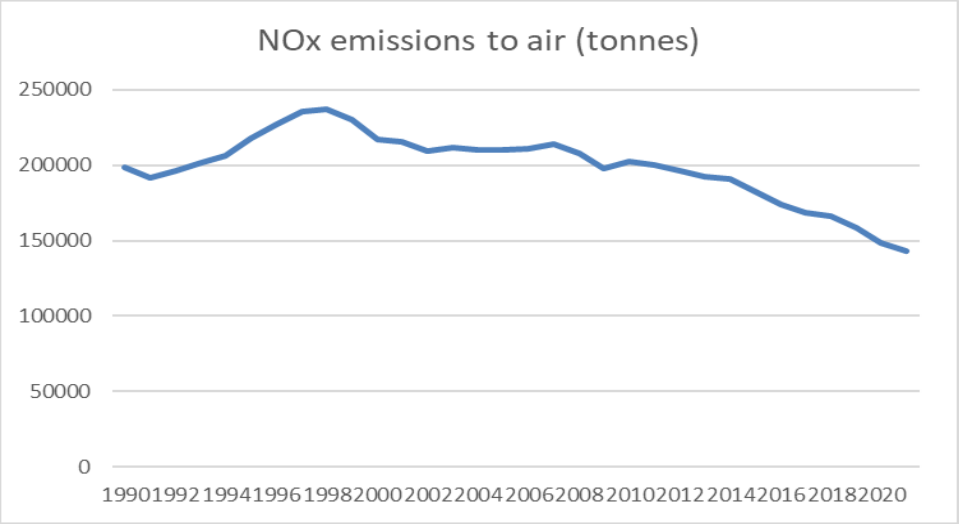

Figure 9-1 Emissions to air of NOx, all sources included. Source: Statistics Norway (https://www.ssb.no/en/natur-og-miljo/forurensning-og-klima/statistikk/utslipp-til-luft). Unit: tonnes NO_x per year.

The Norwegian fiscal NOx tax was introduced in 2007, at NOK 15 per kilo NOx. Therefore, several different business organisations together recommended a solution with a NOx -Fund[18], instead of the fiscal tax, to achieve the highest environmental benefits in relation to accrued expenses for the enterprises. The NOx -Fund was established in 2008 with a NOx Agreement having clear annual reduction obligations. The NOx Agreement has been renewed several times and lately with the 2018-2025 agreement with an extension to 2027. Enterprises pay a small fee to the NOx -Fund instead of the fiscal fee to the government. Fund is paid back to the industry, where affiliated companies can apply for funding of implemented NOx reduction measures. The funding of NOx reduction technologies covers land-based industry, oil and gas production and refineries in addition to domestic ship activities. The NOx -Fund has been and is a strong driver for uptake of NOx reduction technologies in the Norwegian industry and the shipping sector.

In general, the land-based industry often executes large and complex energy, climate, and NOx reduction projects where the NOx reduction benefits can be supported by the NOx -Fund. The applicants to the NOx -Fund receive funding between USD 10 and USD 50 per kg NOx reduced, in which for simpler NOx reduction projects can amount up to 70% of the total costs. For the land-based industry and the oil and gas offshore projects, the NOx reduction effects are often regarded as positive secondary effects which is supported by the NOx -Fund. This is typically projects such as process modifications in the metallurgical industry and electrification of oil and gas production facilities and refineries.

The overall conclusion is that emissions of NOx have decreased in Norway from 1998 to 2021 due to various measures. The cost of these measures has been covered by consumers, businesses, municipalities and through the national funding such as the NOx -Fund. It is also important to stress that due to these measures and these reduced emissions, the concentrations of pollutants have decreased, and air quality has improved in many areas in Norway.

Sulphur dioxide SO_2

The total reported emissions of SO_2 from all of Norway was 14,700 tonnes in 2021, ref. Figure 9-2. This is a 70 % reduction compared to 1990 (49,500 tonnes). The most important sources (2021) are Manufacturing industries and mining process emissions, Energy supply and Costal navigation.

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[18] https://www.noxfondet.no/en/about-the-nox-fond/

The reduction is due to improved cleansing technology and requirements with regard to sulphur content in fuel. The costs of these measures are covered by among others the industry (for industrial emissions) and car drivers (for reduced sulphur content in fuel).

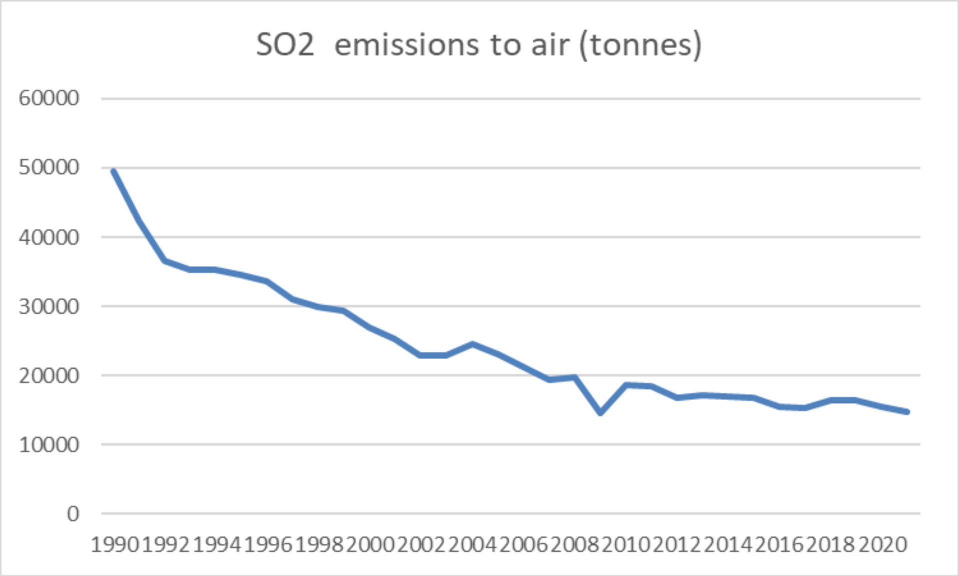

Figure 9-2 Emissions to air of SO_2, all sources included. Source: Statistics Norway (https://www.ssb.no/en/natur-og-miljo/forurensning-og-klima/statistikk/utslipp-til-luft). Unit: tonnes SO_2 per year.

As shown in Figure 9-2 the emissions have been reduced substantially in Norway during the past 30 to 50 years. Sulphur and sulphur dioxide is less of a problem than it used to be in Norwegian cities, except for specific areas influenced by industry, for instance Finnsnes (within the proposed ECA area) and Lillesand and Sarpsborg (outside the proposed ECA area). The Pasvik Valley in Eastern Finnmark (within the proposed ECA area) used to experience high concentrations of SO_2 due to smelter activity in N-W Russia. However, the smelter in Nikel closed in December 2020, and emissions from Zapolyarnyy have been reduced due to introduction of new technology so the problem with regard to air quality is more or less solved for Pasvik.

