European Environment Agency

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European Maritime Transport Environmental Report 2025

EEA-EMSA Joint Report 15/2024

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Commissioners' welcome

Dear reader,

This second edition of the *European Maritime Transport Environmental Report* (EMTER) is brought to you by the European Maritime Safety Agency and the European Environment Agency. It is an honour for us to introduce it together.

Three quarters of our international trade is carried by sea, making maritime transport an economic engine in the European Union (EU). It has also proven itself able to provide timely and fitting responses to crisis situations, such as the COVID-19 pandemic and the energy crisis. And of course, shipping plays a crucial role in ensuring cohesion within the Union, by linking the continent to our islands, remote and ultraperipheral regions.

Shipping carries more than two thirds of intra-EU freight flows, and does so efficiently, in terms of energy consumption. But we can still do better. For the climate and environment, all sectors of the economy have to help reduce pressure on the planet's climate and resources. And maritime transport has work to do there, because alongside GHG emissions, it is also a source of significant air and water pollution, posing a risk for the marine environment and coastal areas. Seas and oceans are the world's greatest carbon sink. They regulate global climate, are an essential source of food, and are central to the health and prosperity of our densely populated coastal areas.

Through the European Green Deal, the EU is proud to be at the forefront of global efforts to curb the sector's GHG emissions, as well as the air and water pollution that it generates. Initiatives such as extending the ETS to shipping, FuelEU Maritime, and the monitoring, reporting and verification of maritime transport CO_2 emissions have paved the way for similar efforts at the global level. It is no coincidence that the International Maritime Organization (IMO) is looking into establishing a global GHG Fuel Standard and a GHG pricing measure just as our EU measures enter into force.

We have also done a lot to limit pollution, with a wide body of legislation in areas such as ship-source pollution, sulphur emissions, ship recycling, port reception facilities for ship-generated waste and – last but not least – strict safety rules. These help, on a daily basis, to prevent maritime accidents and their potentially devastating effects on the environment.

To be effective, new initiatives must be based on reliable, high-quality, up-to-date data and scientific evidence. This is why this second edition of EMTER is so crucial. It provides a comprehensive analysis of the maritime transport sector,its environmental impact, progress made to date, and the challenges it still faces going forward in terms of decarbonisation, pollution reduction, biodiversity protection, circularity and climate adaptation.

EMTER helps us to evaluate our policy initiatives. It will also help us shape the European Oceans Pact, which will target coherence across polices supporting resilient and healthy oceans and coastal areas, those promoting the blue economy and managing the use of our seas and oceans coherently, and policies developing a comprehensive agenda for marine knowledge, innovation and investment. We will also seek inspiration from this report when implementing the new Port and Industrial

Maritime Strategies, which will step up the competitiveness, sustainability and resilience of Europe's maritime manufacturing sector and ports.

Finally, we have to keep in mind that activities at sea are intrinsically linked with those on land – an issue that the Water Resilience Strategy will examine more closely, including from a source-to-sea angle.

EMTER is not only designed for rule-makers and maritime professionals; it constitutes, above all, a science-driven overview of where the EU stands in terms of protecting its marine environment, and what must still be done. With this report, we want to give every EU citizen access to a transparent and objective source of information on the topic.

This report is for you; we hope it inspires you to contribute to the debate on how to reconcile maritime transport and environment protection, and drive global cooperation in this area for a prosperous, safe and healthy future for us all.

We wish you an interesting and inspiring read!

Apostolos Tzitzikostas

Commissioner for Sustainable Transport and Tourism

Jessika Roswall

Commissioner for Environment, Water Resilience and a Competitive Circular Economy

Costas Kadis

Commissioner for Fisheries and Oceans

Foreword

It is with great pride that we present the second edition of the *European Maritime Transport Environmental Report* (EMTER 2025), a collaborative effort between the European Maritime Safety Agency (EMSA) and the European Environment Agency (EEA). Building upon the foundations laid in the first edition published in 2021, this report provides a comprehensive update on the environmental and climate impacts of the maritime transport sector within the European Union, highlighting achievements, identifying challenges and offering insights into future opportunities.

Jointly prepared by the EEA and EMSA in collaboration with the European Commission, the EMTER demonstrates how coordinated efforts among EU institutions can provide up-to-date and policy-relevant information and address the sector's environmental and climate challenges by consolidating expertise and knowledge across the maritime domain.

Since the first edition, significant progress has been made in aligning the practices of the maritime transport sector with the objectives of the European Green Deal and other key EU policy initiatives. However, the scale and urgency of environmental and climate challenges — ranging from decarbonisation and biodiversity protection to pollution reduction and climate resilience within maritime operations — require further action and innovation.

The decision to publish a second edition of EMTER was driven by the urgency of continuing to make progress towards Europe's ambitious decarbonisation, pollution and biodiversity goals, particularly as the maritime sector faces increased regulatory requirements and a need for an accelerated transition to sustainability. EMTER 2025 highlights recent regulatory changes, such as the integration of the maritime transport sector into the EU's Emissions Trading System, the expansion of sulphur emission control areas, the zero pollution action plan and the new Port Reception Facilities Directive to manage waste. Such initiatives underscore the EU's continued commitment to reducing the maritime sector's environmental footprint.

This edition not only assesses progress made over recent years but also emphasises the interconnectedness of maritime activities with broader ecological, economic and social systems. It underscores the importance of implementing a wide range of environmental practices to mitigate the sector's environmental footprint while reinforcing maritime transport as a cornerstone of European trade and competitiveness, and of communities relying on the sector.

We believe the second edition of EMTER can serve as a valuable resource for policymakers, practitioners, researchers and citizens, offering evidence-based insights to support the sustainable transition of the maritime transport sector. EMTER 2025 reflects the progress made thus far and provides guidance on the remaining work. We trust that with coordinated efforts, maritime transport can continue to thrive in a way that benefits the wellbeing of European citizens and protects the environment and climate.

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The second edition of the *European Maritime Transport Environmental Report* (EMTER 2025) was prepared by the European Maritime Safety Agency (EMSA) and the European Environment Agency (EEA). EMSA and the EEA coordinated the report's development with close engagement with the European Commission and other key stakeholders.

EMSA and the EEA acknowledge the contributions of the EMTER Coordination Group members to this publication, thanking them for their insights and comments that helped to improve and enrich the report's content. The Coordination Group included representatives from the following European Commission Directorates-General: Mobility and Transport (MOVE), Environment (ENV), Climate Action (CLIMA), Joint Research Centre (JRC), Maritime Affairs and Fisheries (MARE), and Research and Innovation (RTD). In addition, we would like to thank the European Fisheries Control Agency (EFCA) for their active involvement.

EMSA and the EEA also extend thanks to Member States, industry associations and civil society representatives for their contributions via the EMTER Stakeholder Consultation workshop.

Finally, we wish to acknowledge the contributions of the following organisations, (listed in alphabetical order) whose expertise and data provided valuable input across the report's focus areas: Bundesamt für Seeschifffahrt und Hydrographie (BSH Germany), Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR), Croatian Ministry of Economy and Sustainable Development, Cruise Lines International Association (CLIA), Department of Transport Ireland, European Community Shipowners' Association (ECSA), European Association of Internal Combustion Engine and Alternative Powertrain Manufacturers (EUROMOT), European Sea Ports Organisation (ESPO), EUROSHORE, Exhaust Gas Cleaning Systems Association (EGSA), DG Shipping-FPS Mobility and Transport, Hempel, International Fund for Animal Welfare (IFAW), International Windship Association (IWSA), Mærsk Mckinney Møller Center for Zero Carbon Shipping, Maritime Research Institute Netherlands (MARIN), OceanCare, Registro Italiano Navale (RINA), Seas at Risk, Shipyards' & Maritime Equipment Association (SEA Europe), Stichting De Nordzee and the Surfrider Foundation.

We would also like to express our appreciation to all individuals who supported this report in various capacities.

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Executive summary and key messages

This second edition of the *European Maritime Transport Environmental Report* (EMTER 2025) examines the progress made towards achieving Europe's decarbonisation targets and environmental goals for the maritime sector while indicating the most important trends, key challenges, and opportunities. The objective was to update the indicators developed for the first report, analyse new datasets, and fill existing gaps, to provide a data and knowledge-based assessment of the maritime transport sector's transition to sustainability.

Promising progress in various domains

Sulphur oxides (SOx) emissions

There has been a notable decrease in total Sulphur oxides (SOx) emissions in the EU, with model data for 2023 estimating a reduction of approximately 70% since 2014. While the global sulphur cap, introduced in 2020, contributed to this decline, the primary driver has been the implementation of Sulphur Emission Control Areas (SECAs) in the Baltic Sea and North Sea. Starting 1 May 2025, the Mediterranean Sea will become the third SECA in European waters, and North-East Atlantic countries are considering establishing an ECA, potentially by 2027. These measures should bring substantial health and environmental benefits, improving air quality across the EU. In addition, according to the Long-Range Transboundary Air Pollution Convention (LTRAP) inventory, the share of maritime SOx emissions has slightly declined compared to the other transport modes.

Non-indigenous species

The shipping sector has played a significant role in the introduction of non-indigenous species (NIS) and invasive alien species (IAS) in Europe, mainly through ballast water and hull fouling, which account for 60% of NIS and 56% of IAS introductions. However, while the number of NIS continues to increase, the introduction of IAS peaked between 2000 and 2005 and has since decreased. The International Ballast Water Management Convention entered into force in 2017, and by 2023, 31% of the ships held an International Ballast Water Management Certificate, while 23% had compliant ballast water management systems.

Delivery and collection of waste from ships at EU ports

2023 marked the first full year of data reporting under the Port Reception Facilities (PRF) Directive, providing insights into the volumes and types of waste delivered by ships and collected by ports. The largest amounts of waste delivered to port reception facilities were oily waste and garbage, followed by sewage. Leading ports such as Rotterdam, Antwerp, and Copenhagen handled the highest volumes of waste, highlighting the significant role ports play in managing waste from ships. Additionally, the introduction of the Passively Fished Waste program under the PRF Directive enabled an analysis of 2022 data, revealing that 26% of the waste passively collected by fishermen was plastic. Ongoing efforts to engage the fishing sector in collecting and delivering waste to ports and reporting waste caught in their nets during routine fishing activities remain critical and are being successfully implemented.

Underwater noise

Continuous underwater radiated noise from ships impacts wildlife negatively. To address the lack of consistent monitoring data across the EU, new model data now provides a comprehensive, pan-European overview, allowing quantitative like-for-like comparisons of shipping contributions to ambient sound between regions, vessel categories, years, and forecast scenarios from 2016 to 2050. Areas that have the highest sound pressure level values in Europe include parts of the English Channel; the Strait of Gibraltar; parts of the Adriatic Sea; the Dardanelles Strait; and some regions in the Baltic Sea. The lowest values are recorded in the north-west part of the North-East Atlantic Ocean, particularly around the Denmark Strait and the Irminger Sea, and the southern part of the Mediterranean Sea. Foresight modelling has identified technical and operational mitigation measures that could reduce underwater radiated noise by up to 70% from 2030 to 2050 compared to a business-as-usual scenario, thanks to the implementation of underwater radiated noise and greenhouse gas mitigation measures.

Extensive research on-going

This report underlines the crucial role of research and innovation in facilitating the maritime transport sector's shift towards environmental sustainability. Significant EU investments are driving advancements in clean technologies across diverse areas like renewable energy, hydrogen, and carbon capture. Efforts are focused on developing alternative fuels and energy-efficient ship designs, alongside technologies to reduce air pollutants and improve operational efficiencies through digitalisation. Moreover, research aims to enhance port automation, sustainable waste management practices, and the adoption of circular economy principles to minimise environmental impact.

Environmental pressures from maritime transport

Maritime transport remains vital for EU trade and economic growth (about 75% of EU merchandise imports and exports rely on maritime transport), however, it also contributes to environmental issues, emphasising the need for sustainable practices to mitigate its impact. An analysis of the pressures the sector places on the environment is included in EMTER.

Key pressures

Greenhouse gas (GHG) emissions

Maritime transport in 2022 accounts for 14.2% of EU transport CO_2 emissions, with emissions rising yearly since 2015. While it remains one of the least carbon-intensive transport modes, CO_2 emissions from this sector have increased annually since the Paris Agreement in 2015, except in 2020 due to the pandemic. In 2022, CO_2 emissions from monitored voyages totalled 137.5 million tonnes, an 8.5% increase from 2021. Five types of ships—containerships, oil tankers, bulk carriers, chemical tankers, and general cargo ships—accounted for 80% of these emissions.

Data shows that from 2015 to 2023, the Mediterranean had the highest average yearly CO_2 emissions at 64 million tonnes, followed by the Atlantic at 31 million tonnes, and the North Sea at 26 million tonnes. During this period, CO_2 emissions increased by 46% in the Atlantic, 15% in the Mediterranean, 67% in the Baltic, and 62% in the Arctic, while they decreased by 8% in the North Sea and by 1% in the Black Sea. Most ship types saw an absolute increase in emissions, however, improvements in technical and operational energy efficiency have reduced emissions per unit of transport work (in grammes per tonne-kilometre, g/tkm) for specific ship types, such as cargo, containerships, and tanker vessels.

Additionally, fishing vessels in the EU emitted about 4.8 million tonnes of CO_2 in 2021 (a 25% reduction since 2009) and are estimated to have emitted about 3.7 million tonnes of CO_2 in 2023 (accounting for 2% of total EU transport emissions) due to a reduction in fleet size.

As for methane, emissions from the maritime transport sector have been rapidly increasing, driven by a 32.2% growth in the LNG fleet in 2022. Furthermore, data indicates that in the same year, the maritime sector contributed 26% of the total methane emissions from the entire EU transport sector.

Nitrogen oxides (NOx) emissions
Between 2015 and 2023, Nitrogen oxides (NOx) emissions from the maritime sector have significantly risen by about 10% across the EU. In specific areas, the increase was even more pronounced: 33% in the Atlantic, 8% in the Mediterranean, and 32% in the Arctic. Moreover, data shows that the maritime sector's share of NOx emissions has been growing steadily. In 2022, emissions from this sector accounted for 39% of all NOx emissions from transportation. In addition, the issue of NOx emissions remains important due to the requirements of designated ECAs, notably in the Baltic and North seas, being in force only for new ships. Further to this, the International Maritime Organization (IMO) is poised to address concerns regarding NOx emissions from engines operating at low power loads.

Discharges of oil from ships
While there was a decrease in the detections of possible oil discharges from ships detected by the CleanSeaNet service up to 2022, the data for 2023 displays an inversion, with an average of 6.35 possible pollution incidents detected per million square kilometres. This marks a rise of over 58% compared to 2022, or 16% if only possible spills with high confidence level are accounted for, demonstrating enhanced surveillance capabilities. More pollution incidents are detected in the North Sea, likely due to offshore oil and gas activities, along with the southwest of the Iberian Peninsula, and the Mediterranean Sea which are affected by high maritime traffic. In 2023, 62% of the possible detected pollution incidents were smaller than 2 square kilometres, and 87% were less than 7 square kilometres, showcasing enhanced capability to identify smaller possible spills with higher-resolution satellite imagery.

Water discharges
Discharges from open loop exhaust gas cleaning systems (EGCS) account for 98% of permitted water discharges, largely due to the lower cost of compliance for ships installing EGCS scrubbers under EU and IMO sulphur emission regulations. The remaining 2% consist of grey water, sewage, bilge water, and closed loop EGCS discharges. The volume of grey water discharged has increased by about 40% between 2014 and 2023, primarily due to the growing number of cruise ships in operation. Discharges from EGCS may negatively impact the marine environment through the contaminants' contribution to processes such as bioaccumulation, acidification, and eutrophication, thus underlining the need for further risk assessment and regulatory measures.

Marine litter
Marine litter can be particularly harmful to the marine environment, biodiversity, and local economic activities. Fisheries and shipping are estimated to contribute to, respectively, 11.2% and 1.8% of marine litter in regional seas around Europe, with an estimated 50% decrease over the past decade.

Despite the relatively small number of reported lost containers compared to the total number shipped, notable incidents of container loss can have significant environmental impacts. For example, the CSAV TOCONAO incident in late 2023 led to the release of approximately 26 tonnes of plastic pellets, causing extensive environmental damage and triggering large-scale clean-up efforts along the Galician coastline. Data suggests that the shipping sector contributes between 141 and 279 tonnes to annual pellet losses from European industries. These losses can have both immediate and long-term environmental, socioeconomic, and health impacts, further highlighting the need for robust prevention and response measures.

Collisions with animals
The risk of ships colliding with whales and turtles has significantly increased in the eastern Greater North Sea, the southern Bay of Biscay, the Gibraltar region, and parts of the Aegean Sea due to increased maritime traffic, potentially leading to both safety issues and impacts on marine biodiversity. Additionally, from 2017 to 2022, there has been a notable rise in collision risks within Natura 2000 protected areas across all marine regions. Conversely, this collision risk has decreased along the western coast of the Iberian Peninsula, and in parts of the Celtic Seas, Adriatic Sea, and Black Sea.

Seabed integrity
Approximately 27% of Europe's near-shore seabed (5% facing severe effects) is impacted by maritime transport linked activities such as port expansions, dredging, and anchoring, which lead to physical disturbances and habitat loss. Specifically, 4.2% of broad benthic habitats are disturbed solely by maritime transport, and 0.2% of habitats experience loss due to significant seabed changes from these activities.

Expansion of ports
Between 2000 and 2018, port areas in Europe grew by 12.5%. Port expansions in Europe contribute to impacting marine seabed habitats by disturbing ecosystems through dredging, land reclamation, and increased shipping traffic. The habitats most impacted by port activities were sandy and muddy areas in shallow, near-shore water, which provide homes for various species including seagrass, microalgae, mangroves, saltmarsh, prawns, bivalves, mud crabs, and fish.

What's next? Options to accelerate the transition to sustainability

Ambitious decarbonisation targets in EU legislation
Reductions in maritime transport's GHG emissions will be supported by the implementation of maritime related legislation under the 'Fit-for-55' package. Notably, the EU will become the first jurisdiction to put an explicit carbon price on GHG emissions from the maritime sector with the extension of the EU Emissions Trading System (ETS) to the sector, and its coverage of large ships entering European ports.