Particulate Matter – PM

Furthermore, the emissions of Particulate Matter (PM) have decreased, from maximum in 1997 to 2021, ref. Figure 9-3. The emissions have been reduced due to direct measures, like regulations concerning maximum concentrations in flue gas, maximum emissions from industrial facilities, maximum allowable emissions from cars, road taxes on studded tyres etc., but also indirect measures, like when municipalities introduce cleaning of roads during episodes with high concentrations of PM in springtime to remove road dust and avoid resuspension.

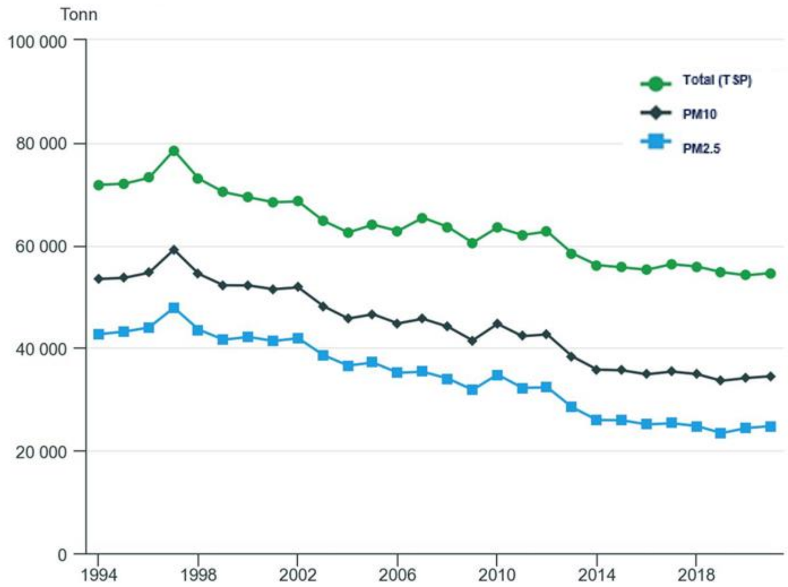

Figure 9-3 Emissions to air of Total Suspended Particles, PM_{10}, and $PM_{2.5}$, all sources included. Source: Statistics Norway. Unit: tonnes particles per year.

As shown in Figure 9-3, the emissions of Particulate Matter have decreased in Norway from 1997 to 2021 due to various measures. The cost of these measures has been covered by consumers (e.g. taxes on studded tyres), businesses (reduced emissions from industries), municipalities (cleaning of roads, financial support to buy new stoves) and through the national budget (e.g. encourage purchase of electric cars rather than diesel cars that emit PM).

10 THE RELATIVE COSTS OF REDUCING EMISSIONS FROM SHIPS AND ECONOMIC IMPACTS

This section presents information that addresses criterion 3.1.8 of Appendix III to MARPOL Annex VI, as quoted: **"The proposal shall include the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade"**.

This chapter presents an analysis of the relative costs of reducing emissions from ships when compared with land-based controls. In the process we present methodology and estimates for both the cost and benefit of ECA designation, before assessing the abatement cost when compared to land-based controls.

No Norwegian studies have been identified that map out abatement costs for land-based air pollution control measures. However, the North American ECA application provides a range of costs for various land-based controls, with PM_{10} abatement costs ranging from USD 16,000 to USD 23,200 per tonne for engine applications and USD 5,800 to USD 66,700 per tonne for stationary diesel engines. Costs for locomotives and harbour crafts vary widely, and SOx abatement costs for stationary sources range from USD 400 to USD 8,700 per tonne, with on-road costs estimated at USD 9,300 per tonne for heavy-duty diesel engines and USD 9,600 per tonne for light-duty engines.

The abatement cost of an ECA designation at USD 10,300 per tonne for SOx is only marginally higher than the costs for land-based controls listed in the North American ECA application. The PM abatement cost with ECA designation is within the lower part of the interval for land-based controls, and the unit cost for NOx emission reduction is estimated at USD 1,670 per tonne. While directly comparing abatement costs is challenging due to variations over time and geography, the figures suggest that the costs of ECA designation are comparable to those of other land-based control measures.

10.1 Onboard costs of NOx and SOx emission reductions

10.1.1 Costs of SOx emission reductions

There are mainly two options on how to comply with the sulphur requirements set forth in Annex VI of MARPOL. The ships can meet the sulphur requirements by using low-sulphur compliant fuel oils or by using an approved equivalent SOx emission reduction method, such as exhaust gas cleaning systems (scrubbers) to reduce the exhaust gas emissions before it is released into the atmosphere. In this case, the equivalent arrangement for SOx reduction must be approved by the ship's Administration (the flag state). The use of low-sulphur compliant fuels or scrubber technologies bring about costs related to capital expenditure (CAPEX) and operational expenditure (OPEX). Uptake of alternative fuels such as LNG, biofuels, hydrogen, ammonia, etc. will eliminate the SOx emissions but the extent of this is not included in the SOx unit cost estimates.

In principle, ships that burn residual fuels can also burn compliant fuel oils such as Low Sulphur Marine Gas Oil (LSMGO) or Ultra Low Sulphur Fuel Oil (ULSFO) with a sulphur content of max 0.1%, and the onboard fuel system modifications for existing ships and upgrades on newbuilds required for such a fuel shift are minimal. The changes include switching to fuel pumps with reduced plunger clearance, replacing fuel valves, altering the fuel injection timing to correspond to the altered fuel calorific value, using finer fuel filters, etc. The required modification is often a necessity for the ships as they also operate in other existing ECA areas, and in that way the CAPEX costs should attributed solely to the proposed ECA area. The added CAPEX related to the use of low-sulphur compliant fuels are therefore assumed to be negligible in this case.

The OPEX related to a fuel shift is mainly connected to the cost difference between bunkering of fuel oils having a sulphur content of max 0.5%, such as Very Low Sulphur Fuel Oils (VLSFO) and low-sulphur compliant fuel oils such as Low Sulphur Marine Gas Oil (LSMGO) or Ultra Low Sulphur Fuel Oil (ULSFO). Figure 10-1 shows the historical bunker prices in Rotterdam[19] for low-sulphur compliant fuels (ULSFO/LSMGO) and VLSFO (max 0.5% S) also known as IMO2020 grade bunkers. The figure shows that the difference between LSMGO/ULSFO and VLSFO has increased gradually over the last two years from about USD 66 in 2021 and up to the record high marine fuel prices in 2022 with a cost difference between USD 230/tonne (mt) and USD 320/tonne. For comparison, the IFO 380 bunker fuels have a cost difference compared to VLSFO of about USD 109/tonne in 2021 and USD 209/tonne in 2022.