The FuelEU Maritime Regulation, implemented from January 2025, mandates a progressive reduction in the GHG intensity of the energy used onboard ships (2% decrease by 2025, 6% by 2030, and an 80% reduction by 2050), which aims at incentivising the uptake of low and zero carbon fuels as well as creating the demand for onshore power supply (OPS). Concurrently, the Alternative Fuel Infrastructure Regulation (AFIR) ensures the development of infrastructure for alternative fuels as well as the deployment of OPS.

The Renewable Energy Directive (RED III) sets binding targets for the use of renewable energy in the transport sector, including maritime transport, driving innovation in advanced biofuels and renewable fuels of non-biological origin. Additionally, a proposal to revise the Energy Taxation Directive aims to align energy taxation with EU climate policies, promoting clean technologies and discouraging fossil fuel use. The EU legislative measures complement global targets set by the International Maritime Organization (IMO), such as the reduction of GHG emissions from shipping by at least 20% by 2030 (striving for 30%), as well as reducing the maritime sector's carbon intensity by at least 40% compared to 2008.

Decarbonisation, alternative fuels, and technologies
While the maritime sector is one of the least carbon-intensive transportation modes, projections suggest a concerning trajectory, with anticipated increases of CO_2 emissions of 14% by 2030 and 34% by 2050 under current trends.

To meet emission reduction targets by 2030, limiting fossil fuel consumption will be crucial, necessitating substantial investment in alternative fuel infrastructure. Various decarbonisation options are under consideration by maritime stakeholders, each with varying levels of technological readiness, availability, sustainability, and suitability for onboard use. Within the next decade, increased use of biofuels, methanol, batteries, and other electric energy/power systems is expected. Biofuels are notable for their rapid adoption due to engine and infrastructure compatibility, but due consideration should be given to sustainability, biomass competition, and safety criteria. Hydrogen, ammonia, and synthetic fuels offer promise but face immediate challenges like production, scalability, storage, distribution, cost, and safety concerns. Wind propulsion shows significant fuel savings, while nuclear and onboard carbon capture both present interesting solutions, but with challenges of their own. Green shipping corridors also aim to accelerate the adoption of zero-emission maritime routes, emphasizing collaborative efforts and technological innovation to achieve sustainable maritime energy solutions. Finally, preparing seafarers with specialised training for the safe operation of new fuels and technologies is essential. Estimates indicate that up to 800,000 seafarers may need training by the mid-2030s in parallel with the target of achieving net-zero emissions by 2050.

In view of these challenges, concerted efforts are underway to promote sustainable practices in the maritime sector. By investing in alternative fuels, enhancing energy efficiency, and establishing international training standards, stakeholders can significantly advance decarbonisation goals and reduce environmental impact. Operational measures can also offer significant results, for example through speed reduction (slow steaming), weather routing, port call optimisation, and improved hull monitoring and maintenance.

Marine ecosystems and zero pollution
Moving forward, the effective protection and sustainable use of marine ecosystems will rely on strong implementation of regulatory frameworks, improved monitoring and reporting, and enhanced international cooperation. This will ensure that maritime transport activities can coexist with efforts to reduce environmental pressures, including pollution.

EMTER serves as an essential information source for the Zero Pollution Monitoring and Outlook Report. The Marine Strategy Framework Directive (MSFD), the revised Ship Source Pollution (SSP) Directive, and the Port Reception Facilities (PRF) Directive are key to achieving cleaner maritime transport and zero pollution targets, addressing underwater noise, oil spills, chemical pollution, microplastic releases, and marine litter. To address underwater noise pollution, operational and technical improvements, such as reducing ship speeds, and implementing efficient propeller and hull designs are necessary. The MSFD has already set noise level thresholds to protect marine species.

To mitigate the risk of ship strikes on marine life, particularly large cetaceans and turtles, the focus must shift to spatial zoning, rerouting shipping lanes, and enforcing speed restrictions. The Marine Spatial Planning Directive (MSPD) provides a framework to enable these protective measures.

Maintaining seabed integrity is also critical, as maritime activities such as port expansions, dredging, and anchoring can physically disturb marine habitats. The MSFD sets monitoring standards and thresholds to limit adverse effects on benthic habitats and prevent habitat loss. Sustainable dredging practices, green infrastructure, and ecological engineering - such as natural materials and designs for port structures - combined with habitat compensation and restoration projects, will help protect coastal ecosystems and prevent further damage.

Remaining data and knowledge gaps

This report has benefited from the availability of new data. Specifically, the detection of smaller possible oil spills with higher-resolution satellite imagery has improved with EMSA's CleanSeaNet service, which is empowered by enhanced satellite surveillance capabilities. Estimates of the environmental impacts of the fishing fleet (vessels carrying AIS and over 12m in length) have progressed, especially in connection with CO_2 emissions. Information on the amount of waste delivered by ships to EU ports has improved due to the reporting under the Port Reception Facilities Directive. Additionally, there has been significant progress in estimating the impacts on the seabed as well as in understanding the total CO_2 emission from ships while at berth, thanks to the reporting under the MRV regulation.

Nevertheless, maritime transport would benefit from more effective monitoring and enhanced reporting systems to support the implementation of current and future regulations aimed at reducing its environmental impact, while also minimising administrative burdens. Standardising data collection and reporting of the source of pollution would ensure more accurate, reliable, and comparable emission measurements. With the notable exception of CO_2 under the MRV regulation, there are no mandatory monitoring and reporting requirements for pollutants such as NOx, Volatile Organic Compounds, Particulate Matter, and Black Carbon, creating gaps in understanding the sector's environmental impact, particularly in high-seas operations. A fuller picture of vessels' complete life cycle emissions is needed, requiring more data on manufacturing, shipbreaking, and maintenance. Filling these gaps would strengthen the implementation of key EU policies, further supporting the European Green Deal and the Fit-for-55 package. For instance, work on fuel lifecycle reporting under Renewable Energy Directive (RED) and the improved reporting requirements with the revised Ship Source Pollution (SSP) Directive will also contribute to tackling these issues.

Advancements in maritime technologies, including alternative fuels and novel power solutions present new challenges in assessing emissions and safety risks, making international collaboration, standardised monitoring and reporting frameworks, and regulatory measures essential.

Overall key messages

Air emissions

- The maritime sector accounts for 14.2% of the EU's CO_2 emissions from transport, behind the road sector, and almost equivalent to the aviation sector. CO_2 emissions from maritime transport have increased annually in the EU since 2015 (except for 2020), amounting to 137.5 million tonnes in 2022, 8.5% more than the previous year.

- Methane (CH_4) emissions from maritime transport have at least doubled between 2018-2023 and constitute 26% of the transport sector's total methane emissions in 2022.

- Sulphur oxides (SOx) emissions in the EU have decreased by about 70% since 2014, largely due to the introduction of Emission Control Areas for SOx (SECAs) in Northern Europe. The Mediterranean SECA, set to take effect on 1st May 2025, is expected to replicate this success in that region, and North-East Atlantic countries are considering establishing an ECA, potentially by 2027. In contrast, Nitrogen oxides (NOx) emissions from the maritime sector have risen significantly in 2015-2023, by an average of 10% across the EU, despite the North and Baltic Seas being designated as NOx ECAs since 2021 due to low penetration rates as requirements apply to new ships only.

Water pollution

- Maritime transport contributes to water pollution through the emission of hazardous substances, primarily oil spills, but also through operational discharges such as grey water and waste from exhaust gas cleaning systems (ECGS). Noticeably, open-loop ECGS account for 98% of permitted water discharges, with the remaining 2% comprising of grey waters, sewage, bilge water, and closed-loop ECGS. Furthermore, the discharge of grey water has increased by 40% from 2014 to 2023, mainly due to the growth in cruise ship operations.

- Enhanced satellite technology can now detect smaller possible oil spills on the sea's surface than ever before. Most of the 2023 possible incidents detected from space by the CleanSeaNet service covered an area of less than two km^2.

- New pan-European model data allows for quantitative comparisons of underwater radiated noise from shipping, revealing high sound pressure level (SPL) values in parts of the English Channel, the Strait of Gibraltar, parts of the Adriatic Sea, the Dardanelles Strait and some regions in the Baltic Sea. Forecast data suggests that technical and operational mitigation measures could reduce noise by up to 70% between 2030 and 2050.

- Marine litter attributed to fisheries (11.2%) and shipping (1.8%) sources in the regional seas around Europe is estimated to be decreasing, reaching half of the values from a decade ago. In addition, there is an increasing amount of data on waste deliveries from ships to EU ports each year. However, challenges remain in tackling plastic pollution, such as the release of pellets from lost containers.

- In 2022, while 13.2% of the global fleet was flagged under an EU Member State, only 7% of end-of-life vessels recycled carried such a flag at the time of disposal. This underscores how re-flagging continues to undermine EU efforts for safe and environmentally sound ship recycling.

Biodiversity

- Maritime transport impacts biodiversity through activities like port expansions, dredging and anchoring that affect 27% of Europe's near-shore seabed and lead to physical disturbances or habitat loss. There has also been a notable rise in collision risks of ships with marine wildlife within Natura 2000 protected areas.

- While the number of non-indigenous species (NIS) keeps increasing, the introductions of invasive alien species (IAS) peaked in 2000-2005 and has since decreased. The International Ballast Water Management Convention entered into force in 2017, and by 2023, 31% of the ships held an International Ballast Water Management Certificate, while 23% had compliant ballast water management systems.

Decarbonisation, alternative fuels, and technologies

- Recently adopted EU legislation, such as the extension of the ETS to maritime transport and the FuelEU Maritime initiative, can be expected to advance the decarbonisation of the sector. An increasing number of ships are being equipped with alternative fuel systems, indicating a shift towards greener energy solutions. The use of batteries is increasing, with the fleet using them expected to double in the coming years. While the number of ships using methanol remains low, it is growing, as are the numbers of ships using wind propulsion and hydrogen.

- At least 44 EU ports have already implemented onshore power connections (OPS), with 352 berths having shore-to-ship power supply facilities. However, only a limited number of ships have the necessary equipment to connect to high voltage OPS.

Data and knowledge gaps

- The absence of monitoring data and standardised reporting requirements in the maritime sector, for example for pollutants such as NOx, Volatile Organic Compounds, Particulate Matter, and Black Carbon, hinders the comprehensive assessment of their environmental impacts. Digitalisation, along with advanced remote and in-situ monitoring technologies, can help bridge these gaps.

1 Introduction

Key messages

- The maritime transport sector plays a key role in the EU's economy. Around 74% of EU merchandise imports and exports rely on maritime transport.
- In 2021, the maritime transport sector generated a Gross Value Added (GVA) of €44.3 billion. Ports generated a GVA of €29.5 billion, representing a 9.2% decrease from the peak registered in 2020.
- Employment in the sector has been steadily increasing, reaching 292,000 persons directly employed in 2022 (not including fisheries and ports). About 410,000 persons were employed in port activities in 2021.
- There has been a decline in the EU fishing fleet since 2016, with about 72,500 vessels registered in 2022, compared to 77,500 in 2016. This reduction is visible also in terms of the fishing fleet capacity, both in total engine power and tonnage.

1.1 Aim and objective

The *European Maritime Transport Environmental Report* (EMTER) assesses the environmental footprint of the maritime transport sector. It supports the pollution prevention and decarbonisation targets of the sector, as indicated by the European Green Deal and the Fit for 55 package, and is reflected in key initiatives such as the Sustainable and Smart Mobility Strategy and the Zero Pollution Action Plan (EC, 2021g).

The objective of this second EMTER report is to update the indicators developed for the first report (EMTER 2021; EEA and EMSA, 2021), analyse new datasets, and fill existing gaps, to provide a data and knowledge-based assessment of the maritime transport sector's transition to sustainability. As with the first version of the report, EMTER 2025 is targeted to a wide range of stakeholders, including European Union (EU) policy decisionmakers, EU Member States' maritime and environmental national administrations, industry and science organisations, business and environmental NGOs, and civil society. It will also feed into other policy monitoring frameworks such as the Zero Pollution Monitoring and Outlook to help determine the contribution of the maritime sector to achieving the European Green Deal targets.

1.2 From EMTER 2021 to EMTER 2025

The first edition of the EMTER report, published in 2021, provided the first comprehensive analysis conducted by EU agencies of the EU maritime transport sector's environmental footprint. It presented information on the relevant environmental standards and described actions to reduce the sector's impact on the environment, highlighting challenges and opportunities which exist when it comes to the necessary implementation and cooperation at European level.

Within this context, the European Maritime Safety Agency (EMSA) and the European Environment Agency (EEA) have updated the first edition of the report, to fill in gaps and to provide a set of new elements. These include biodiversity-related indicators, the analysis of observational air emission measurements from remotely piloted aircraft systems, insight on water discharges, underwater radiated noise forecast scenarios, marine litter, fishing vessels, EU 2030 targets for decarbonisation, alternative carbon-free energy sources, as well as an up-to-date CO_2 emission outlook and energy transition foresight. The report also provides new information on how the maritime transport sector contributes to preventing marine litter in Europe's seas, with new data on waste collected during fishing activities (passively fished waste).

Nevertheless, it is important to note that some of the gaps identified in EMTER 2021 still remain in this new edition – on air quality in ports, for example, where data is still missing and further research is required.

The report is split into four main chapters. Chapter 1 introduces the economic and social status of the maritime transport sector. Chapter 2 offers an update of the key data, indicators and trends of EMTER 2021, evaluating the trends and progress made to reach maritime environmental targets. Where possible, it also provides new elements. Chapter 3 examines the opportunities and challenges of the sector regarding the implementation of the new legislative framework on decarbonisation, in line with the ambition of the European Green Deal and the proposals related to the maritime transport sector.

The report concludes with a summary of the major remaining gaps (Chapter 4), while highlighting priority areas in need of development to further reduce the environmental footprint of the maritime transport sector and support the EU decarbonisation roadmap. Annex 1 covers all the international and EU environmental regulatory and monitoring frameworks relevant to the maritime transport sector, thereby providing the context for the monitoring and reporting of data, indicators and trends presented in Chapter 2.

1.3 State of the maritime transport traffic and trade

Throughout the report, the term 'maritime transport' is used to describe all shipping and related port activities of a commercial or private nature linked to the transport domain. It therefore includes activities of cargo, carriers, containers, tankers, vehicle/passenger (Ro-Ro and Ro-Pax ([1])) and cruise ships alike. In contrast to EMTER 2021, this version of the report includes commercial fishing vessels in its definition, while offshore and other marine and maritime industrial platforms are not within its scope. However, there remains a distinction between shipping vessels and fishing vessels. This differentiation is necessary because in many instances these two categories are subject to different regulatory frameworks (for further details see Annex 1 Regulatory and monitoring frameworks).

([1]) Ro-Ro and Ro-Pax ships are those built for freight vehicle transport and passenger accommodation.

Maritime transport plays a crucial role in sustaining trade, economic growth, connectivity and accessibility, while also contributing to energy security and job creation. It handles and delivers large volumes of cargo, resulting in reduced energy consumption and transportation costs, along with increased efficiency (economies of scale) compared to other modes of transport (UNCTAD, 2020).

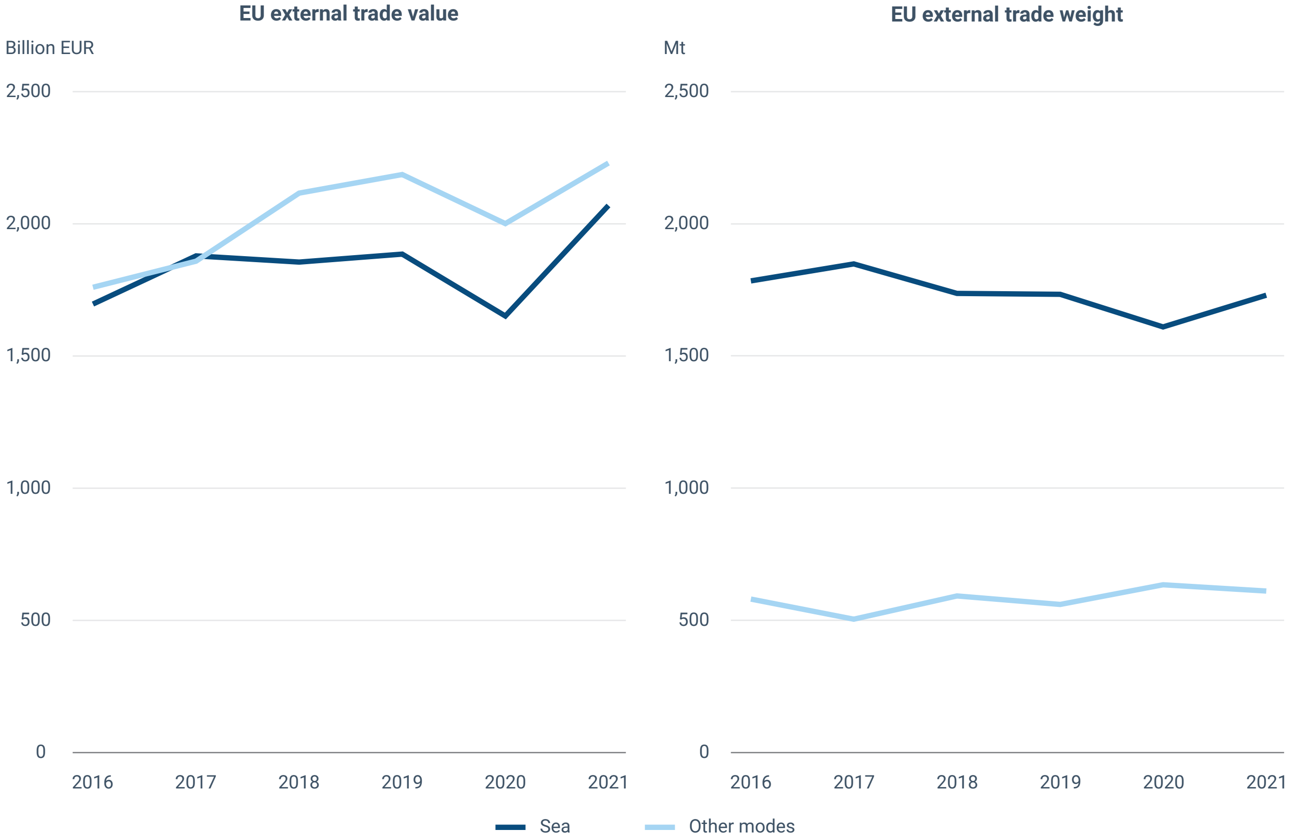
However, increased transport demand for the maritime sector comes with additional environmental impacts on the atmosphere and marine ecosystems. The majority of goods transported in and out of the EU are shipped using maritime transport.In 2021, 74% of the EU's total merchandise imports and exports were traded by sea. The maritime transport sector, excluding fisheries and ports, generated a gross value added (GVA) of EUR 44.3 billion in 2021, a 42% increase compared to 2020 and 23% compared to the 2019 peak. Gross profit, at EUR 28.1 billion, increased by 77% on the previous year. Over half (58%) of the sector's GVA (EUR 25.5 billion) was generated by freight transport activities, followed by services with EUR 14.8 billion (33%) and then passenger transport with EUR 4 billion (9%). The turnover reported for 2021 was EUR 176.7 billion, a 16% increase on the previous year (EC and JRC, 2024).

In 2021, the maritime sector directly employed almost 380,000 people, excluding fisheries and ports, 2% more than in 2020. Nearly half of them were employed in activities related to services related to marine and maritime transportation equipment. The other half were employed in passenger transport activities (25%) and freight transport operations (25%) (EC and JRC, 2024). This overall number then decreased by 23%, to 292,000 in 2022 (Eurostat, 2023a). Employment in the maritime sector (excluding fisheries) has been increasing steadily since 2014, reaching the record level of 403,000 people in 2019 before suffering an 8% drop due to travel restrictions imposed during the COVID-19 pandemic (EC and JRC, 2023). These employment numbers are anticipated to rise further due to the EU's substantial role in developing new maritime technologies and services aimed at decarbonising the sector.

EU-27 external trade is dominated in both weight and value by maritime transport, with only a slight decline during the COVID-19 outbreak in 2020 as seen in Figure 1.1. More precisely, the pandemic highlighted the importance of maritime transport in supporting the European economy. Demand for maritime transport is continuously growing, with the amount of goods handled by EU ports in 2021 at 3,463 million tonnes for external trade as per Figure 1.3 (Eurostat, 2023d).

The EU accounts for 17.6% of the total commercial world fleet by gross tonnage (GT). It therefore faces a critical decade where it must lead the transition towards a more economically, socially and environmentally sustainable maritime transport sector (EEA, 2021). The realisation of the EU's integrated policies and strategies are crucial in reducing environmental impacts and achieving a more sustainable maritime transport sector. These include the Fit for 55 package (EC, 2021d),the Sustainable and Smart Mobility Strategy (EC, 2020c), the EU Biodiversity Strategy (EC, 2020b), the Zero Pollution Action Plan (EC, 2021g), as well as the implementation of EU regulations and directives such as the extension of the Emission Trading Scheme (ETS) to the maritime sector (EU, 2023b), the FuelEU Maritime Regulation (EU, 2023d), the Marine Strategy Framework Directive (EU, 2008a), the Water Framework Directive (WFD) (EU, 2000), the Habitats and Birds directives (EU, 2010, 2013a), the Marine Spatial Planning Directive (EU, 2014a),the Ship-Source Pollution Directive (EU, 2009b), as well as the revised Ambient Air Quality Directive (EU, 2024).

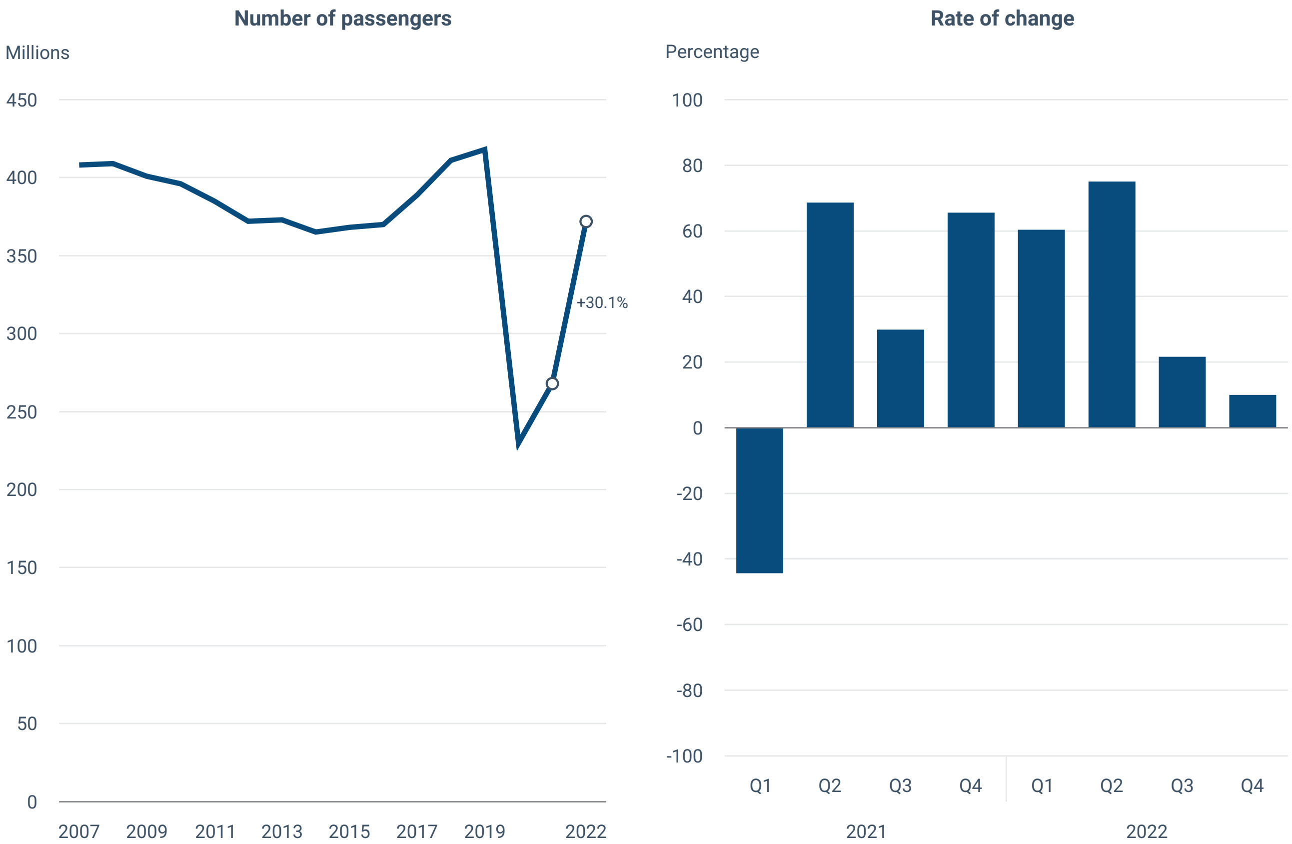
Figure 1.1 **External trade per mode in the EU-27**



Source: EC, Statistical Pocketbooks 2017 to 2022, Section 2.1 (EC, 2022).

In 2020, the volume of seaborne imports and exports in Europe diminished by 7.3% and 7.8% respectively compared to the previous year. However, in 2021 there was a sound rebound (+8.3% and +7.9%, respectively compared to the previous year) due to the gradual reopening of economies (UNCTAD, 2022). Due to the pandemic, other economic activities of the sector suffered more than freight transport. In 2019, approximately 400 million passengers embarked and disembarked at EU ports each year. In 2020, this figure plummeted to about 230 million (EC, 2023a). The number of seaborne passengers only partially recovered in 2022. Despite a 30% increase on the previous year, it remains below 2019 levels (Figure 1.2).

Figure 1.2 Seaborne passengers (embarked and disembarked) in all EU ports, 2007-2022



Sources: Eurostat, 2023a, 2023b.

Ports are integral to the maritime ecosystem and sit at the heart of the sustainable development of the maritime transport sector. EU ports vary in size and may receive port calls from a range of ship types calling in, or from specific types of vessels (EEA and EMSA, 2021).

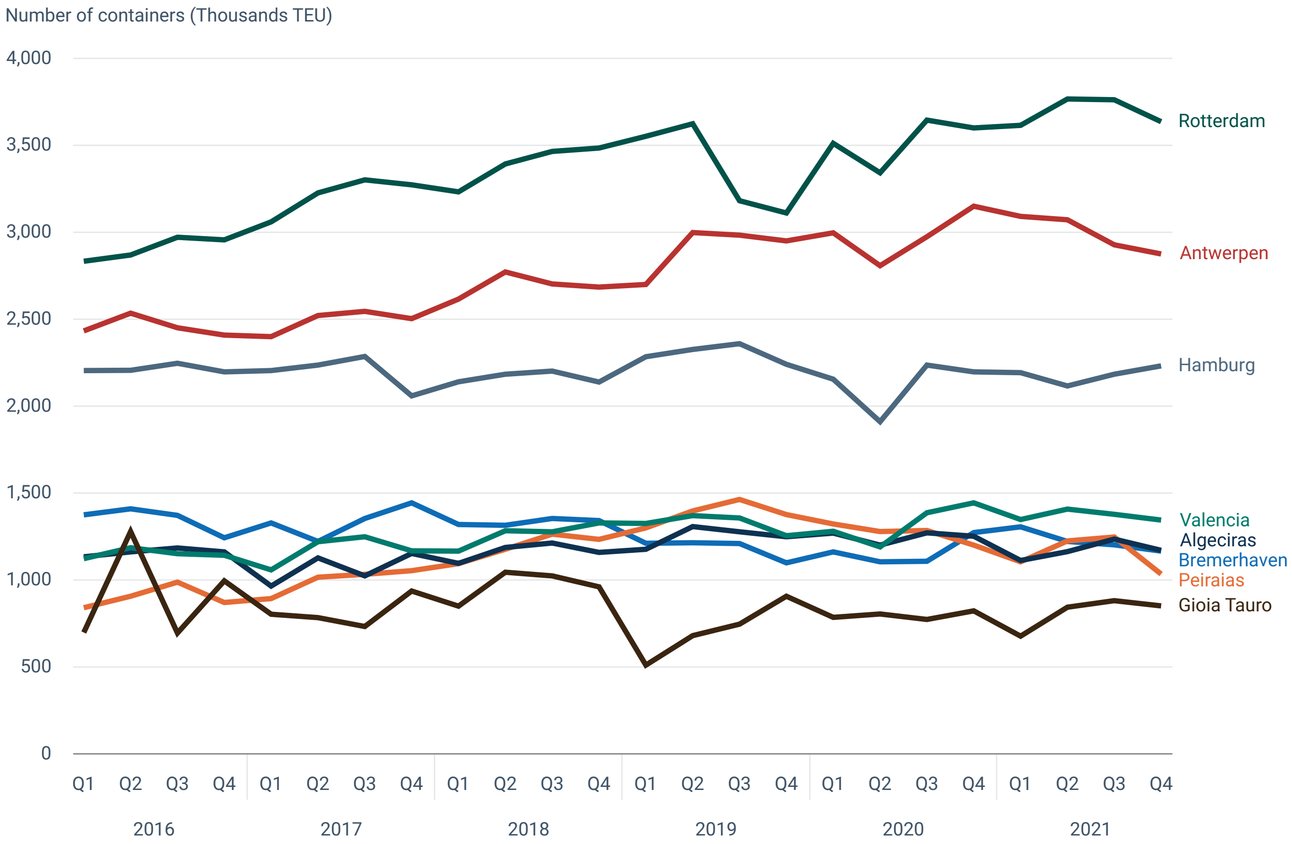
Ports are crucial to the European economy and are essential pieces of infrastructure with pivotal commercial and strategic importance. They are gateways for EU trade and instrumental in supporting the free movement of goods and persons across Europe. They also enable economic and trade development through traditional activities such as cargo handling, logistics and servicing, while supporting a complex cross section of industries and facilitating the clustering of energy and industrial companies in their proximity.

In 2021, ports generated a GVA of EUR 29.5 billion, representing a 9.2% increase from 2020 (EUR 26.9 billion) and a 3.5% increase from the 2019 peak (EUR 27.9 billion). Gross profits registered a year-on-year drop of EUR 1 billion, although they remained relatively steady across the past decade at approximately EUR 10.8 billion on average. Reported turnover, at EUR 76.0 billion in 2021, marked the sharpest year-on-year increase since 2009 (+EUR 8.1 billion from 2020) (EC and JRC, 2024).

The port activities sector directly employed nearly 410,000 people in 2021, up from 385,627 in 2020. Nearly 60% worked in cargo and warehousing activities, with the remaining 40% in the port and water projects sub-sector. In 2021, the two sub-sectors generated an almost equal share of the sector's GVA, i.e., approximately EUR 15 billion each (EC and JRC, 2024).

North Sea EU ports remain at the top of the list in terms of total containers handled, with figures twice those of Mediterranean Sea ports, as shown in Figure 1.3.

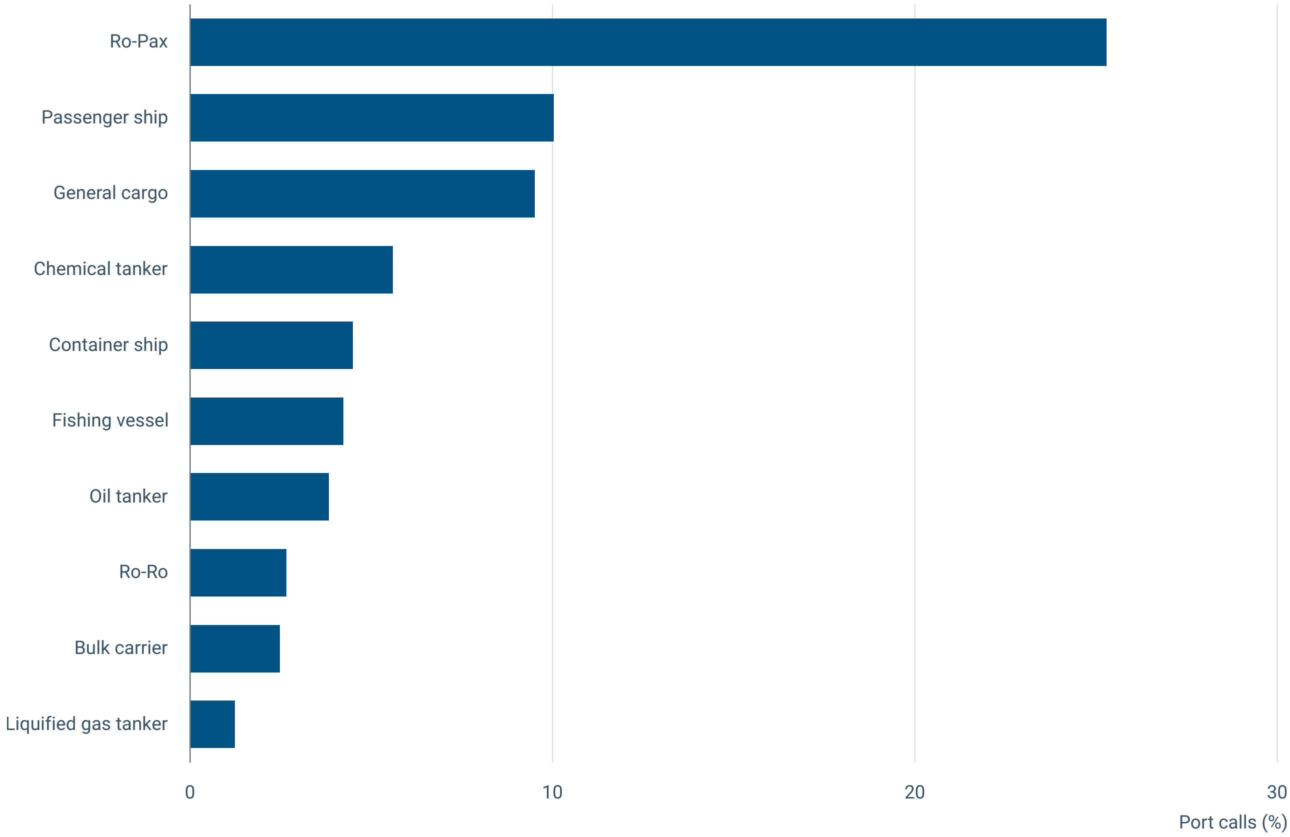
Figure 1.3 Volume of containers handled in EU top 8 ports



Note: TEU, Twenty-foot Equivalent Unit (standard unit for counting containers of various capacities).
Source: Eurostat, 2022.

However, it is also important to highlight the role of trans-shipment ports in neighbouring countries. In these ports, containers are unloaded from a ship in port for the purpose of being loaded onto another ship. Although this report focuses on maritime transport in the EU, there are substantial interlinkages with neighbouring non-EU ports which should ideally be considered when assessing the environmental impacts of ports.

Figure 1.4 Port call distribution across EU ports per ship type in 2022



Notes: Ro-Ro, roll-on, roll-off.
Ro-pax, roll-on, roll-off passenger (ships).

Source: EMSA, 2023.

EU ports handle a significant proportion of the total port calls made each year around the world. In 2022, more than 12 million port calls took place globally, with almost 3 million (approximately 23%) located in EU and European Economic Area ports.

This report examines the impact of fishing vessels on the marine environment for the first time. Overall, the total number of EU fishing vessels has declined from around 77,500 in 2016 to 72,500 in 2022 (-6.5%). However, both in terms of size and power needs, the fishing fleet is smaller than the merchant fleet, hence the overall related emissions and environmental impacts can be assumed to be lower, irrespective of where the fleet operates ([2]). Table 1.1 shows that the majority of the fishing fleet belonging to EU Member States is registered in five countries, namely Greece, Italy, Spain, Portugal and Croatia, which collectively account for 68% of the total. The same countries account for 51.2% of the gross tonnage and 53.1% of the engine power across the fleet. Interestingly, while the Greek fleet is numerous (at 19.5% the largest in terms of numbers), but relatively small in gross tonnage (5.2%) and engine power (7.8%), the French fleet is smaller in numbers (8.4%), but largest in engine power (18.3%). This is down to the Greek fleet being dominated by small-scale vessels, as can be inferred by the EU Fleet Register data shown in Table 1.1.