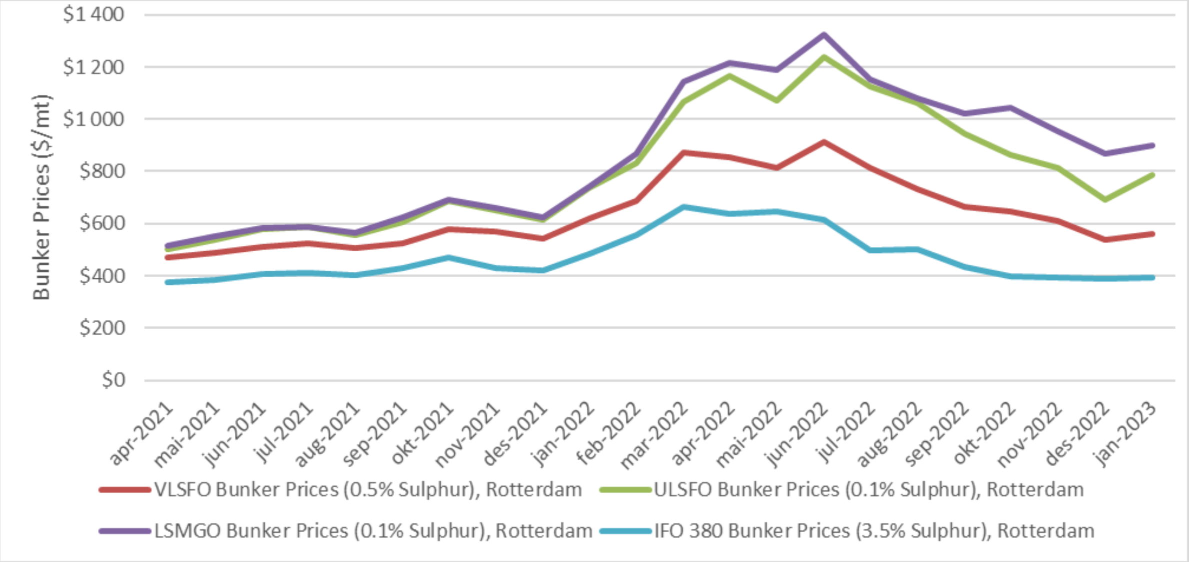

Figure 10-1 Bunker fuel prices, Rotterdam

The alternative to a fuel shift is the use of scrubber technology. With a scrubber the ships can continue to use the cheaper high-sulphur fuel and still meet the stricter sulphur restrictions. There are in principle two different types of scrubbers on the market for marine use, wet scrubbers and dry scrubbers, and a scrubber can be installed on both existing and new ships. Scrubbers[20] come in three varieties open-loop, closed-loop, and hybrid. Open-loop systems use seawater, which is sprayed into the exhaust gas stream before the water is discharged overboard. Instead of using seawater, closed-loop systems have a tank of alkaline-dosed freshwater onboard. After it is sprayed into the exhaust, the water is filtered to remove solid particles and then recirculated, with a small amount of “bleed-off” water discharged overboard. Hybrid scrubbers can be operated in open-loop or closed-loop mode. About 80% of scrubbers installed on ships are open loop.

The cost to install a scrubber on a vessel varies depending on the type of technology and how difficult and complex the installation is. The installation of a scrubber takes typically 15-30 days although on large and complex ships it could be longer. It is more costly to install a system on an old ship than a new one, and closed systems are more expensive than open systems. A scrubber installation could therefore cost between USD 1 million and USD 6 million mainly depending on the scrubber size and capacity (amounts of fuel to be treated and sulphur reduction capabilities) (Andersson et al., 2020). In addition, there will be a cost related to ships being out of service in the installation period, which can add up to USD 0.5 million in loss of revenue during the installation process. Using a write down period of 20 years an annual CAPEX cost of USD 0.1 – USD 0.4 can be assumed. As the ships typically operate in several ECA areas, the CAPEX costs will be taken regardless of introducing the proposed ECA area or not. The CAPEX is therefore regarded as negligible for the proposed ECA area.

The OPEX related to use of scrubbers involves extra energy used for running the system, potential use of chemicals, maintenance, and costs for dispatching of waste. The increase in fuel consumption is around 2%. Depending on the fuel price, the fuel penalty would increase the OPEX with USD 10 – USD 15 per tonne fuel used. The SOx in the exhaust reacts with water and forms sulphuric acid, and in an open loop system there is no need for chemicals since the natural

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[19] https://shipandbunker.com/prices/emea/nwe/nl-rtm-rotterdam

[20] https://theicct.org/scrubbers-on-ships-time-to-close-the-open-loophole/

alkalinity of seawater neutralizes the acid when discharged to sea. If closed loop systems are used, caustic soda is used to neutralize the acid, hence resulting in an additional OPEX cost. According to Wartsila[21], the caustic soda consumption in weight is roughly 6 -15% of the diesel engine fuel oil consumption depending on the sulphur content and cleaning efficiency of a closed loop system. The price of caustic soda varies largely by region, and in the European market[22], FOB Hamburg caustic soda prices fluctuated between USD 465 and USD 450 per tonne in early October 2022. As a result, the added cost of using caustic soda on a closed loop system will then be in the range of USD 60 – USD 70 per tonne fuel used. This means that the OPEX cost for operating the scrubber technology could be as high as USD 80 – USD 100 per tonne fuel used when including fuel penalty, costs for consumption of chemicals, maintenance, landing of wastes, etc.

The preferred option to comply with the ECA sulphur requirements depends on a range of factors and is typically based on calculations on return of investments. Generally, a high price difference between the sulphur compliant fuel oils and the high sulphur fuels together with a large share of ECA operations favor the uptake of scrubber technologies. Similarly, a small price difference and a small share of operations within an ECA favor a fuel switch. As a best estimate for calculating the cost of SOx reductions an additional cost of USD 100 per tonne fuel is used in this study.

The total fuel consumption for the 2030 ECA reference scenario is estimated to 1,130,000 tonnes per year, ref. Table 7-7. Using the same fuel mix as presented in the 2020 baseline scenario, ref. Figure 7-3, approximately 27% of the total fuel consumption will then be VLSFO having a sulphur limit above the ECA requirements, and consequently a shift to low-sulphur compliant fuels or exhaust gas scrubbing is required.

This study projects that switching from VLSFO with a sulphur content of 0.5% to 0.1% or using scrubber technology would increase fleetwide OPEX costs in the proposed ECA area with about USD 30 million per year. The consequent reduction in SOx emissions will be close to 3,000 tonnes per year and the unit costs for the fuel shift will then be about USD 10,300 per tonne SOx.

10.1.2 Costs of NOx emission reductions

Estimating the effects of introducing an ECA on the NOx emission from shipping is rather more complex than for the SOx-emissions. The reason for this is that, while SOx-emissions may be regulated by controlling the sulphur content of the fuel, regulating NOx -emissions involves potentially costly technical additions to non-Tier-III machinery and systems for each specific vessel. Hence, while the ECA SOx regulations are introduced for all vessels from a set date, IMO has agreed that the ECA NOx regulations only will be affecting ships constructed on or after the entry into force of the regulation. Hence there will be no immediate effects on the investments required when an NOx emission control area is introduced, and both the environmental effects as well as the economic impact will be gradually following the fleet renewal.

For the affected vessels there are mainly three alternatives for ECA (Tier-III) compliance.

- Zero emission technology (electric, fuel cells etc)
- Gas internal combustion engines
- Traditional diesel engines with emission reduction technology (SCR)

Constructing ECA-compliant (Tier-III) propulsion technology, will involve an increase in CAPEX. However, by 2030, it may be assumed that Tier-III technology will be standard for all new-builds, driven mainly by other already established ECAs. Therefore, it is a fair assumption that there will be no extra CAPEX related to the introduction of a Norwegian Sea area ECA.

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[21] https://www.wartsila.com/encyclopedia/term/sox-scrubber-systems

[22] https://www.procurementresource.com/resource-center/caustic-soda-price-trends

However, particularly for the two latter Tier-III alternatives, there will be an increase in the OPEX due to high LNG prices and the requirement for urea for the operation of SCRs. Hence, there are OPEX cost implications related to the introduction of a NOx emission control area.

Assuming a gradual implementation of Tier-III compliant technology from 2030 and a full replacement of older technology within 20 years, a NOx reduction trajectory towards 2050 may be estimated. As discussed in chapter 7.1.3, the maximum feasible implementation potential for Tier-III requirements indicated a total NOx reduction potential of close to 30,000 tonnes. When distributed over 20 years, you will get a yearly reduction of 1,500 tonnes.

Assuming all reductions are done using SCRs in combination with a diesel engine, we may calculate the added OPEX related to the regulation. Figures collected by the Norwegian NOx-Found shows that for every tonne of NOx reduced with SCR, 1,665 tonnes of urea are required. The price of urea is tightly connected to LNG prices, and hence a considerable price increase has been experienced the last year, but also a more recent drop. Pre-Russian invasion of Ukraine, prices were as low as USD 400 per tonnes, but has lately peaked at USD 1,500 per tonne. For this study we have decided to apply a price of USD 1,000 per tonne. Hence, the unit cost for the NOx emission reduction is estimated to be about USD 1,670 per tonnes NOx, which amounts to a yearly cost of USD 2.5 million.

10.2 Cost effectiveness of ECA designation

As previous ECA proposals states, the literature find that ranges for PM_{10} and SOx abatement costs are broad and overlapping (Marine Environment Protection Committee, 2022). The costs assigned to removal of any single species (of either SOx or PM) cannot be treated as fully independent, as PM and SOx pollutant species are entwined. Therefore, though the costs are attributed to a single pollutant, there will likely be co-reductions for both SOx and PM with any abatement measure. As a result, we use the cost estimate of SOx emission reduction when assessing the abatement cost both for SOx emission and for PM_{10}. The unit cost for reduction of NOx emission is estimated to be about USD 1,670 per tonnes NOx, as shown in chapter 10.1.2. The abatement cost states the cost of reducing emissions per unit with ECA designation and does not take into account the benefits of reduced emissions. Table 10-1 shows the marginal abatement costs of ECA designation for NOx, SOx and PM.

Table 10-1 Emission reductions and abatement costs. 2022 USD

Emission component	2030 ECA emission reduction (tonnes/year)	Abatement cost (USD /tonne)
NOx emissions	1,500*	1,670
SOx emissions	2,910	10,300
PM_{10} emissions	1,300	23,100

* The annual reduction of NOx emissions, 1,500 tonnes per year, apply to a period of 20 years after introduction of the Norwegian Sea as a NOx emission control area

There are to our knowledge no studies mapping out abatement costs for land-based control measures addressing air pollution in Norway. However, the North American ECA application (EPA, 2009) lists a set of land-based source controls. The studies listed span across several years and do not necessarily reflect current abatement costs due to policy changes. Nevertheless, the studies are relevant as examples of indicative intervals for abatement costs. All figures are in 2022 USD. The report lists costs of between USD 16,000 - USD 23,200 per tonne for PM_{10} for non- and on-road diesel and gasoline engine applications and a range of USD 5,800 per tonne to USD 66,700 per tonne for stationary diesel engines. Locomotive and harbour craft costs range from USD 13,500 per tonne for new builds up to USD 72,500 per tonne for retrofits.

Stationary source SOx abatement costs range from USD 400 - USD 8,700 per tonne SOx, whereas on-road SOx abatement costs are estimated at USD 9,300 per tonne SOx for heavy-duty diesel engines, and USD 9,600 per tonne SOx for light duty gasoline/diesel engines.

The abatement cost of ECA designation of USD 10,300 per tonne SOx is only marginally higher compared to the listed land-based controls in The North American ECA application. PM abatement costs of USD 23,100 per tonne with ECA designation within the lower part of the interval for different land-based control measures. The unit cost for the NOx emission reduction is estimated to be about USD 1,670 per tonne NOx.

It is difficult to directly compare the abatement costs from this ECA designation with land-based control measures as they are affected by factors varying both over time and with geography.

Still, the figures indicate that the abatement cost of an ECA designation is comparable to other land-based control measures.

10.3 The benefit of ECA designation

We have estimated the benefits associated with some of the effects of reduced pollution due to the ECA designation using two different approaches:

- **Approach number 1:** In this method, we estimate the benefits from reduced emission due to an ECA designation using costs per tonne emissions set out by the Norwegian Coastal Administration for economic analyses of policies and projects. Input in this analysis is emission reductions due to the ECA designation from the ship traffic analysis. This approach uses average emission costs given the population in the affected area. The emission costs reflect human health impacts and environmental damage on nature and/or animal life. However, this approach does not consider how emissions can be spread through atmospheric circulation and how the health effects can vary with demographics.
- **Approach number 2:** This method focuses solely on the health effects of ECA designation. Health impacts accounts for the majority of benefits related to regulations of the air pollutants subject to ECA designation, (Roy & Braaten, 2017). This approach uses annually average concentrations of NOx, SOx and PM from the EMEP model, in combination with concentration-response functions to estimate health impacts from ECA designation. We combine these data with granular population data sorted by municipality to estimate effects from prevented lung cancer and cardiovascular diseases.

In the following, we first present the methodology for estimating costs of emissions and the results from Approach 1. Secondly, we present the methodology for estimating health costs of exposure to pollutants before we present results from Approach 2. In both approaches, we estimate the benefits of introducing the proposed ECA area as the difference between the 2030 ECA scenario and the 2030 reference scenario.

10.3.1 Benefits of reduced emissions

10.3.1.1 Methodology for estimating cost of emissions

The methodology uses estimated average costs per unit of emissions, where a broad range of effects are considered. Emissions in more populated areas are given a higher cost as more people are exposed.