([2]) Relevant data is available on the Scientific, Technical and Economic Committee for Fisheries (STECF) website: https://stecf.jrc.ec.europa.eu/index.html.

Table 1.1 Total EU size, gross tonnage and engine power of fishing fleet per EU Member State in July 2021

MS	Number of vessels	%	Gross tonnage	%	Engine power in kW	%
BE	67	0.1%	13,627	1.0%	44,733	0.8%
BG	1,816	2.4%	6,005	0.5%	53,117	1.0%
DK	2,005	2.7%	66,815	5.1%	216,798	4.1%
DE	1,281	1.7%	57,293	4.3%	128,391	2.4%
EE	1,856	2.5%	17,551	1.3%	49,182	0.9%
IE	1,935	2.6%	58,954	4.5%	173,852	3.3%
EL	14,581	19.5%	69,016	5.2%	414,943	7.8%
ES	8,776	11.7%	329,374	25.0%	772,803	14.6%
FR	6,262	8.4%	176,331	13.4%	970,535	18.3%
HR	7,535	10.1%	43,272	3.3%	342,999	6.5%
IT	12,168	16.3%	146,777	11.1%	937,532	17.7%
CY	814	1.1%	3,808	0.3%	38,985	0.7%
LV	659	0.9%	22,371	1.7%	39,384	0.7%
LT	137	0.2%	36,030	2.7%	41,913	0.8%
MT	884	1.2%	6,451	0.5%	72,279	1.4%
NL	720	1.0%	99,440	7.5%	244,503	4.6%
PL	821	1.1%	32,396	2.5%	80,430	1.5%
PT	7,791	10.4%	86,945	6.6%	344,925	6.5%
RO	178	0.2%	1,624	0.1%	6,343	0.1%
SI	137	0.2%	671	0.05%	8,853	0.2%
FI	3,179	4.3%	15,922	1.2%	171,440	3.2%
SE	1,136	1.5%	28,577	2.2%	148,208	2.8%
EU-27	74,738	100.0%	1,319,250	100.0%	5,302,148	100.0%

Source: EU Fleet Register (EC, 2021).

2 Trends, status and prospects

This chapter explores the state of play in relation to the various environmental impacts of the maritime transport sector, along with an analysis of the trends, status and future prospects. This builds on the indicators developed in the first edition of EMTER, released in 2021, which are herein expanded and updated.

2.1 Emissions to the atmosphere

2.1.1 Greenhouse gases

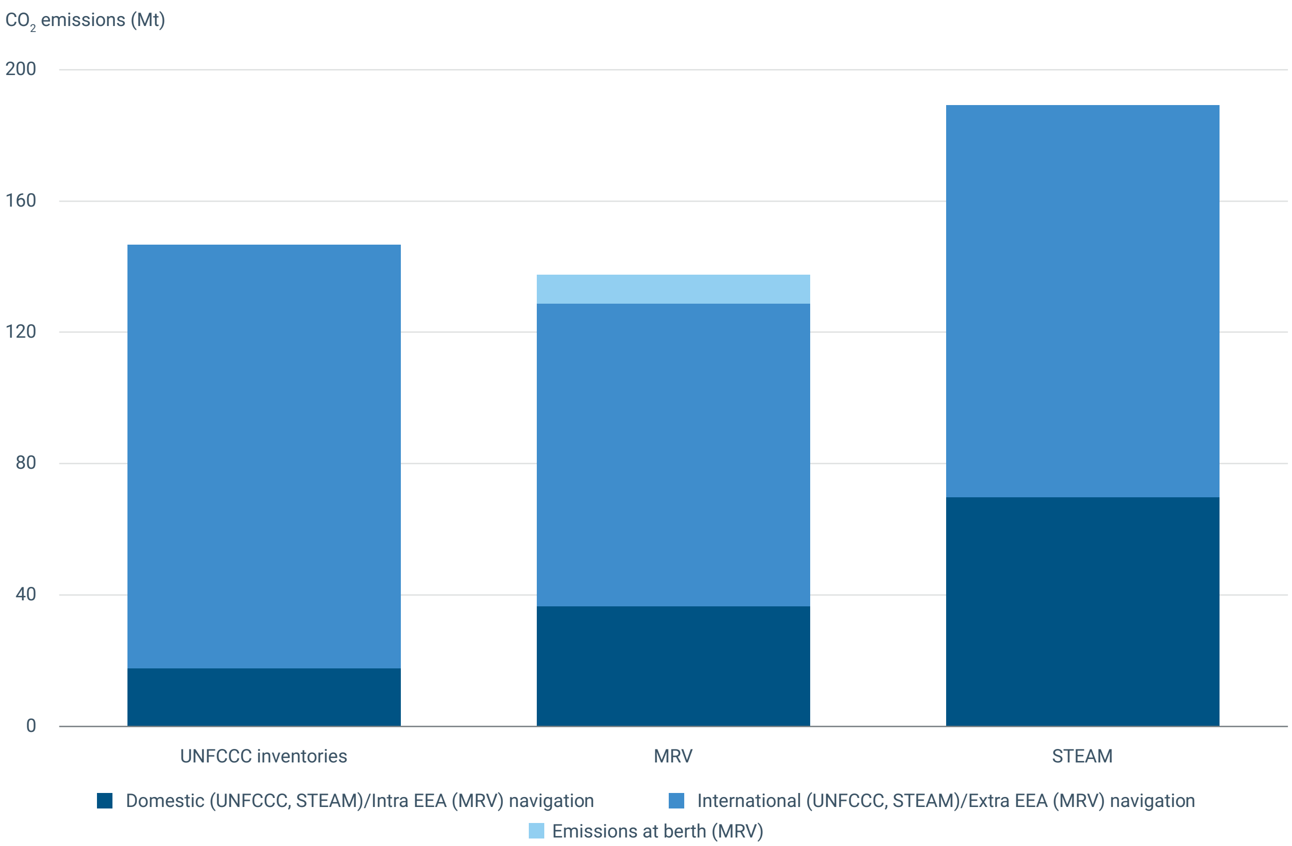
Key messages

- CO_2 emissions generated by the maritime transport sector account for approximately 3-4% of all EU CO_2 emissions,and specifically in 2022 for 14.2% of all CO_2 emissions from the EU transport sectoras a whole.
- CO_2 emissions of the shipping sector increased in 2022, with 137.5 million tonnes of CO_2 emitted into the atmosphere, 8.5% higher than in 2021.
- Between 2015-2023, CO_2 emissions increased by 46% in the Atlantic, 15% in the Mediterranean, 30% in the North Sea, and 67% in the Baltic, while there was a decrease of 8% in the North Sea and 15% in the Black Sea.
- In the Arctic region, CO_2 emissions have increased by 62% between 2015-2023, accompanied by an increase in the ships' distance travelled in the area of 48%.
- Fishing vessels in the EU emitted about 4.8 million tonnes of CO_2 in 2021 (a 25% reduction since 2009) and are estimated to have emitted about 3.7 million tonnes of CO_2 in 2023, accounting for 2% of total EU transport emissions.
- The contribution of the maritime transport sector to the EU region's overall transport emissions of methane (CH_4) has increased over time, reaching approximately 26% in 2022. CH_4 emissions across EU marine regions have increased between 2 and 5 times in 2018-2023.

Data reported under the EU's Monitoring Reporting Verification (MRV) shows that, in 2022, relevant maritime voyages and activities emitted 137.5 million tonnes of CO_2 into the atmosphere ([3]). This reflects a 8.5% growth in maritime emissions compared to 2021, originating from a fleet of nearly 13,000 ships (6.5% larger than 2021 and the highest number of ships recorded) (EC, 2024a). This accounts for around 55% of the ships calling to European Economic Area ports and covers 90% of all CO_2 emissions of the fleet ([4]) in tonnes of CO_2 equivalent (EC, 2023c). Additional information on MRV regulation and the legal and monitoring framework for greenhouse gases (GHGs) can be found in Annex 1.

Ship emissions are also monitored based on ships' activities, whether they are arriving to or departing from ports in the European Economic Area or travelling between them (see Figure 2.1). In 2022, ships arriving at ports in the European Economic Area accounted for 35% of the total shipping emissions, with voyages departing from European Economic Area ports representing 32.4%. Voyages between European Economic Area ports contributed 26.2%, while around 6.4% of the emissions came from ships at berth (EC, 2024a).

Figure 2.1 CO_2 emissions from the maritime sector in 2022



Notes: Data reported under: United Nations Framework Convention on Climate Change (UNFCCC) GHG inventories (left), MRV regulation (centre), Ship Traffic Emissions Assessment Model (STEAM) (right) ([5]).

Figures are in Mt, million tonnes of carbon dioxide.

Sources: UNFCCC; MRV; STEAM (EEA, 2022; FMI, 2024).

([3]) MRV system allows for the correction of already submitted emissions on a rolling basis.

([4]) From 2025, MRV will cover general cargo ships and offshore ships above 400 GT and below 5,000 GT, which will lead to an increased pool of ships being accounted.

([5]) Note that the definitions of the categories differ across the dataset. MRV emissions are classified as 'intra European Economic Area', 'extra European Economic Area' and 'at berth'. For inventories and Ship Traffic Emissions Assessment Model (STEAM), emissions are classified as 'domestic' or as 'international' navigation. Notice that these categories are defined in a different way in the two datasets.

Table 2.1 Data used in the report and differences between EU MRV, UNFCCC GHG inventories and STEAM model

		MRV	GHG Inventories	Steam
	Vessel	> 5,000 gross tonnage (GT) cargo/passenger ships: exceptions apply (military, fishing vessels, etc.)	Any waterborne vessel. Includes navigation on lakes and inland waterways. Fishing and military vessels are reported as separate categories.	All vessels entering the scope of the AIS system regardless of location.
Scope	Geographical	European Economic Area: EU-27 + Iceland, Liechtenstein and Norway (6)	EU-27: There is a difference between EU inventory and UNFCCC inventory due to differences in territory accounted for Denmark and France.	Global
	Emissions	Tank-to-Wake	Tank-to-Wake	Tank-to-Wake
Categorisation		Intra European Economic Area /extra European Economic Area /at berth	Domestic/international based on port of departure/arrival (for each segment of a trip). EU-27 results are obtained by summing Member State contributions.	Total/Domestic/international. International: ship movements which occur between two different countries. Domestic: between ports belonging to the same country.
Main approach		Fuel consumed on board	Fuel sold	Vessel activity through AIS data
Main output		CO_2 emissions	GHG (CO_2, CH_4, N_2O) emissions	GHG, AP, and contaminants
Reporting cycle/ timeliness		Yearly, T-1	Yearly, T-2	Yearly, T-1

Notes: MRV, Monitoring, Verification, and Reporting.
UNFCCC GHG, United Nations Framework Convention on Climate Change GreenHouse Gas.
STEAM, Ship Traffic Emissions Assessment Model.

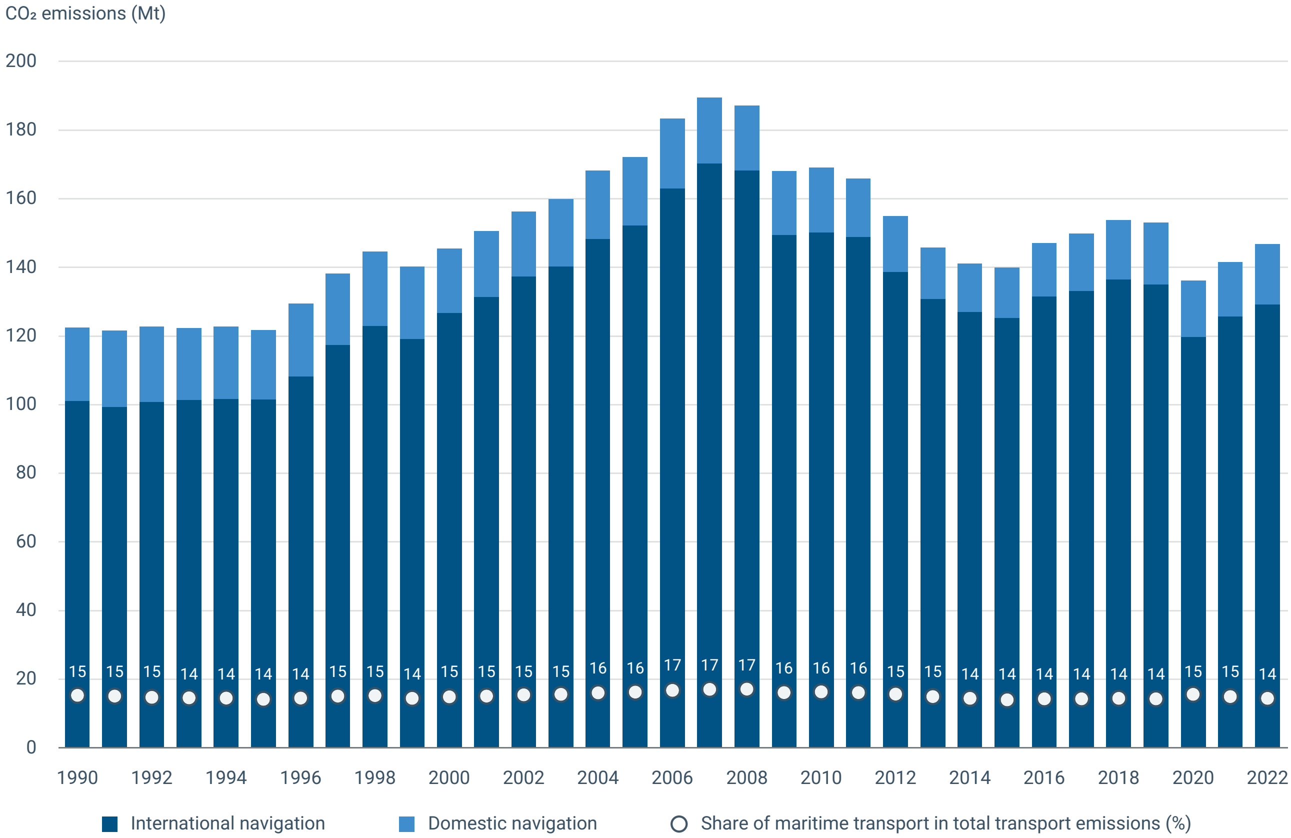
Sources: EEA, 2022; EMSA, 2023f; FMI, 2024.

Calculations of CO_2 emissions from the shipping sector are currently performed using a variety of methodologies, depending on the context. Figure 2.1 illustrates the differences between the EU's MRV system, the United Nations Framework Convention on Climate Change (UNFCCC) GHG inventories and the Ship Traffic Emissions Assessment Model (STEAM) (FMI, 2024). While the data resulting from these three approaches are not directly comparable, they give complementary visions of the sector's emissions. For example, STEAM shows the geographical distribution of emissions at regional level, while the UNFCCC inventories provide an historical data series. In 2022, the UNFCCC and MRV methodologies calculate total CO_2 emissions from shipping to be 147 million tonnes and 137.55 million tonnes, respectively, a difference of 7%.

(6) MRV Data from 2021 onwards excludes the UK.

Calculations of domestic emissions are similarly varied across the three tools. The UNFCCC approach accounts for emissions from voyages starting and ending in ports located in the same Member State; in 2022, these amounted to 18 million tonnes, approximately 12% of the total. According to STEAM, 2022 domestic navigation (with a similar definition) totalled 70 million tonnes and accounted for 37% of all shipping emissions. Finally, the MRV data for 2022 reveals that, intra- European Economic Area and extra-European Economic Area emissions accounted for 27% and 67% of the total share, respectively, with the remaining emissions occurring at berth.

Figure 2.2 CO_2 emissions from the maritime sector and their share in total transport emissions between 1990 and 2022 in the EU-27



Note: Figures are in Mt, million tonnes of carbon dioxide equivalent.
Source: EEA, 2022c.

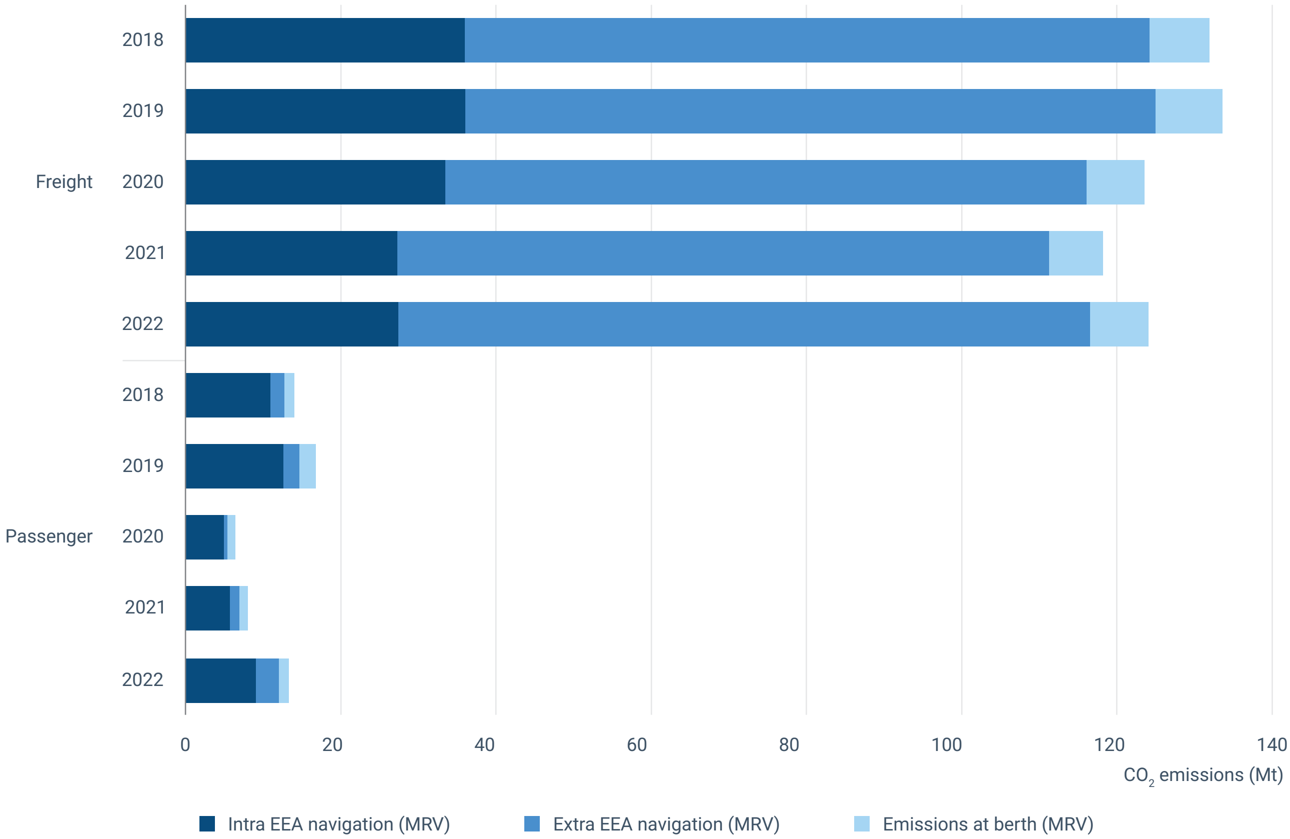
The maritime transport sector's share of total EU transport CO_2 emissions has remained roughly constant in time and was approximately 14% in 2022 (see Figure 2.2). At the same time, domestic freight maritime transport activity in the EU (measured in billion tkm (7)) increased by 45% between 1995 and 2022, despite the impact of COVID-19 pandemic. Meanwhile, the passenger activity (in billion pkm (8)) decreased by 22% (EC, 2023b).