Input in this analysis is emission reductions due to ECA designation from the ship traffic analysis. The emissions data is given in 0.1x0.1-degree grids, while the cost-estimates are based on municipality-type. More populated municipalities are given a higher cost per unit of emissions, due to more exposed populations. Table 10-2 sums up the costs per tonne of emissions. The cost estimates cover human health impact, as well as environmental damage on local nature and/or animal life (The Norwegian Coastal Administration, 2021). Emissions costs outside of Norwegian municipalities are not included.

The grid cells do not correspond perfectly to municipalities. To account for this, we disperse the emissions in each grid cell into smaller grid cells of 250x250 meters, illustrated by the figure below. We assume a uniform distribution of emissions, so that each 250x250 grid cell is assigned a share of the emissions equal to the emissions in the large cell divided by the number of small grid cells. Each 250x250 grid cell is assigned to a municipality, and a cost per unit emitted based on the total population of the municipality. Costs of emissions is calculated per cell by multiplying the unit cost by the emission in each cell. Finally, total costs are calculated for the entire area by adding up the costs in each cell. The benefit is the difference in cost of emissions in the 2030 ECA scenario compared to the 2030 Reference scenario.

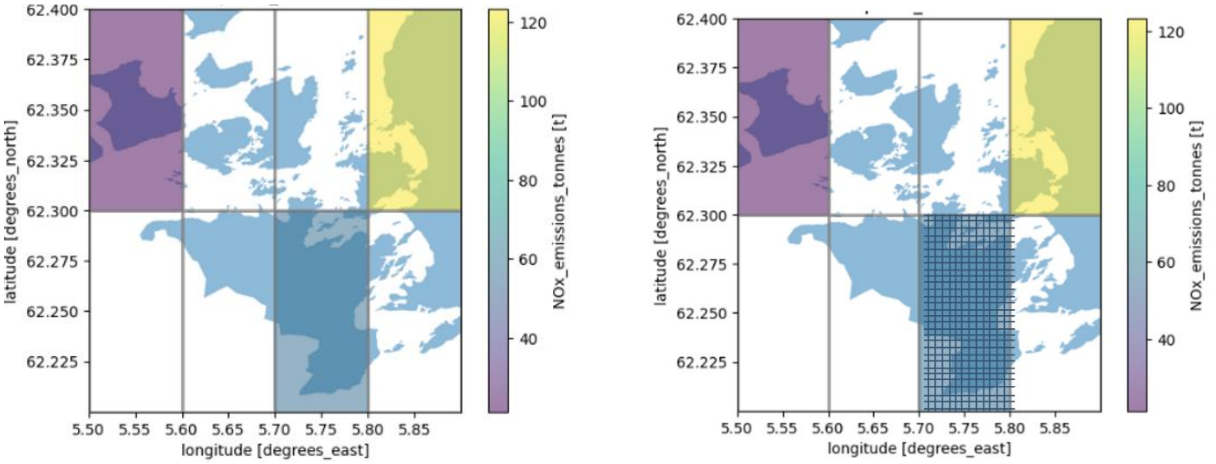

Figure 10-2 Illustration of the distribution of emissions. The large grid illustrates the emissions data, where the colour corresponds to the quantity of emissions. The blue areas are municipalities, in this case surrounded by sea. Emissions in each grid cell is distributed uniformly to smaller grid cells of 250*250 meters, as illustrated in by the figure to the right.

Table 10-2 shows average costs of emissions given the population in the area where the emissions take place. The cost of emissions reflects human health impacts and environmental damage on local nature and/or animal life. For more about the methodology behind costs, see (Vista Analyse, 2015).

Table 10-2 Cost per kg of emissions. Source: (The Norwegian Coastal Administration, 2021), 2022 USD.

Pollutant	Rural areas (<15 000 inhabitants) (USD /kg)	Small cities (15 000 – 100 000 inhabitants) (USD /kg)	Cities (>100 000 inhabitants) (USD /kg)
NOx	2.7	10.6	42.6
SOx	0.0	1.4	2.7
PM_{10} (including $PM_{2.5}$)	0.0	99.8	712.2

10.3.1.2 Estimated emission reduction benefits

The quantified benefits of reduced emissions are estimated to USD 6.9 million in 2030, see Table 10-3. The reduction in PM_{10} amounts to about one third of the benefits. NO_x represents about two thirds, while SO_x is only a small share of the total, about 2%. In the valuation matrix used in this methodology, neither SO_x nor PM_{10} is assigned a cost in rural areas. The majority of costs related to these pollutants are related to health outcomes, and as a result the costs of emissions in rural areas are very low. Since Northern Norway is sparsely inhabited, large areas are assigned no cost, except for the cost related to NO_X emissions. This assumption might mean that the total impact of emissions is somewhat underestimated based on this methodology. In addition, this approach does not consider that emissions can spread through atmospheric circulation. As a result, the impact of emissions does not necessarily occur where the emissions are.

Table 10-3 Economic benefit of emissions reductions due to ECA designation in 2030.

Pollutant	Benefit from emission reduction (USD)
SOx	108,111
NOx	4,539,718
PM_{10}	2,247,471
Total	6,895,301

10.3.2 Benefit of human health impact

10.3.2.1 Methodology for estimating the health cost of exposure to pollutants

In this approach we focus solely on the health impacts from ECA designation. Health impacts account for the majority of benefits related to regulations of the air pollutants subject to ECA designation (Roy & Braathen, 2017). This approach uses yearly mean data on concentrations of pollutants from the EMEP model, in combination with concentration-response functions to estimate health impacts from ECA designation. We combine these data with granular population data for municipalities to estimate effects from prevented lung cancer and cardiovascular disease.

The methodology for modelling health impacts follows the methodology used in the proposal to designate the Mediterranean Sea as an ECA (Marine Environment Protection Committee, 2022). We calculate avoided lung cancer and cardiovascular disease mortality based on the change in $PM_{2.5}$ concentration due to the ECA designation.

We follow the methodology published in Nature Communications developed by (Sofiev, et al., 2018) closely. The paper employs a linear concentration-response (C-R) function developed by (Lepeule, Laden, Dockery, & Schwartz, 2012), which is based on updated epidemiology from the Harvard Six Cities study (Dockery, et al., 1993). The cities in the Harvard Six Cities study have a somewhat higher level of $PM_{2.5}$ exposure than the area proposed here. We assume that the linear relationship between exposure and health outcomes holds at slightly lower levels. (Sofiev, et al., 2018) applies the same methodology to world emissions, where the levels are both higher and lower than the Six Cities studies. However, recent studies have noted that the effect of reduced exposure appear to be higher at lower levels of exposure than higher levels. In addition, here the estimated health costs for cardiovascular and lung cancer mortalities are calculated, but there are also other potential health impacts of exposure. This indicates that the following results are likely underestimating the effect of the proposed ECA.

We apply a more finely grained population and age grid than the (Sofiev, et al., 2018) paper. 2019 population data from SSB on a 250x250 meter grid is used, as this ensures that the specific regional demography of Northern Norway is maintained in the analysis. The exposure of each cell in the grid is determined by the overlapping concentration data, which is given in 0.1x0.1-degree grids. County-level age cohort fractions were applied to obtain the age cohort populations in each grid cell. This allows us to account for regional differences in age cohorts, which is important because Northern Norway has an older population than the country as a whole.

Like the (Sofiev, et al., 2018) paper, we divided reported deaths by population estimates for age cohorts 30-99 to calculate an incidence rate per 100,000 for people over 30 years of age. We thus assume that all cardiovascular disease and lung cancer deaths can be attributed to the over 30 population. The assumption is demonstrated to be plausible after reviewing cause of death data by age cohort. The population in each grid cell is therefore weighed by the age cohort over 30 years in the respective municipality.

Municipality-specific reported deaths from cardiovascular disease and lung cancer are collected from the Norwegian Cause of Death Registry (Norwegian Institute of Public Health, 2021). Data on age cohorts are collected from (Statistics Norway, 2023). Table 10-4 sums up the data.

Table 10-4 Incidence rates for lung cancer and cardiovascular disease mortality for persons over 30 years of age, as well as population shares over 30 years for counties affected by the ECA zone. Source: (Statistics Norway, 2023; Norwegian Institute of Public Health, 2021)

County	**Lung cancer** (mortality rate per 100,000)	**Cardiovascular** disease (mortality rate per 100,000)	**Age cohort** > 30 years
Innlandet	72.6	378.8	67.9%
Vestland	62.1	311.1	63.0%
Møre og Romsdal	67.0	355.8	65.1%
Trøndelag	59.6	296.7	63.0%
Nordland	76.6	350.9	66.3%
Troms og Finnmark	82.6	350.8	64.6%

Specifically, avoided mortality due to changes in $PM_{2.5}$ was calculated as follows. For each grid cell, the total effect (E) of changes is given as:

$$E = AF \times B \times P$$

Here, P is the relevant exposed population (population weighed by age cohort), B is the incidence rate of the health effect, and AF is the attributable fraction of disease due to the shipping-related PM pollution. AF is given by:

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

The assumed linear C-R model gives the response RR by the function:

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

$(C_1 - C_o)$ is the change in concentration due to ECA designation. Plugging these definitions into the initial equation means that the total effect can be written as follows:

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

where b = 0.023111 (95% CI = 0.013103, 0.033647) for cardiovascular mortality; and where b = 0.031481 (95% CI = 0.006766, 0.055962) for lung cancer related mortality (Lepeule, Laden, Dockery, & Schwartz, 2012; Burnett, et al., 2014; Tsimpidi, et al., 2010).

10.3.2.2 Quantified human health impacts from exposure to ship emissions

The total health impact of the reduced exposure to emissions is a reduction in mortality of almost two deaths in 2030. The reduction in mortality is higher for cardiovascular issues, which accounts for 1.53 of the lives, while avoided lung cancer mortality accounts for 0.43. The confidence intervals are relatively large, with a 95% confidence interval of about 1 and 3 lives. The results of the analysis are summed up in Table 10-5.

To quantify the economic benefits of the reduced mortality, we use the Norwegian "Value of a statistical life" (Finansdepartementet, 2021). According to this metric, one human life should be valued at USD 4.2 million. The total change in mortality adds up to USD 8.5 million. The uncertainty in the mortality estimates (there are no uncertainty bounds for the VSL) translates into a 95% confidence interval of USD 4.2 million and USD 13 million. The lower bound roughly corresponds to the estimate arrived at using the other methodology.

Table 10-5 Reduced mortality and economic benefits of the reduced mortality, due to ECA designation.

	Reduced mortality	**Economic benefit:** Mortality x Value of Statistical Life (**USD** 4.26 million) **USD million**
Avoided cardiovascular mortality	1.53 (CI 95 % 0.87,2.23)	6.67 (95% CI = 3.79, 9.72)
Avoided lung cancer mortality	0.43 (CI 95 % 0.09,0.76)	1.87 (95% CI = 0.39, 3.31)
Total	**1.96 (CI 95 % 0.96,2.99)**	**8.54 (95% CI = 4.19, 13.04)**

10.3.3 Summary of evaluated benefits

We have quantified the benefits of the ECA using two separate methodologies. Using standardized values linked to the amount of emissions gives a lower estimate than a direct quantification of mortality tied to exposure to pollution. The results are within the same order of magnitude, with the standardized values estimate only slightly lower than the lower bound of the 95% confidence interval of the exposure estimate. As explained above, there is reason to believe that the first methodology tends towards underestimating the total benefits, and it is therefore not surprising that the estimated benefits are somewhat lower. These results are still a relevant anchor point for the total benefits. The second approach quantify benefits relating to avoided mortality due to cardiovascular disease and lung cancer, but there are also other potential health impacts of exposure not quantified here. Thus, we have not estimated the total health benefits relating to the effect of the proposed ECA, but we capture the most important components.

These benefits will accrue over a much larger period of time than the year 2030 which has been analysed here and are likely to increase over time.

There are several uncertainties regarding the quantified benefits in this study. One of the main sources for uncertainties are the size of the grids of emissions data and concentrations, of 0.1x0.1 degree. It is likely that there are areas within these grids, such as ports, where concentrations of PM_{10} are higher. Further, ports are usually located close to densely populated areas. This possible correlation between concentrations and affected population would cause us to underestimate health effects of introducing ECA designation. The same applies for emissions. It is likely that there is a correlation between emissions and populations within each grid. The areas within each grid where emissions are high, may be the areas within the grid which are more densely populated.

Human health outcomes make up more than 90 percent of economic costs to society of air pollution (Roy & Braathen, 2017). The fact that human health outcomes make up the bulk of economic costs relating to air pollutants, and our approach of quantifying human health impacts uses more precise data for concentrations and corresponding concentration-response functions, speaks towards emphasising the results from the second approach, rather than average costs per unit emission.

Another source of uncertainty is benefit relating to avoidance of negative health impacts, other than lung cancer and cardiovascular disease. Lung cancer and cardiovascular disease make up the majority of negative health impacts from PM. However, there are other health impacts from PM, such as asthma, which are not included in our estimates.

Other benefits which are not included in our estimates include loss of production related to improvement of health and avoided resource usage in the health sector. Improved health due to ECA designation may reduce production loss and public health expenses. Therefore, the total economic benefits may be higher than estimated here. Still, the majority of the effects of human health is estimated and monetized in this study.

The cost of air pollutants subject to ECA designation is not only related to health effects alone. NOx and SOx can impact both the built environment, animal and plant health and ecological systems. These costs are reflected in our first approach, but not in our second approach. Costs of emissions related to NOx and SOx consider environmental damage on local nature and/or animal life (The Norwegian Coastal Administration, 2021). However, these costs related to SOx, PM, and NOx emissions are small when compared to human health effects and are assumed to be zero in rural areas. This is a simplification knowing that there are negative impacts from SOx on the environment, regardless of population density.