(7) Tonnes-kilometre (tkm): unit of measure of freight transport which represents the transport of one tonne of goods over the distance of one kilometre: https://ec.europa.eu/Eurostat/statistics-explained/index.php?title=Glossary:Tonne-kilometre_(tkm)
(8) Passenger-kilometre (pkm): unit of measure of passenger transport which represents the transport of one passenger over a distance of one kilometre: https://ec.europa.eu/Eurostat/statistics-explained/index.php?title=Glossary:Passenger-kilometre

Changes in maritime activity are also reflected in the volume of ships calling at EU ports during this period. Between 2019 and 2020, a period affected by the COVID pandemic, ship calls at EU ports declined by 3.5%. They rebounded in 2021 however, growing by 3.7% over the course of the year. Gross tonnage (GT) also fell by 11.1% between 2019 and 2020 and continued to fall into 2021, leading to a total reduction of 9.1% between 2019 and 2021. Factoring in data from the first half of 2022 highlights a shift in this trend, with a total increase of 4.2% on port calls. GT continued to decline, however, by 16.2% compared with 2019 — likely due to the ongoing crisis in Ukraine (EMSA, 2022).

Data from the UNFCCC GHG emissions inventories shows that the overall emissions from maritime transport decreased by 11% from 2019 to 2020. As a share of Europe's total transport emissions, they remained stable however, as all EU transport activity declined during this period. Indeed, freight and passenger activity declined 6% and 50% respectively during the same period (EC, 2023b).

Figure 2.3 **Distribution of CO_2 emissions from freight and passenger vessels between 2018 and 2022 in the European Economic Area**



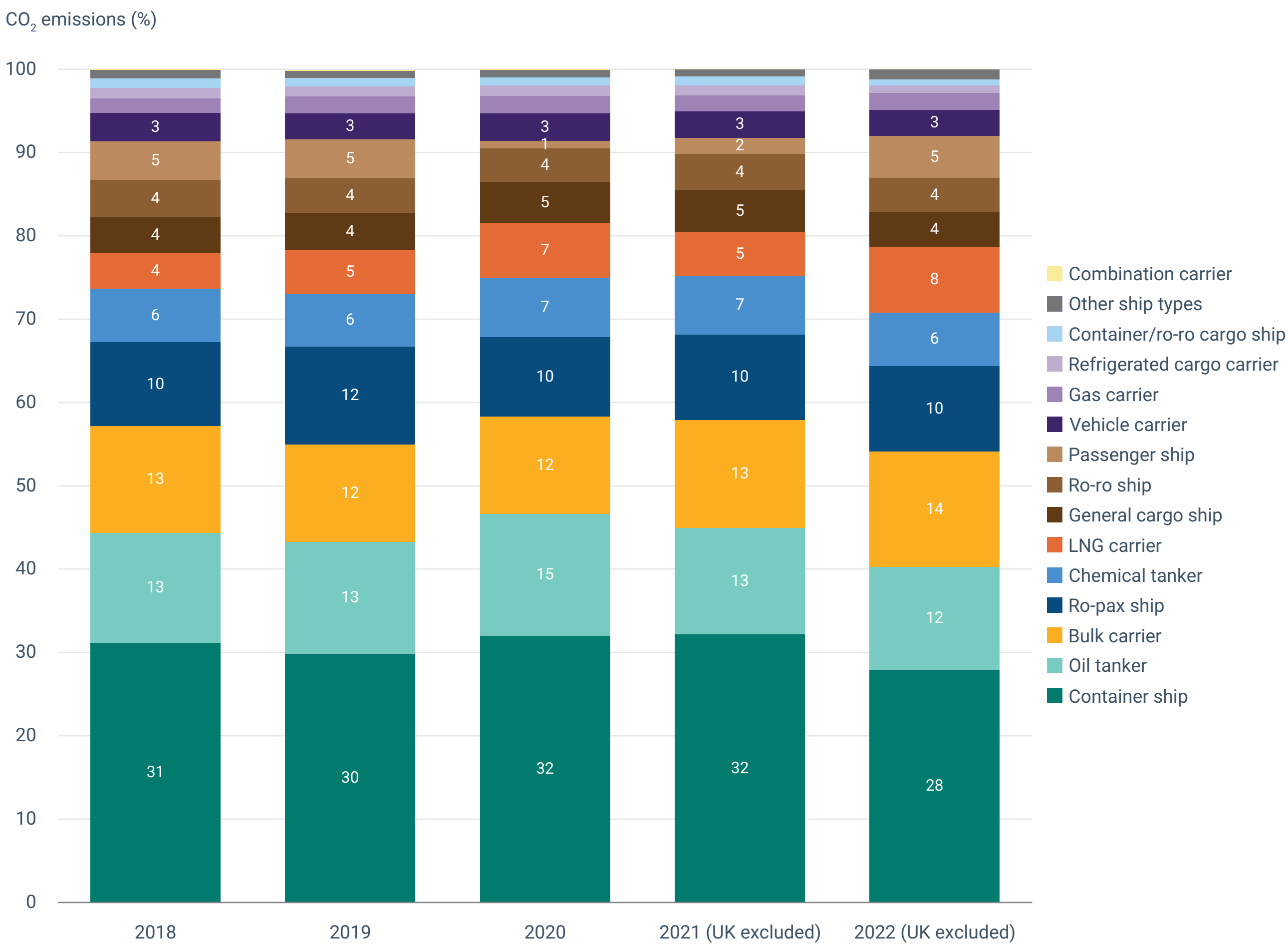
Notes: Data from 2021 onwards excludes the UK.
Figures are in Mt, million tonnes of carbon dioxide.

Source: THETIS-MRV (EMSA, 2023f).

The split in maritime emissions shows that freight emissions are four times the magnitude of passenger emissions, totalling 124 million tonnes in 2022 (see Figure 2.3). Among intra-European Economic Area voyages, the difference of emissions between the two categories has shrunk in absolute terms. Total emissions from freight transport fell by 5.9% between 2018-2022, while passenger transport emissions decreased by 5.2% in the same timeframe (with the caveat regarding the impact of the COVID-19 pandemic, as well as the fact that emissions from 2021 and 2022 do not include UK-related emissions). Emissions at berth for freight remained relatively stable at approximately 6% of the total between 2018 and 2022. For passenger transport, this value oscillated between 9% and 15%, depending on the year.

From 2018 until 2022, five types of ships constituted the majority (80%) reporting under the MRV (see Figure 2.4 for the yearly breakdown). For 2022, the reporting included bulk carriers (31%), oil tankers (15%), container ships (14%), chemical tankers (11%) and general cargo ships (9%). Together, containerships, oil tankers, bulk carriers and tankers alone accounted for 54% of the total CO_2 emissions for 2022. Notably, in 2022 container ships and oil tankers reported their lowest share of CO_2 emissions compared to the overall five year reporting period. Bulk carriers also surpassed oil tankers as the second largest emitter for the first time. Identifying the main contributors serves as a starting point to prioritise decarbonisation strategies and identify the sectors requiring urgent investments to accelerate the transition towards cleaner fuels and power solutions alternatives.

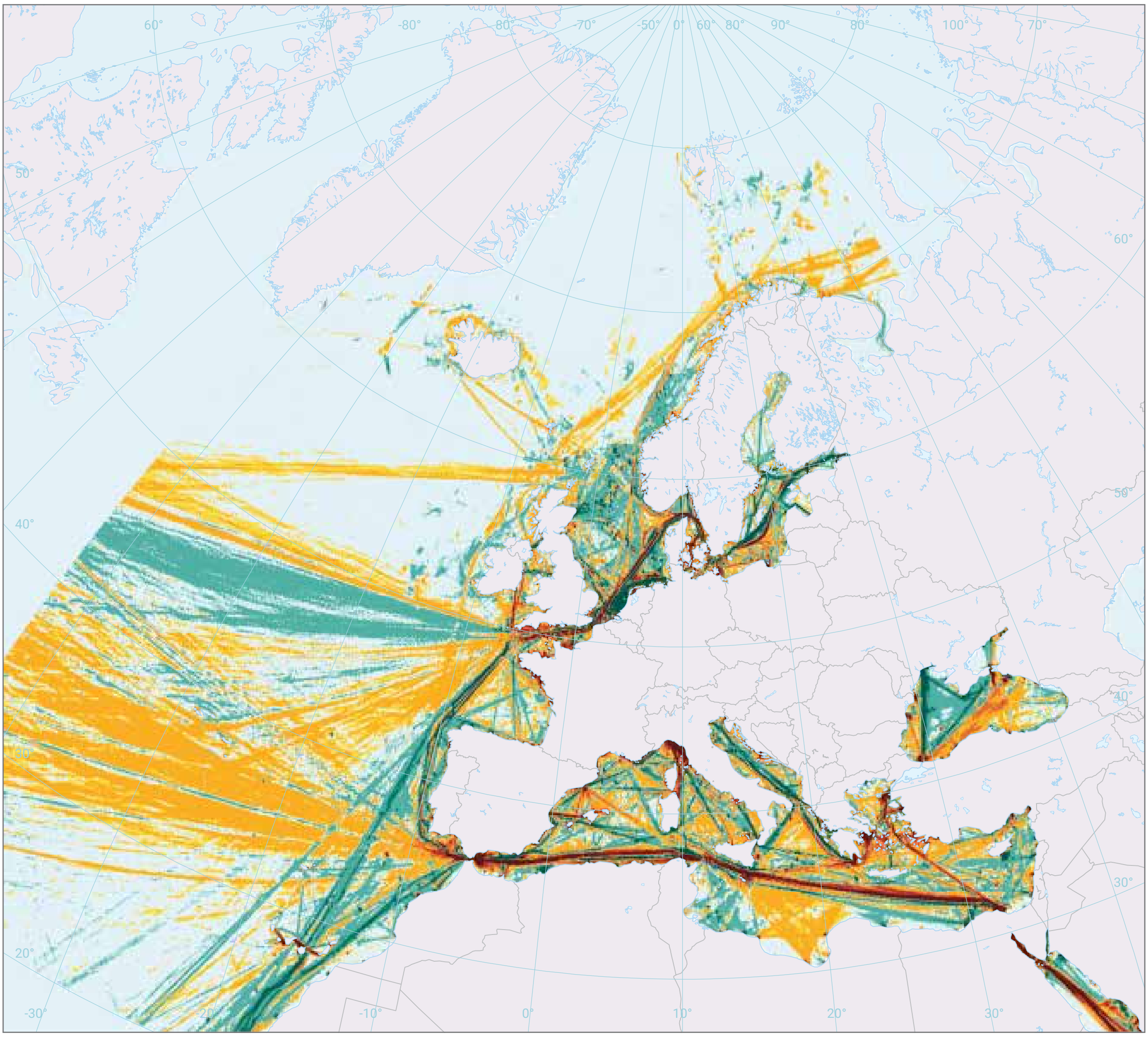
Figure 2.4 Shares in total fleet CO_2 emissions by ship type between 2018 and 2022



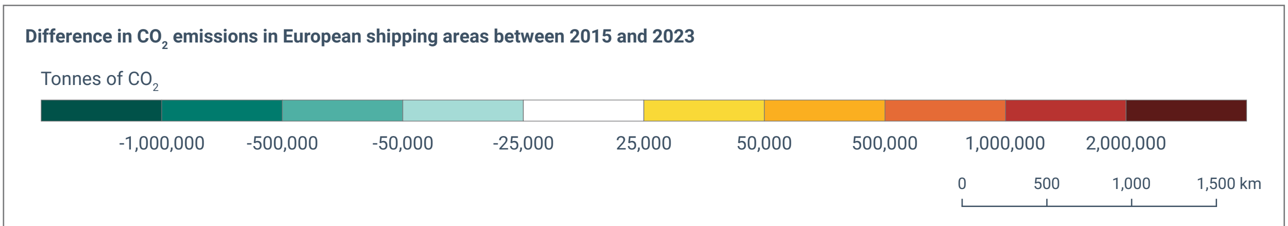
Notes: UK is not included for the years 2021 and 2022.
Ro-ro, roll-on, roll-off; Ro-pax, roll on passenger.

Source: THETIS-MRV (EMSA, 2023f).

Map 2.1 **Difference in CO_2 emissions in European shipping areas between 2015 and 2022**



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO



Source: STEAM (FMI, 2024).

STEAM modelled data provides additional insights into the uneven distribution of CO_2 emissions across different regions of Europe (see Map 2.1). It is important to consider that variables such as the traffic volume (in absolute number of vessel position messages) will influence the total emissions. Between 2015-2023, STEAM data shows that the Mediterranean had the highest average yearly CO_2 emissions, equal to 64 million tonnes/year, followed by the Atlantic with 31 million tonnes/year and the North Sea with 26 million tonnes/year.

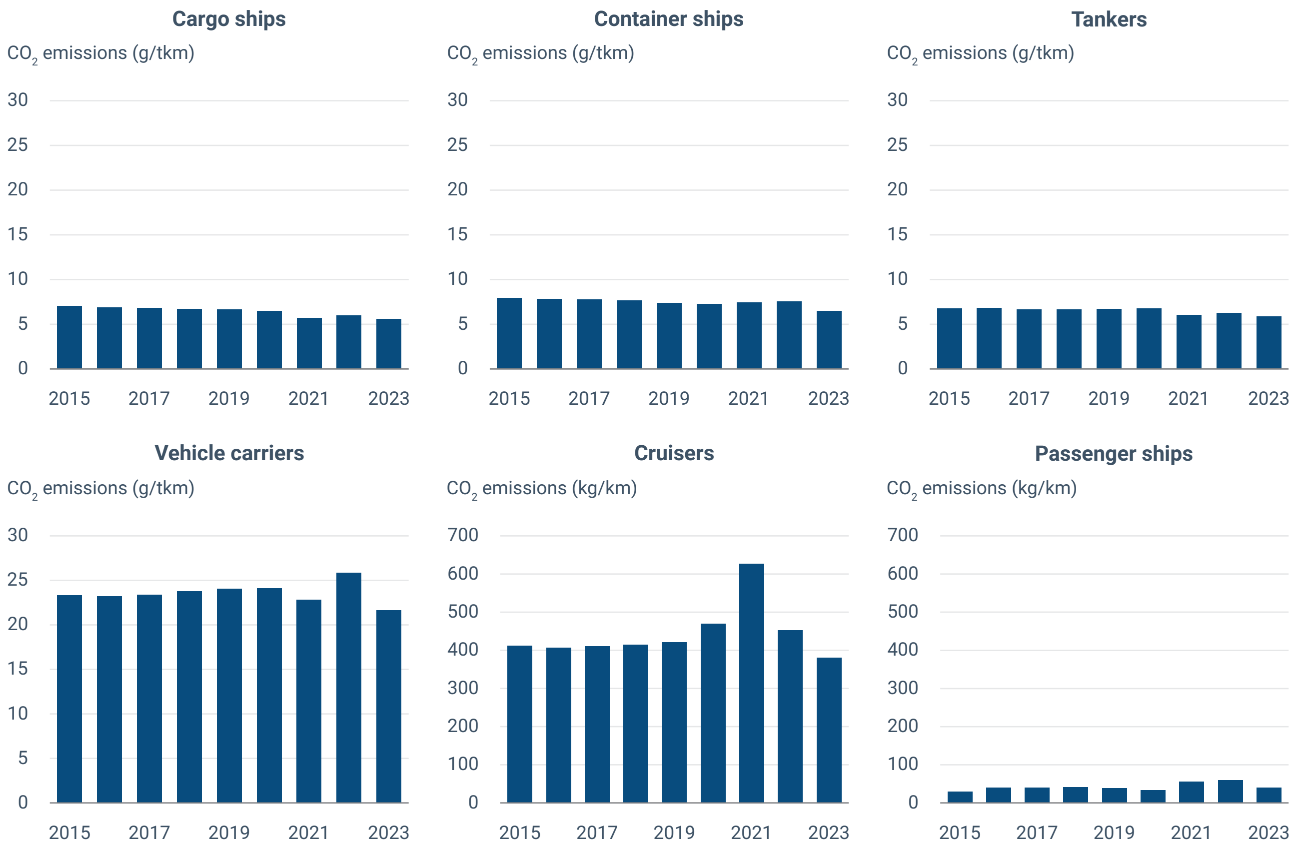
Between 2015 and 2023, CO_2 emissions increased by 46% in the Atlantic, 15% in the Mediterranean and 6% in the Baltic, while the North and Black Seas experienced a decrease of 8% and 1% respectively. Over the same timeframe, the variation in distance travelled by ships on a per region basis increased by 45%, 19%, and 7% for the Atlantic, Mediterranean and Baltic Seas and fell by 7% and 12% for the North and Black Seas respectively. In the Arctic region, CO_2 emissions have increased by 62%, alongside an increase of 48% in the distance travelled within the area.