There are various recent studies valuation of environmental impacts from shipping. Repka et al (2021) value the environmental benefits of the Sulphur Emission regulation (SECA) that came into force in 2015, changes in depositions of SOx and NOx from ship exhaust gas emissions were modelled and monetized for the Baltic Sea region for the years 2014 and 2016. They noticed that there is a lot of uncertainty in the monetarization methods. In addition, they also claimed that it is the first attempt to monetarise the environmental benefits of SECA regulation. Ytreberg et al. (2021) established a conceptual framework for valuation of environmental impacts from shipping, with Baltic Sea shipping as a case study.

Recently also Mueller et al (2023) reviewed health impact assessments of shipping and port-sourced air pollution on a global scale, incl. considering health-cost externalities. They reviewed thirty-two studies, predominantly European Sea shipping/port-sourced emissions with health impacts for global or respective European populations. Their conclusion based on the review was that maritime transport is an important source of air pollution and health risk factor, which needs more research and policy attention and rigorous emission control efforts.

Total health benefit relating to ECA designation in 2030 is probably somewhat higher than our point estimate of USD 8.54 million.

10.4 Summary of economic impact and cost effectiveness

This section summarizes the economic impact and cost effectiveness of ECA designation and comment on distributional effects.

This study projects that switching from VLSFO with a sulphur content of 0.5%S to 0.1%S fuels, or using scrubber technology, would increase fleetwide yearly operational costs (OPEX) with about USD 30 million because of the ECA implementation. Assuming gradual implementation of NOx ECA compliant technologies in the fleet from 2030 and onwards and full implementation within 20 years (MFNR scenario), an annual average NOx reduction of 1,500 tonnes is estimated. The subsequent annual cost of the NOx reductions amounts to about USD 2.5 million per year. No additional costs are assumed for the PM reductions as it is directly related to the SOx reductions. The total annual cost for implementation of the ECA's is therefore about USD 33 million per year.

The abatement cost of ECA designation at USD 10,300 per tonne for SOx is only marginally higher than the costs for land-based controls listed in the North American ECA application. The PM abatement cost with ECA designation is within the lower part of the interval for land-based controls, and the unit cost for NOx emission reduction is estimated at USD 1,670 per tonne. While it is challenging to directly compare abatement costs due to variations over time and with geography, the figures suggest that the costs of ECA designation are comparable to those of other land-based control measures.

The benefit is the difference in economic cost of emissions in the 2030 ECA scenario compared to the 2030 Reference scenario. Using Approach 1 we estimate the yearly benefits of total reduced emissions to USD 6.9 million from 2030 and onwards. The reduction in PM_{10} amounts to about one third of the benefits. The estimated annual NOx reductions represent slightly less than two thirds, while SOx emission is only a small share of the total, about 2%.

In the valuation matrix used in this methodology, neither SOx nor PM_{10} is assigned a cost in rural areas. The majority of costs related to these pollutants are related to health outcomes, and as a result the costs of emissions in rural areas are very low. Since Northern Norway is sparsely inhabited, large areas are assigned no cost. The economic benefits of reduced concentration of PM (reduced mortality) are estimated to USD 8.5 million (Approach 2). The uncertainty in the mortality estimates translates into a 95% confidence interval of USD 4.2 million and USD 13 million.

The quantified improved health outcomes are smaller than the costs of complying to ECA designation. However, there are several uncertainties regarding the estimates, both relating to costs and benefits of ECA designation.

ECA designation would have some distributional effects as well. We have quantified the economic costs and benefits, but it is also relevant to highlight the distributional effects, i.e., who bears the economic costs and who reaps the health benefits of the ECA designation. The costs will be carried by shipping operators and their customers. The extent to which operators can charge their customers for their increased costs, relies on several factors. However, the high competition in the freight market suggests that most of the cost will be carried by operators' customers, i.e. businesses and consumers of the affected ship traffic. The ECA designation thus redistributes the costs to the part which causes the emissions. This follows the "polluter pays principle", which makes the party responsible for producing pollution responsible for paying for the damages. The benefit of reduced emissions accrues to the population of the affected area, primarily the inhabitants of Norway north of 62° N.

11 UNCERTAINTIES REGARDING ASSUMPTIONS, EMISSION INVENTORIES AND DISTRIBUTION OF MODELLED RESULTS

Quality assurance and control efforts have been taken to minimise the uncertainties in the modelled results. The uncertainties are mainly related to quality of input data, the applied model algorithms to estimate energy consumption, fuel consumption and emissions, and the systematics for distribution of modelled results. Frequent update of the databases, validation and calibration routines are established to secure that the input data hold highest possible standard.

Emission modelling

From the MASTER model, the estimated energy consumption, fuel consumption and emissions for cargo carrying ships correspond well with reported data from the IMO Data Collection System (DCS) and the reported results from the EU's MRV scheme. A deviation of up to 5% is observed when comparing a large dataset of modelled results with reported data form DCS and EU-MRV (Longva & Sekkesæter, 2021). However, large uncertainties could occur for individual ships, and particular for non-cargo ships. This is in line with the activity-based modelling and uncertainties related to the use of AIS data as reported by the Fourth IMO GHG study (IMO, 2020). Similar error sources and quality considerations for AIS data are also reported by the UN Statistics Wiki (2020). We expect that potential errors in the data sources and AIS modelled results will not have significant impact on the modelled results.

There are also uncertainties connected to the 2030 scenario modelling, which projects the future projection of ship traffic, implications of short-term regulative implications, fleet technology and alternative fuel uptake. Moderate uncertainties of 15-20% are assessed to accompany the scenario modelling.

Atmospheric chemistry calculations

In this study, the EMEP model is applied in a 0.1°×0.1° grid resolution. This is the same model and model resolution used to study effects of strengthening the Baltic Sea ECA regulations (Jonson et al., 2019). The 0.1°×0.1° resolution (3,8 km W-E × 11.1 km N-S at 70°N) makes the model more suitable to study effects of ship emissions on a regional scale rather than detailed dispersion of ship emissions in specific cities, ports etc. To study dispersion from the plume from a specific ship, a detailed Computational Fluid Dynamics (CFD) model will be needed. To study dispersion of pollution from ships in a port, a high resolution Eulerian (divide the atmosphere into grid boxes) or Lagrangian (represent atmospheric dispersion by a large number of particles/air parcels) model will be needed, i.e. with spatial resolution of 50-10 m or less. However, this is beyond the scope of this study.

The concentrations of the gases and oxidants are calculated as an average for each grid box. Consequently, all sub grid local maxima will be levelled out in the model. Hence coarse spatial resolution will introduce some uncertainties in the model calculations. The effects of elevated emissions in ports will therefore be poorly resolved in the dispersion calculations, and the effects there are likely to be higher than shown in this study, also reported by Jason J.E. et al, 2015.