CO_2 emissions and ship types

Specific emissions declined for most of the ship types between 2015 and 2023 (see Figure 2.5). While average cargo ships' CO_2 emissions fell by 21% during this period, those of containerships and tankers fell by 18% and 14%. Vehicle carrier vessels also cut their emissions by 7%. For reference, in the same region and timeframe, the payload carried by these vessel types grew by 34%, 25%, 57% and 10%, respectively, while in absolute terms, CO_2 emissions of the same vessels type increased by 6%, 3%, 35% and 2%, respectively.

Cargo ships and tankers had the lowest yearly emissions per tonne-kilometre with 6.456g/tkm (grammes per tonne-kilometre) and 6.517g/tkm. By comparison, container ships emitted on average 7.508g/tkm, while emissions from vehicle carriers rose to 23.585g/tkm.

Figure 2.5 CO_2 specific emissions from selected freight and passenger ship types in the EU between 2015 and 2023



Notes: Emissions for freight and passenger ships in (g/tkm) or (kg/km) respectively. g/tkm, grammes per tonne-kilometre; kg/km, kilogrammes per kilometre.

Source: STEAM (FMI, 2024).

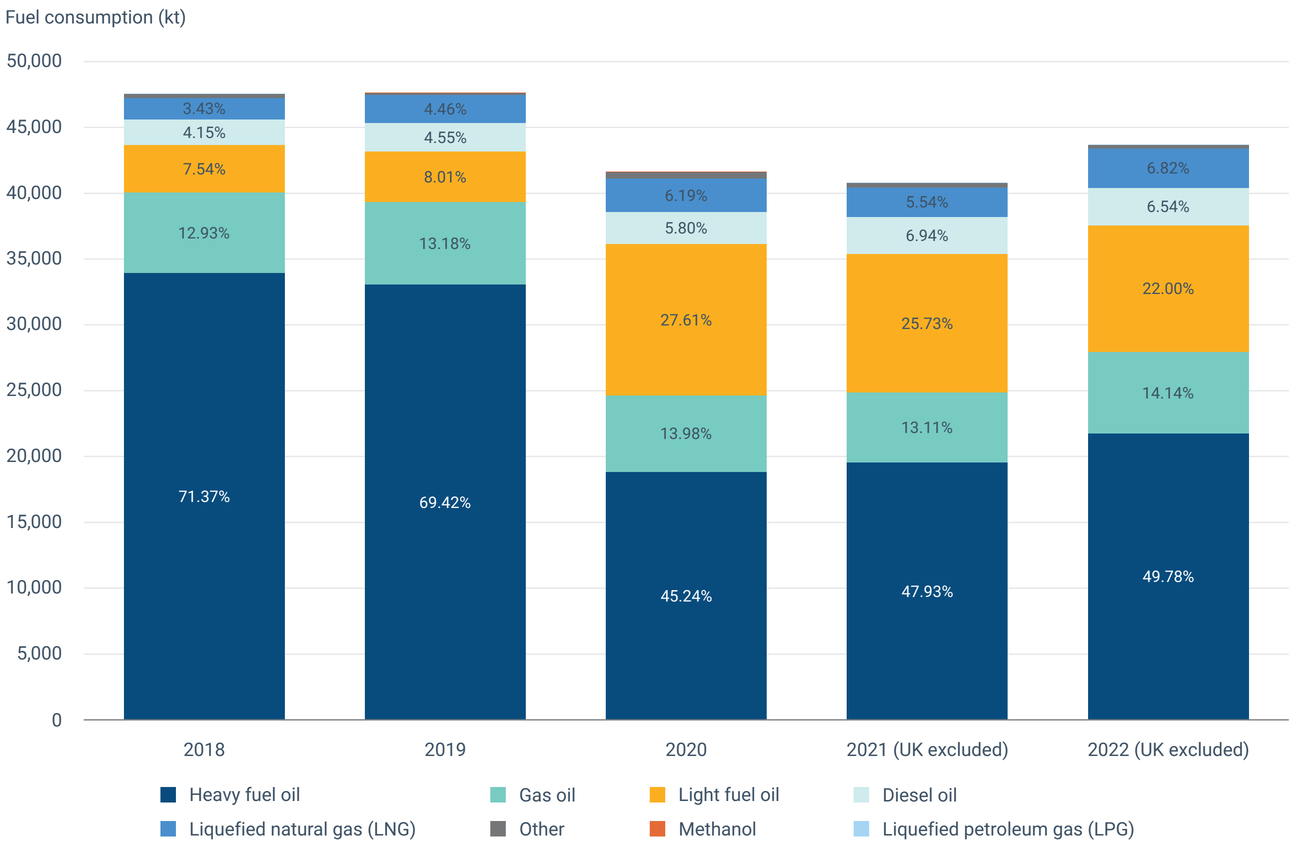
Specific emissions of cruisers in Europe fell by 7%, while the distance travelled increased by 17%. Conversely, emissions from passenger ships increased sharply by 34%, while the distance travelled reduced modestly by -4%. At the same time, absolute CO_2 emissions increased by 8% for cruise ships and by 28% for passenger ships.

Cruise ships emitted 444kg/km during this same period, approximately 11 times higher than conventional passenger ship emissions in the same region and period, (42kg/km). However, it is important to note that these figures do not consider the number of passengers transported.

Trends in fuel consumption

Regarding fuel consumption, data reported under the MRV regulation shows that there has been a shift in the types of fuel used. Since 2020, the use of heavy fuel oil (HFO) has declined while light fuel oil (LFO) has grown, as shown in Figure 2.6. The implementation of the global sulphur cap in 2020 and the prohibition on the carriage of such fuel without abatement technologies onboard are two factors that can help explain this trend (IMO, 2020b). All vessels covered by the MRV regulation consumed approximately 43.7 million tonnes of fuel in 2022, a 7.2% increase compared to 2021 (40 million tonnes).

Figure 2.6 Total fuel consumption of the EU MRV fleet 2018 to 2021 and consumption per fuel type between 2018 and 2022



Notes: UK is not included for the years 2021 and 2022.
LNG, Liquefied natural gas; LPG, Liquefied petroleum gas.
Figures are in kt, kilotonnes of fuel.

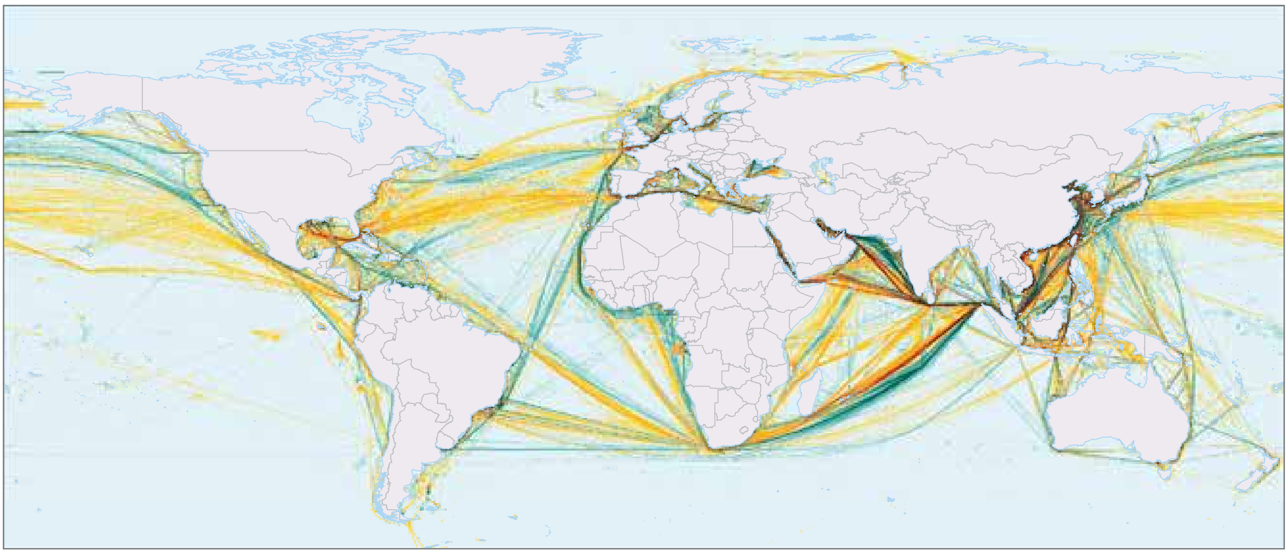
Source: THETIS-MRV (EMSA, 2023f).

CO_2 and fishing vessels

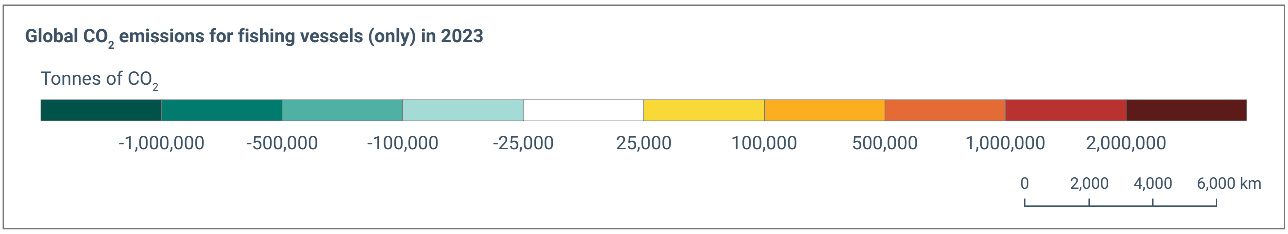
Finally, STEAM data shows the average emissions per ship of fishing vessels, which fell by 1% from 2015 to 2023. A typical fishing vessel emitted approximately 473.2 tonnes of CO_2 per year on average in 2020. In 2023 this increased to 505.6 tonnes of CO_2 per year. The fishing fleet shrunk by 14.8% over the same period, while absolute CO_2 emissions decreased by 10%.

CO_2 emissions for fishing vessels in the EU were equivalent to 3.7 million tonnes, according to the STEAM model. This accounts for 31.6% of global fishing vessels emissions (see Map 2.2). For 2023, STEAM estimates that fishing vessels accounted for 2% of CO_2 emissions in the EU and 1.3% globally, when considering all vessel types, activities and voyages.

Map 2.2 Global CO_2 emissions for fishing vessels (only) in 2023



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO



Source: STEAM (FMI, 2024).

It is nevertheless important to note that these estimates are based on the Automatic Identification System (AIS) occurrences. Recent studies have shown that about three-quarters (72-76%) of globally mapped industrial fishing vessels did not appear in public monitoring systems between 2017 and 2021, compared with one-quarter (21-30%) for other vessel activities (Paolo et al., 2024). The same study also indicates that relying solely on AIS data may inaccurately suggest that Europe and Asia have similar levels of fishing activity. However, the study reveals that Asia predominates in industrial fishing, representing 70% of all fishing vessel detections. As a result, the estimated 31.6% share of CO_2 emissions from fishing vessels in the EU may be overstated. This exposes some limitations when using solely AIS to estimate CO_2 emissions from fishing vessels.

The European Parliament's Communication paper on the Energy Transition in EU fisheries and aquaculture (EP, 2023) highlights the EU fishing fleet's current energy intensity and reliance on fossil fuels. It also examines the need to strengthen fuel efficiency by switching to alternative and low-carbon energy sources. It reports that: 'At present, most fishing vessels rely on marine diesel for their operations, although smaller vessels may use petrol. In total, the EU fleet consumed over 1.81 billion litres of marine diesel in 2021. This fuel consumption led to direct emissions of approximately 4.8 million tonnes of CO_2, a 25% reduction compared to 2009 (EC and JRC, 2024).

However, STEAM data for 2020 suggests the EU fishing fleet consumed 725 thousand tonnes of marine diesel oil, equivalent to the emission of 2.3 million tonnes of CO_2. This confirms that quantifying fishing vessel emissions on AIS data alone is not sufficient. Data from the EU Blue Economy Observatory (9), shows the evolution of CO_2 emissions for the different sizes of fishing vessels (by length), as well as per kg of fish landed (which can be relevant to control for the efficiency of the fishing vessels and overall sector).

Figure 2.7 shows the evolution of CO_2 emissions from fishing vessels as a function of the vessel length, both in absolute terms and per unit mass of fish landed between 2008 and 2021. The analysis shows that in absolute terms, smaller vessels (<12m) emit the least CO_2 emissions per year and larger fishing vessels (>40m) are the second least emitting vessel type. It is important to consider that in 2021, the last reporting year for which data is available — and according to the EU fleet register — smaller vessels accounted for the majority (around 86%) of the registered EU fishing fleet. A total of 11% of the fleet ranged from 12-24m and the remaining 3% were vessels larger than 24m (EC, 2021f).

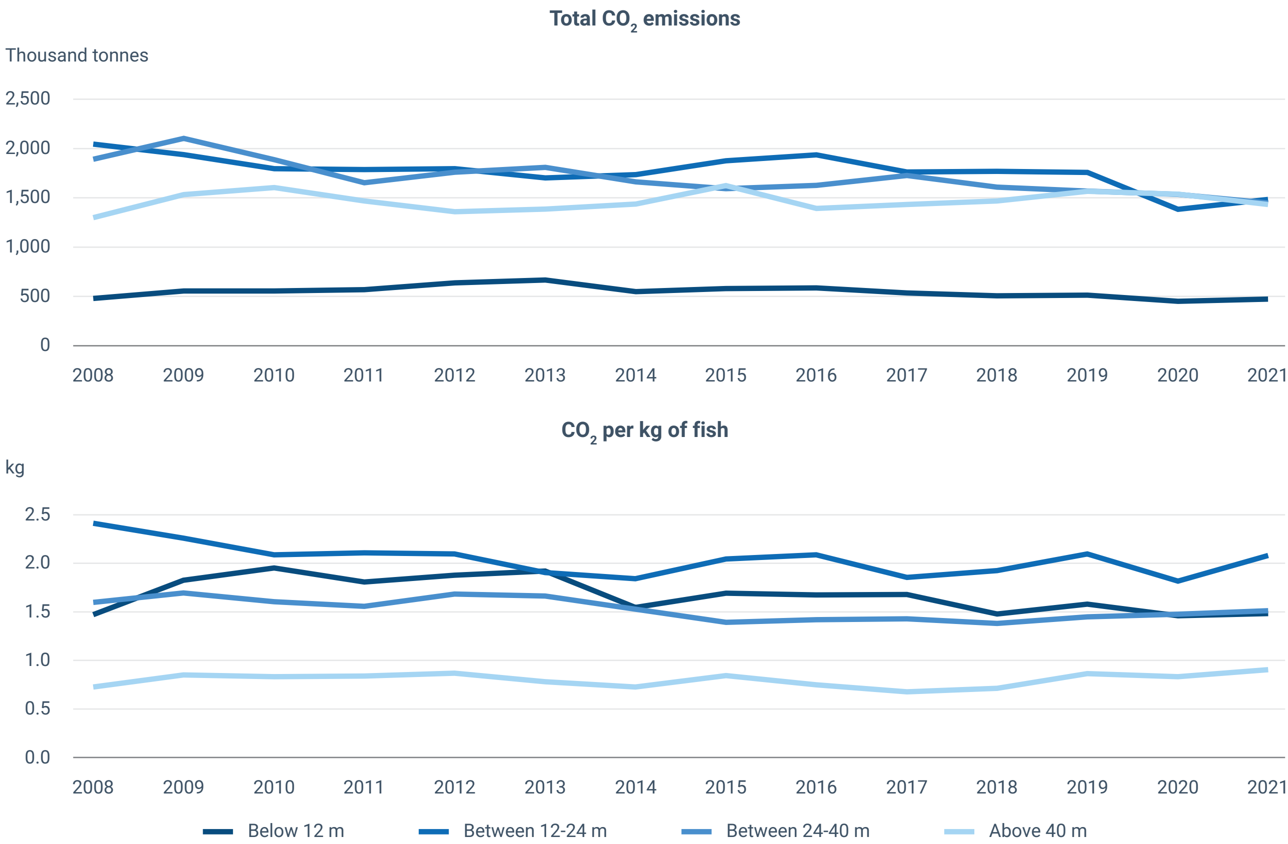
However, if the analysis considers the emissions per kilo of fish landed, vessels <12m, emit more on average than both larger vessels (> 40m) and those ranging from 24-40m. The larger the fishing vessel, the less it emits per kilo of fish landed. Another aspect which emerges from the total emissions of CO_2 is that vessels ranging from 12-24m and 24-40m emit more CO_2 than those larger than 40m. This may be influenced by several factors, including fishing techniques, the efficiency of the fleet, as well as the number of vessels in each category.

Nevertheless, these values should be interpreted with caution due to the diverse fishing gear used by vessels within each size class. These variations in gear can lead to significant differences in both fuel consumption and CO_2 emissions. Moreover, the distribution of vessels among different fishing gear types can also impact emissions within each length category. Factors such as stock status and target species are also key considerations, as healthier and more productive stocks may require less time and effort to locate and catch. Additionally, targeting small pelagic fish stocks typically demands less time and effort to catch larger quantities.

In terms of absolute emissions, the total number of vessels in the EU fishing fleet has decreased since 2008. Consequently, while emissions have indeed declined, this reduction may not be statistically significant.

(9) https://blue-economy-observatory.ec.europa.eu/fishing-fleet-fuel-analysis_en

Figure 2.7 Evolution of CO_2 emissions per fishing vessel by length group and CO_2 emissions per kg of fish landed



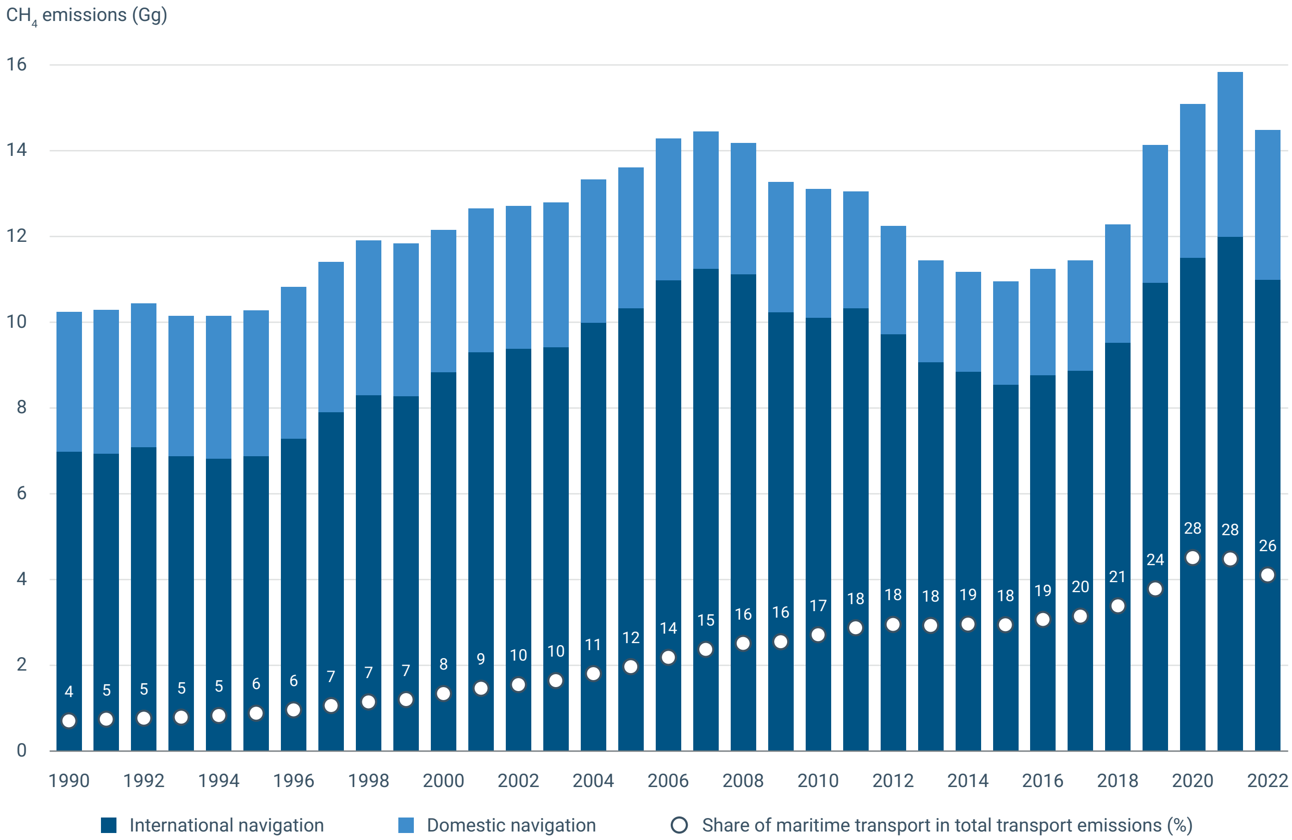
Note: JRC elaboration based on the Scientific, Technical and Economic Committee for Fisheries (STECF) data (Annual economic report).

Source: EC, 2023.

Methane

The scope of the EU MRV has expanded in light of the inclusion of maritime transport. This means relevant methane emissions data will be reported and published for the first time in 2025, for the reporting year 2024.

Figure 2.8 **CH_4 emissions from the maritime sector and their share in total transport emissions (%) in the EU-27**

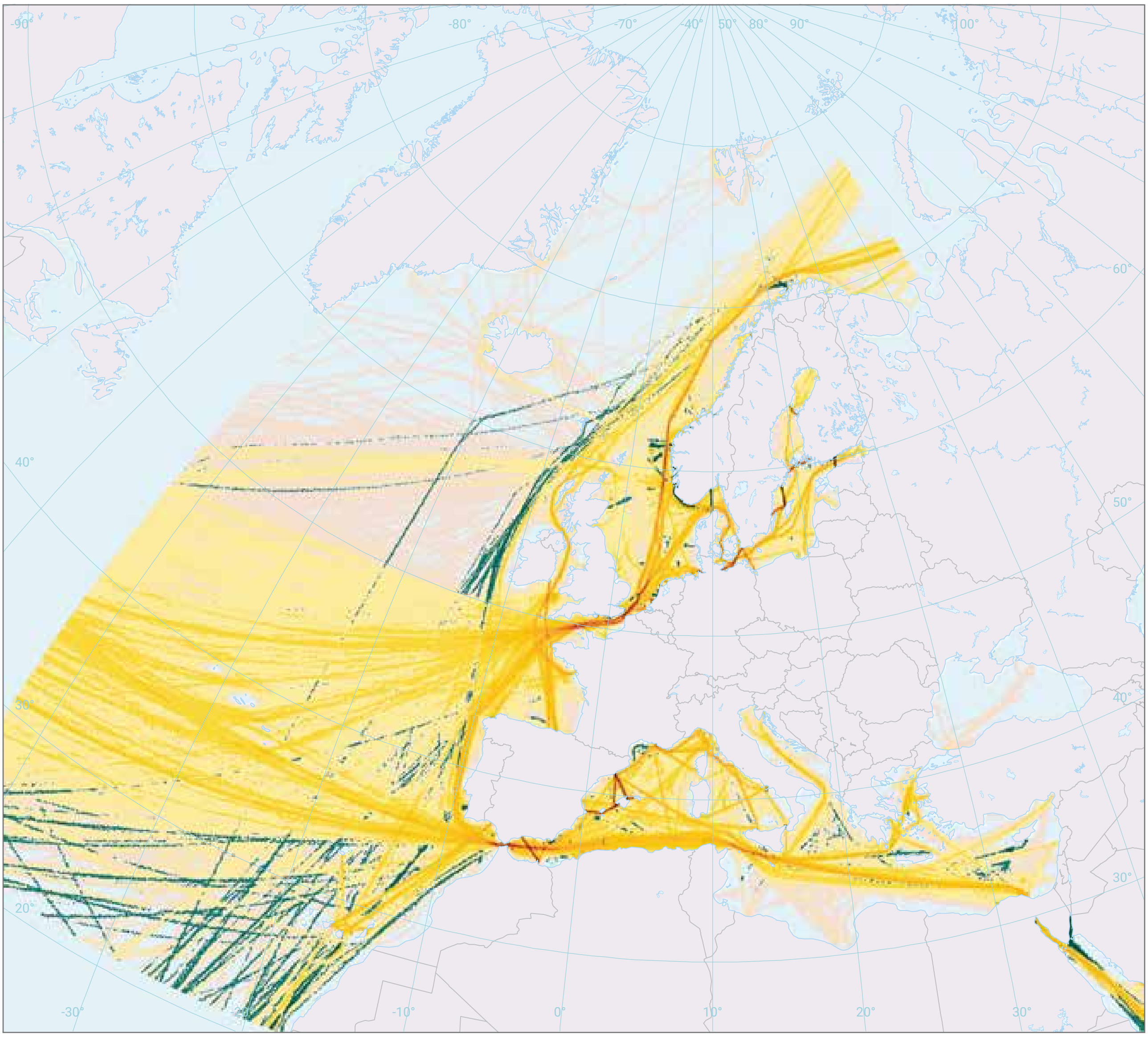


Note: Gg, gigagrams.

Source: UNFCCC (EEA, 2022).

According to the UNFCCC inventories data (see Figure 2.8) the contribution of the EU's maritime transport sector to overall transport methane emissions of CH_4 has increased over time, reaching approximately 26% in 2022. Methane emissions from the maritime transport sector reached 14Gg in this year. Additional details on the methodology used to account for CH_4 emissions in inventories can be found in the dedicated guidelines (IPCC, 2006).

Map 2.3 **Difference in CH_4 emissions in European shipping areas**



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Difference in CH_4 emissions in European shipping areas between 2015 and 2023

Tonnes of CH_4

-250 | -25 | 0 | 25 | 250 | 750 | 2,500 | 6,500 | 10,000 | 20,000

0 | 500 | 1,000 | 1,500 km

Source: STEAM (FMI, 2024).

The STEAM model offers insights into the spatial distribution of CH_4 pollution across Europe (Map 2.3). It also shows that CH_4 emissions, accounted as methane slip, started to grow more significantly from 2018 ([10]). This is associated with an increase in the overall number of ships using liquefied natural gas (LNG) (Comer et al., 2024; EEA and EMSA, 2021).

([10]) In calculating CH_4 emissions, the STEAM model distinguishes between spark-ignited, low-pressure (Otto) dual-fuel and high-pressure (Diesel) dual-fuel engines (Kuittinen et al., 2023). Ongoing work on these emissions continues to evolve with the growing availability of experimental data on CH_4 slip.

More specifically, CH_4 emissions increased significantly across all EU marine regions between 2018 and 2023: by 454% in the Atlantic, 375% in the Baltic, 291% in the Black Sea, 211% in the Mediterranean and 97% in the North Sea. The variation in distance travelled was 52%, 10%, -5%, 24% and 2%, respectively. In the Arctic region, CH_4 emissions increased 108%, coinciding with an increase in distance travelled of 41%. This is of particular concern given the vulnerability of the region to the effects of CH_4 pollution, which is considered an important GHG after CO_2 (Prather et al., 2001). The Atlantic had the highest average yearly CH_4 emissions over this period, equal to 9Gg/year, followed by the Mediterranean with 8Gg/year and the North Sea with 5Gg/year.

Note however that CH_4 emissions are not measured directly at source, neither during real operation nor during certification cycles. Indeed, recent research (Comer et al., 2024) showed that the average CH_4 emissions, e.g. for LPDF 4-stroke engines, can be significantly higher than is normally assumed. Loading and unloading operations of LNG can also emit relevant quantities of CH_4. Notice that CH_4 is not only an air pollutant but also a climate forcing compound, with a Global Warming Potential (GWP) of approximately 81 for a 20-year time (IPCC, 2021).

Ozone depleting substances and fluorinated greenhouse gases (ODS and F-gases)

In the maritime sector, emissions of ozone depleting substances (ODS) and fluorinated gases (F-gases) into the atmosphere can occur due to the use of refrigeration and air-conditioning systems onboard vessels. These are estimated to amount to approximately 18.2 million tonnes of carbon dioxide equivalent (CO_2e), i.e. ca. 15% of the total EU F-gas emissions (based on EU NIR UNFCCC F-gas emissions for the same year) (IMO, 2020a). F-gases often show high global warming potentials which are up to several thousand times higher than the climate impact of CO_2.

These emissions can result from high annual leakage of the cooling systems deployed. Research from the United Nations Environment Programme (UNEP, 2011) and the European Commission (Birchby et al., 2022; Schwarz and Rhiemeier, 2007) indicate that cooling systems on ships typically show an average leakage rate of 40%, which is several times higher than leak rates of stationary systems. Ships exhibit specifically high emission rates due to many factors, including long piping systems, constant exposure to sea wave vibrations, motion, as well as insufficient crew expertise in refrigeration technologies which can inhibit leakage repairs. Limited onboard expertise poses challenges that are characteristic for the maritime sector, especially in case of maintenance and repair needs during extended voyages (UNEP, 2022). Technical data on the actual leakage rates of refrigeration and air-conditioning systems on ships is usually not available.

In 2024, the EU adopted new F-gas and ODS regulations to further address the impact of these substances on global warming. Emission reductions are crucial and need to consider all applications but especially refrigeration and air conditioning, including international maritime shipping. Due to the maritime sector's relevance concerning emissions from cooling coupled with the considerable sector growth, transitioning to environmentally friendly alternatives needs to be fostered across ship types (IMO, 2020a). Refrigeration technology is heterogenous across the fleet, reflecting diverse needs. For example, passenger cruise ships can use 7,000-8,000kg of refrigerant for the storage and provision of food, fishing vessels up to 1,500kg to preserve fish catch, refrigerated containers (reefers) up to 6kg of a mixture of refrigerants (per container) to prevent spoilage of the load, while in general cargo ships will use up to 150kg, mainly for air conditioning purposes.

The wide variety of refrigerants types used in the systems mentioned above have diverse environmental performances and climate impacts (IMO, 2020a), making the impact of each of these emissions complex to estimate.

2.1.2 Air pollutants

Key messages

- Sulphur oxides emissions (SOx) have decreased by about 70% since 2014, largely due to the introduction of Sulphur Emission Control Areas (SECAs). However, there is limited data on the impacts of the reductions onto actual SOx concentrations particularly in ports, and the incoming implementation of new SECAs.

- Between 2015 and 2023, Nitrogen oxides (NOx) emissions increased by 33% and 8% in the Atlantic and in the Mediterranean Sea, while they decreased by 17%, 7% and 6% in the North, Black and Baltic Seas, respectively. It is important to note that data and trends are also influenced by ongoing conflicts, other contingent situations, and the implementation of NOx Emission Control Areas (NECAs). However, these latter requirements apply only to new ships, meaning that penetration rates remain low.

- The contribution of the maritime sector to the overall $PM_{2.5}$ in transport emissions has slightly increased over time, reaching approximately a 43% share in 2022. In 2022, domestic navigation constituted approximately 14% of the total maritime $PM_{2.5}$ emissions.

- Annual mean PM_{10} and NO_2 concentrations in 2021 were higher in port areas compared to the surrounding regions.

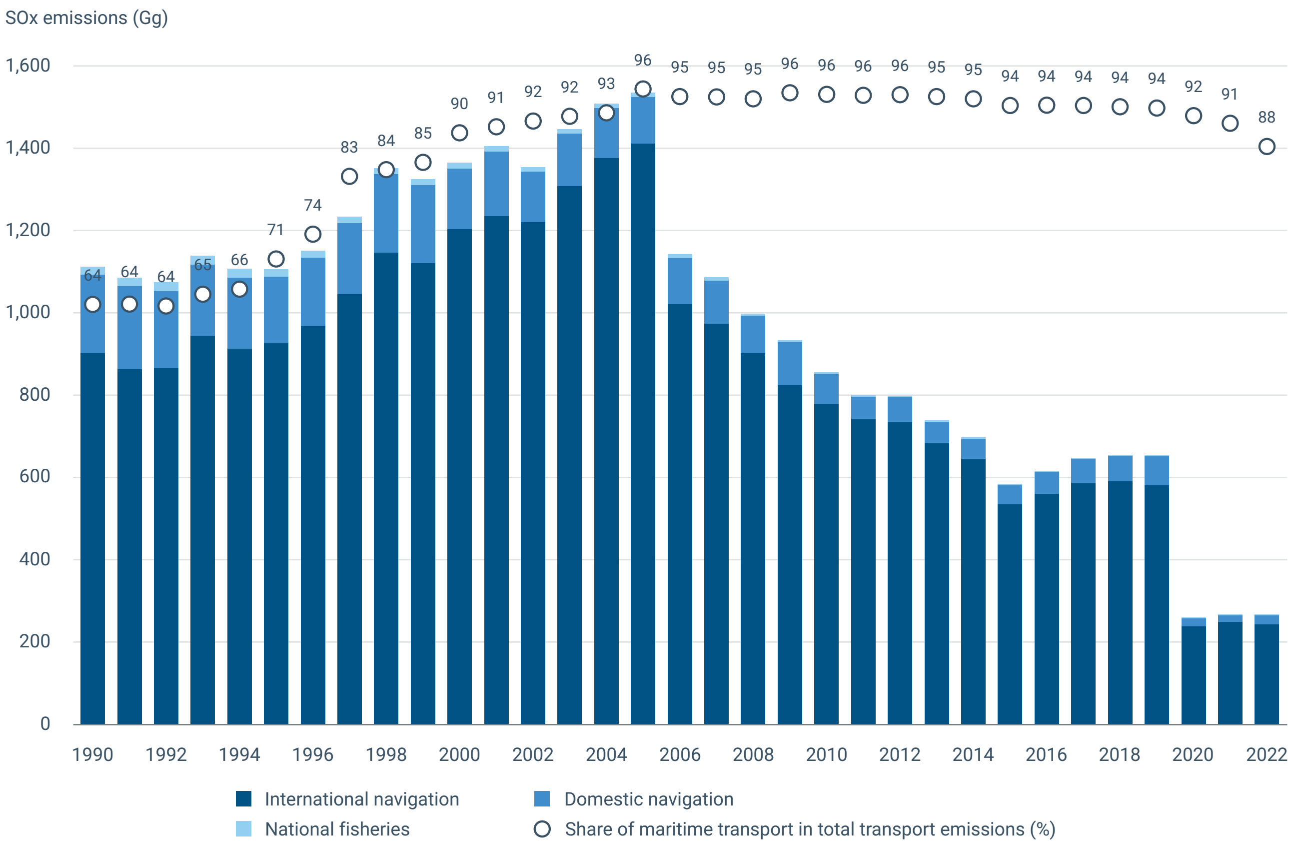
- Black Carbon emissions from the maritime sector, and the contribution to the EU transport sector overall emissions has steadily increased over time. The latter reached approximately 17% in 2022.

- The EMSA Remote Piloted Aircraft Systems (RPAS) emission monitoring campaigns observed Fuel Sulphur Content (FSC) concentrations within the limits for both SECA (0.1%) and non-SECA (0.5%) areas for the majority of the measurements taken. For both areas, average measured FSC has decreased over the past few years according to the available data. This is a result of compliance with threshold values set by control areas and the Global Sulphur Cap.

Sulphur oxides (SOx)
Figure 2.9 shows the contribution of the maritime sector to overall transport SOx emissions in the EU-27 from 1990 to 2022. The data are drawn from the Long Range Transboundary Air Pollution Convention (LRTAP) (EEA, 2024). The figure shows a steady increase over time, reaching a peak of 96% in 2005, which in absolute terms represents an emission of approximately 1,500 gigagrams (Gg) of SOx. It has since declined, reaching approximately 88% of the transport total share in 2022. This latter value corresponds to total emissions from the sector of 267Gg.

In 2022, fisheries and domestic navigation constituted approximately 1% and 8% of the total maritime SOx emissions, with the remainder coming from international navigation. From 2019 to 2020 the overall emissions from the sector decreased by 60%, also due to the reduction of activity caused by the COVID-19 pandemic restrictions. In the same period, for the maritime sector, freight activity decreased by 6% while passenger activity decreased by 51%.