The meteorological parameters represent the year 2019. There are interannual variability concerning weather. Some years show heavy rainfall, some years show little rainfall, some years show high temperatures, some show low temperatures etc. A different pattern concerning wind direction and/or wind speed will give different results in the way that maximum values will occur in other locations and slightly different magnitude. However different meteorology will not alter the overall conclusions concerning the effect of ship emissions.

Cost benefit analysis

Emission reductions due to ECA designation uses data from the ship traffic analysis to estimate benefits from reduced emission. The emissions data is given in 0.1x0.1-degree grids and we assume that emissions are uniformly distributed within each grid. Ship traffic is likely to be concentrated in populous areas, and hence the cost per unit emission is also likely to be underestimated.

Similarly, we assume that concentrations of pollutants are constant within each grid. In practice, concentrations vary within a geographical area of 0.1x0.1 degrees. This is also a source for uncertainty, especially if the areas where concentrations are the highest are correlated with population density. This would cause an underestimation of the benefit to human health impact from an ECA designation.

We have used a methodology published in Nature Communications developed by (Sofiev, et al., 2018). The paper employs a linear concentration-response (C-R) function, which is based on updated epidemiology from the Harvard Six Cities study (Dockery, et al., 1993). The cities in the Harvard Six Cities study have a somewhat higher level of $PM_{2.5}$ exposure than the area proposed here. We assume that the linear relationship between exposure and health outcomes holds at slightly lower levels. Recent studies have noted that the effect of reduced exposure appear to be higher at lower levels of exposure than higher levels (Vodonos, Awad, & Schwartz, 2018). As a result, the assumption of a linear relationship is considered conservative and the effect of an ECA designation in the Norwegian Sea is most likely underestimated.

The estimated health costs for cardiovascular and lung cancer mortalities are calculated and account for most health costs related to air pollution. But there are also other potential health impacts of exposure. This indicates that the following results are likely underestimating the effect of the proposed ECA.

The cost of air pollutants subject to ECA designation is not only related to health effects alone. NOx and SOx can impact both the built environment, animal and plant health and ecological systems. These costs are reflected in our first approach, but not in our second approach. Costs of emissions related to NOx and SOx consider environmental damage on local nature and/or animal life (The Norwegian Coastal Administration, 2021). However, these costs related to SOx / PM emissions are small when compared to human health effects and are assumed to be zero in rural areas. This is a simplification knowing that there are negative impacts from SOx/PM on the environment, regardless of population density. Even though the costs per unit probably is very low, there are some costs that are not taken into account when considering emissions in sparsely populated areas.

12 VALIDATION OF ASSUMPTIONS MADE ON THE MODELLING RESULTS

Validation of the emission reduction potentials by introducing an ECA area in the Norwegian Sea in 2030 using updated 2022 ship activity data and projections for NOx, SOx and PM emissions

The 2020 data set uses AIS ship activity data for 2019 as a starting point because the 2020/21 ship activity is expected to be less representative due to the COVID-19 pandemic. In addition, the 2019 emission inventory was adjusted for the 2020 sulphur cap as specified under MARPOL Annex VI with a subsequent reduction in SOx and PM emissions. Finally, a 2030 reference was established incorporating expected changes in the future fleet activity levels changes in the uptake of fuels, technologies, and ship operations. This then provides the basis for evaluating the effects of introducing and ECA area in the Norwegian Sea in 2030.

Early 2023, when a full 2022 dataset was available, it was decided to re-evaluate these assumptions to validate the conclusions initially made.

Main findings

The emission data assessment updated from the 2020 baseline to the 2022 inventory, shows that there are no changes to the conclusions based on the initial 2020-based analysis.

The re-iteration based on the 2022 dataset shows that the development path in the ship activity and fuel consumption is slightly higher than the assumptions made in the 2019-based estimates. The updated 2022 inventory shows that:

- There has been an increase in the annual fuel consumption by approximately 1.7% in this period, while an increase of about 1% was anticipated. The main increase is found among large bulk ships, LNG carriers, cruise and “other vessels”, while the main fuel reduction is found in the passenger segment and general cargo vessels.
- There has been a shift in the fuel composition used by the ships operating in the proposed ECA area influencing the SOx and PM emissions. An annual increase of 1,3% MDO and 2% LNG/BOG is observed, while the use of heavy fuel oils is reduced nearly by an equal amount. This means that the emissions of SOx and PM is reduced as initially assumed.
- Based in the 2022 dataset, it is seen that the main increase in the fuel consumption is within the ship categories using lighter, and already ECA (SOx) compliant fuel types (smaller vessels), whereas the greatest reduction is amongst the larger vessels using heavy fuel oils which would have been most affected by the introduction of an ECA. This change in consumption from larger to smaller vessels very much cancels out the overall increase in reduction potential with the general increase in fuel consumption.
- The NOx emissions are relatively unaffected by the increase in the total fuel consumption over the period. This is due to the fact that the increase in fuel consumption is mainly found in the distillate fuels used by the smaller – high-speed – engines and LNG-fueled ships, whereas there has been a relative reduction in the use of the heavy fuel oils used by the larger slow-speed engines. Since the latter will have a much higher relative NOx emission than the high-speed and LNG engines, the observed increase in fuel consumption is, like for the SOx and PM emissions, cancelled out - resulting in only marginal changes in the projected 2030 ECA reduction potential.

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APPENDIX A

Boundaries of the proposed emission control area

The boundaries of the proposed ECA, Norwegian Sea, is as set forth in MARPOL Annex II Reg. 13.9.4 “Control of discharges of residues of Noxious Liquid Substances”. The sea area located off the Norwegian coast are enclosed by geodesic lines connecting the following coordinates:

Point	Latitude	Longitude
1	69°47.6904' N	030°49.059' E
2	69°58.758' N	031°6.2598' E
3	70°8.625' N	031°35.1354' E
4	70°16.4826' N	032°4.3836' E
5	73°23.0652' N	036°28.5732' E
6	73°35.6586' N	035°27.3378' E
7	74°2.9748' N	033°17.8596' E
8	74°20.7084' N	030°33.5052' E
9	74°29.7972' N	026°28.1808' E
10	74°24.2448' N	022°55.0272' E
11	74°13.7226' N	020°15.9762' E
12	73°35.439' N	016°36.4974' E
13	73°14.8254' N	014°9.4266' E
14	72°42.54' N	011°42.1392' E
15	71°58.2' N	009°54.96' E
16	71°37.5612' N	008°43.8222' E
17	70°43.161' N	006°36.0672' E
18	69°36.624' N	004°47.322' E
19	68°58.3164' N	003°51.2154' E
20	68°14.9892' N	003°17.0322' E
21	67°25.7982' N	003°10.2078' E
22	66°49.7292' N	003°25.1304' E
23	66°25.9344' N	003°17.1102' E
24	65°22.7214' N	001°24.5928' E
25	64°25.9692' N	000°29.3214' W
26	63°53.2242' N	000°29.442' W
27	62°53.4654' N	000°38.355' E
28	62° N	001°22.2498' E
29	62° N	004°52.3464' E

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