Figure 2.9 **SOx emissions from the maritime sector and their share in total transport emissions in the EU-27**



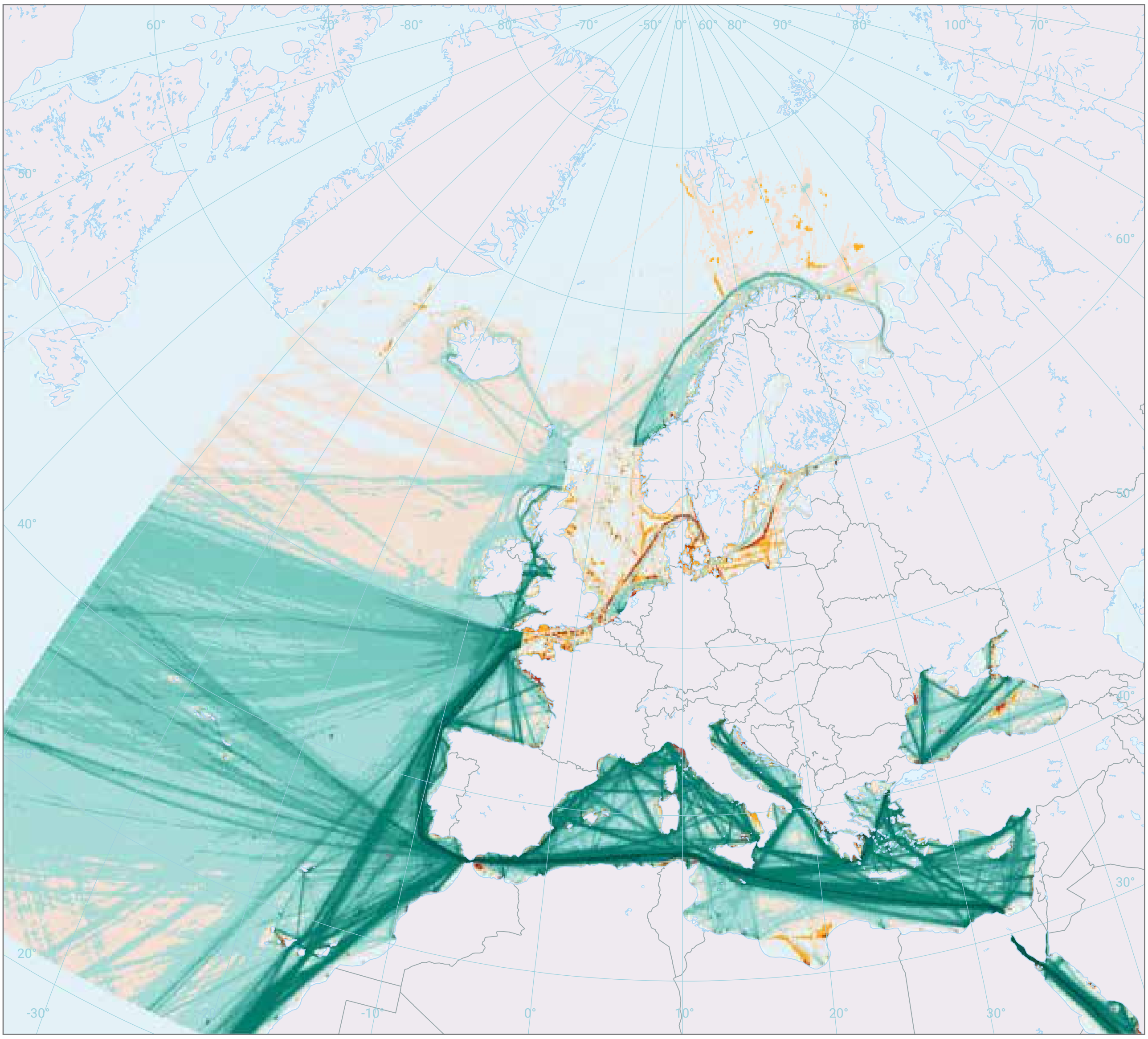
Note: Gg, gigagrams.
Source: LRTAP (EEA, 2024).

The implementation of SOx Emission Control Areas (SECAs) and the global sulphur cap have limited the content of sulphur in marine fuels. Based on the data from the STEAM model, Figure 2.10 shows that there has been a large reduction in the monthly SOx emissions for the EU region as a whole.

Figure 2.10 SOx emissions in the EU-27

Note: Gg, gigagrams.
Source: STEAM (FMI, 2024).

Map 2.4 Difference in SOx emissions across Europe's shipping areas



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Difference in SOx emissions in European shipping areas between 2015 and 2023

Tonnes of SOx

-100,000 -15,000 -7,500 -4,500 -2,000 -500 -100 100 1,000

0 500 1,000 1,500 km

Source: STEAM (FMI, 2024).

STEAM data illustrates the uneven distribution of SOx emissions in the different regions of Europe (see Map 2.4). As for GHG emissions, it is important to consider variables such as the traffic volume (in absolute number of vessel position messages), which will influence the total air pollutant emissions. SOx emissions decreased by 76%, 75%, 71% and 11% in the Mediterranean, Atlantic, Black and North regions, respectively between 2015-2023, while they remained unchanged in the Baltic Sea. The variation in distance travelled was respectively 19% and 45% for the

Mediterranean Sea and Atlantic and -7%, -12%, and 7% in the North, Black, and Baltic Seas. In the Arctic region, SOx emissions decreased by 57%, while distance travelled in the area grew by 48%.

Within the same period, the Mediterranean had the highest average yearly SOx emissions, equal to 482Gg/year, followed by the Atlantic with 255Gg/year and the North Sea at 29Gg/year.

Figure 2.11 **SOx specific emissions from selected freight and passenger ship types in the EU-27**

Notes: Measurements in (mg/tkm) or (kg/km) for freight and passenger ships, respectively. mg/tkm, milligrammes per tonne-kilometre; kg/km, kilogrammes per kilometre.

Source: STEAM (FMI, 2024).

SOx specific emissions have been declining for all ship types between 2015 and 2023 (see Figure 2.11), by 79%, 86%, 83% and 82% for cargo, containers, tanker and vehicle carrier vessels, respectively. This is related to a combination of factors, including the increased average payload transported and the introduction of new policies such as the IMO SOx ECAs in force from 2015 and the global sulphur cap in 2020. For reference, the payload carried by each ship type increased by 34%, 25%, 57% and 10%, respectively over the same period. Despite the increased activity, there has been an overall absolute reduction in sulphur emissions from these vessel types by 72%, 82%, 73% and 80% respectively. This shows the important role of cleaner fuels and aftertreatment technologies. Between 2015-2023, tankers, cargo ships and container ships had the lowest yearly average emissions with 38mg/tkm, 39mg/tkm and 55mg/tkm. By contrast, vehicle carriers emitted 129mg/tkm.

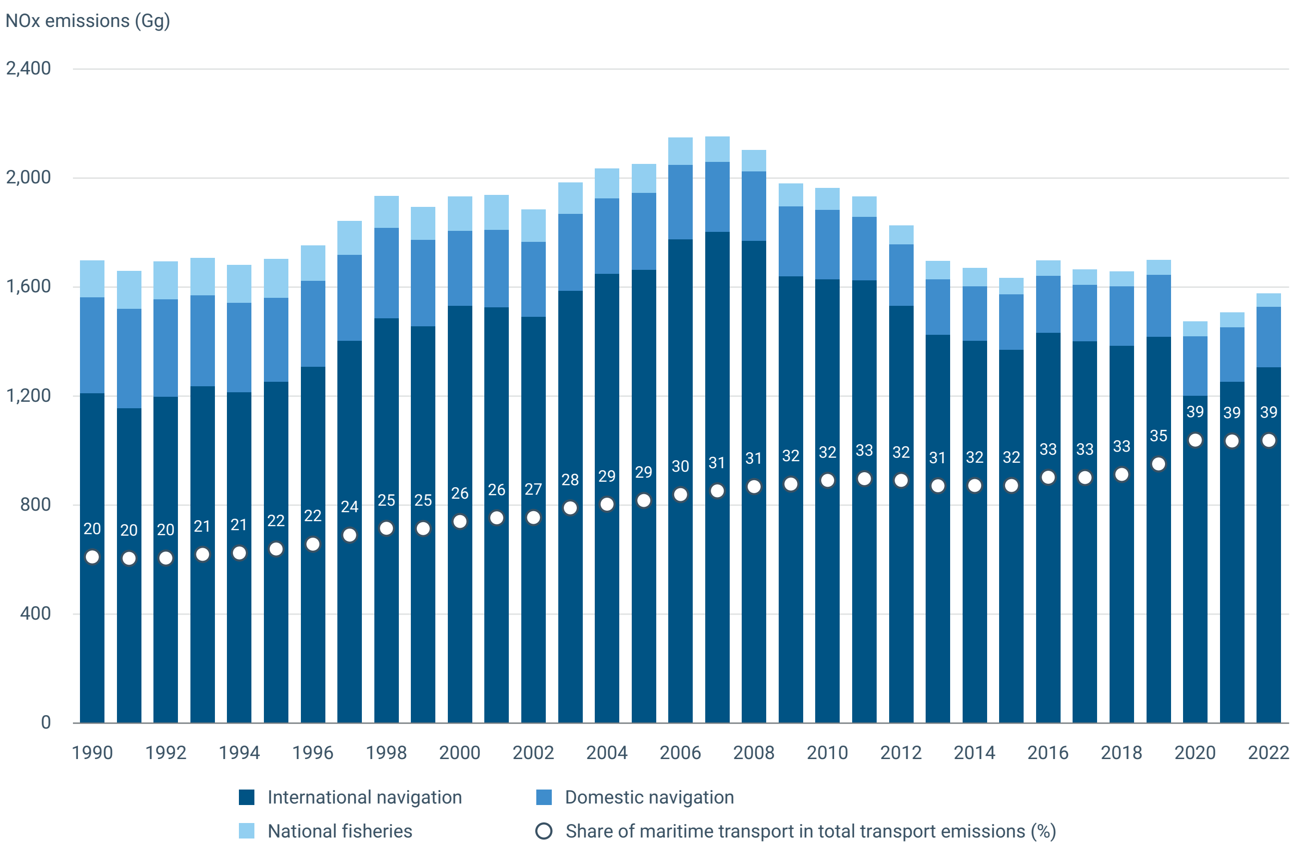
Specific emissions of cruisers in Europe fell by 78%, with an increase in the distance travelled of 17%. In absolute terms, the emissions of these ship types have decreased by 74%. The STEAM model provides separate information on passenger ships and cruise ships. It shows a decrease of passenger ships emissions by 30%, with a decrease of 4% in the distance travelled. In absolute terms, SOx emissions decreased by 33%. It is important to highlight that these two modes of passenger transport are of a different magnitude and that cruiser ships emitted an average of 1kg/km per year, while a conventional passenger ship emitted 12 times less.

Finally, STEAM data also shows that average emissions per fishing vessel have decreased by 36% from 2015. On average in 2023, a fishing vessel was emitting approximately 1,132kg of SOx per year. It is worth noting that the fishing fleet has only slightly decreased over the same period, i.e. 15%, while absolute SOx emissions decreased by 45%.

Nitrogen oxides (NOx)

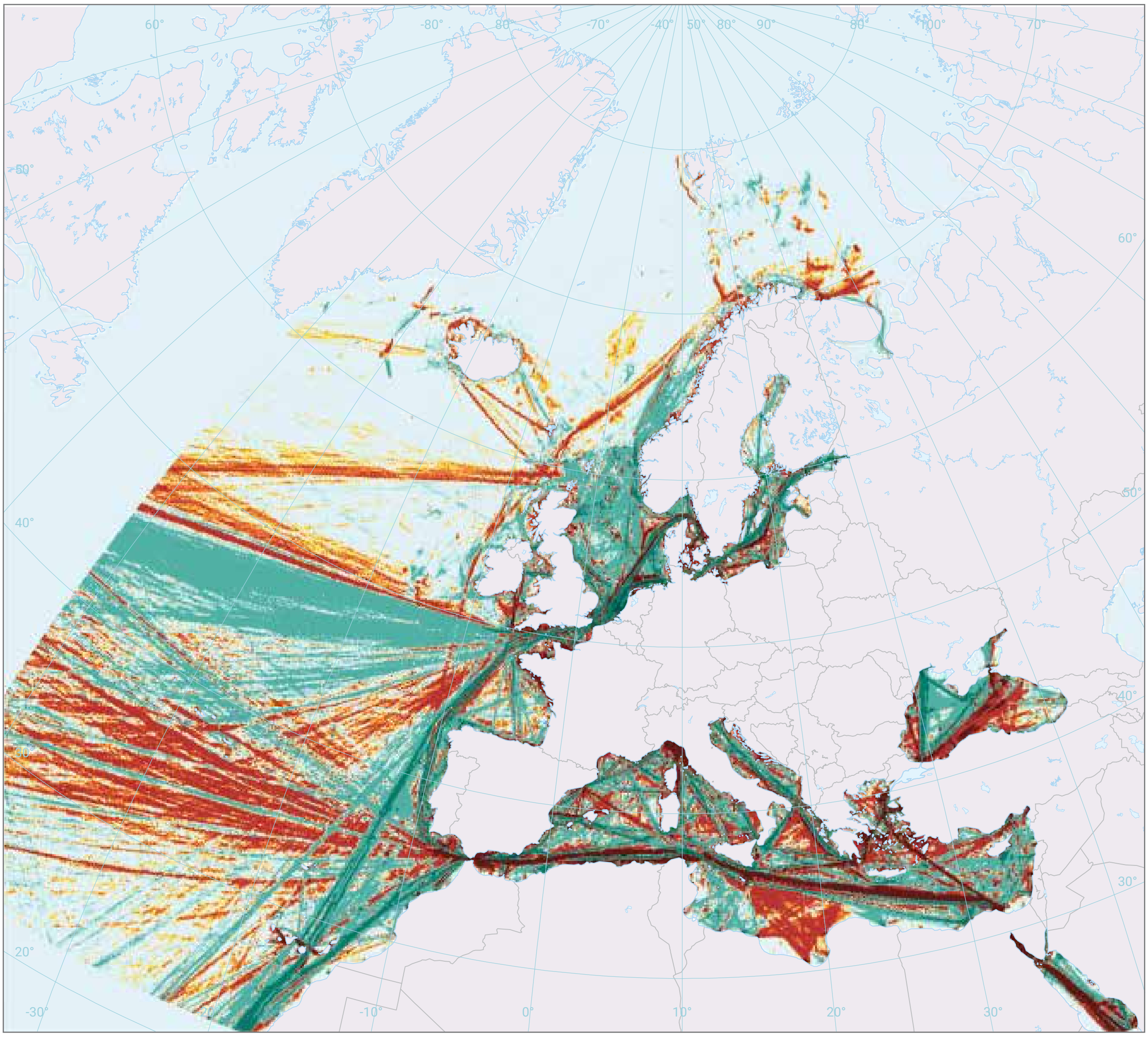
Figure 2.12 shows the contribution of the maritime sector to overall transport NOx emissions in the EU-27 from 1990 to 2022 based on LRTAP data, highlighting how emissions have steadily increased over time. In 2022, they reached 39% of all transport emissions of NOx, totalling 1,577Gg. Overall emissions from the sector decreased by 13% from 2019 to 2020, in line with the reduction of activity caused by the COVID-19 pandemic restrictions. In 2022, fishing and domestic navigation constituted approximately 3% and 14% of the total maritime NOx emissions.

Figure 2.12 **NOx emissions from the maritime sector and their share in total transport emissions in the EU-27**



Note: Gg, gigagrams.
Source: LRTAP (EEA, 2024).

Map 2.5 Difference in NOx emissions across European shipping areas



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Difference in NOx emissions in European shipping areas between 2015 and 2023

Tonnes of NOx

-100,000 -10,000 -1,000 -500 -250 250 500 1,000 10,000

0 500 1,000 1,500 km

Source: STEAM (FMI, 2024).

STEAM data provides insights into the uneven distribution of NOx emissions across Europe (see Map 2.5). In the period considered, the Mediterranean Sea had the highest average yearly NOx emissions at 1,237Gg/year, followed by the Atlantic with 622Gg/year and the North Sea with 446Gg/year.

NOx emissions increased by 33% and 8% respectively in the Atlantic and in the Mediterranean Sea, while they decreased by 17%, 7% and 6% in the North, Black and Baltic Seas between 2015-2023. In the same timeframe and for the same regions, the variation in shipping activity (via the proxy distance travelled) saw a respective increase of 45%, 19% and 7% in the Atlantic, Mediterranean Sea and Baltic Sea, with a decline of 7% and 12% in the North and Black Seas. In the Arctic region, NOx emissions increased by 32% and the distance travelled by 48%. This is of particular concern given the vulnerability of the region to the effects of NOx pollution.

Figure 2.13 NOx specific emissions from selected freight and passenger ship types in the EU-27

Notes: Measurements in (mg/tkm) or (kg/km) for freight and passenger ships, respectively. mg/tkm, milligrammes per tonne-kilometre; kg/km, kilogrammes per kilometre.

Source: STEAM (FMI, 2024).

Cargo ships and tankers had the lowest yearly NOx emissions over the time period considered, at 123mg/tkm. By comparison, container ships emitted on average 163mg/tkm, while yearly emissions from vehicle carriers were up to 433mg/tkm (see Figure 2.13).

Specific emissions (i.e. in mass per tkm) declined for all ship types, particularly by 24%, 22%, 25%, and 17% for cargo, containers, tanker and vehicle carrier vessels respectively. This relates to a combination of factors, including the increased average payload transported. For reference, in the same region and timeframe, the payload carried increased respectively by 34%, 25%, 57% and 10%. This overcompensated the absolute pollutant emission increase for cargo and tankers by 2% and 18%, respectively (not shown in the figure).

Specific emissions (i.e. in mass per km) from cruisers in Europe decreased by 19% during this period, with an increase in the distance travelled of 17%. In absolute terms, NOx emissions decreased by 5%. The situation is different for passenger ships for which emissions have increased significantly (by 29%), with a small decrease on the distance travelled of 4%. In absolute terms, NOx emissions increased by 23%.

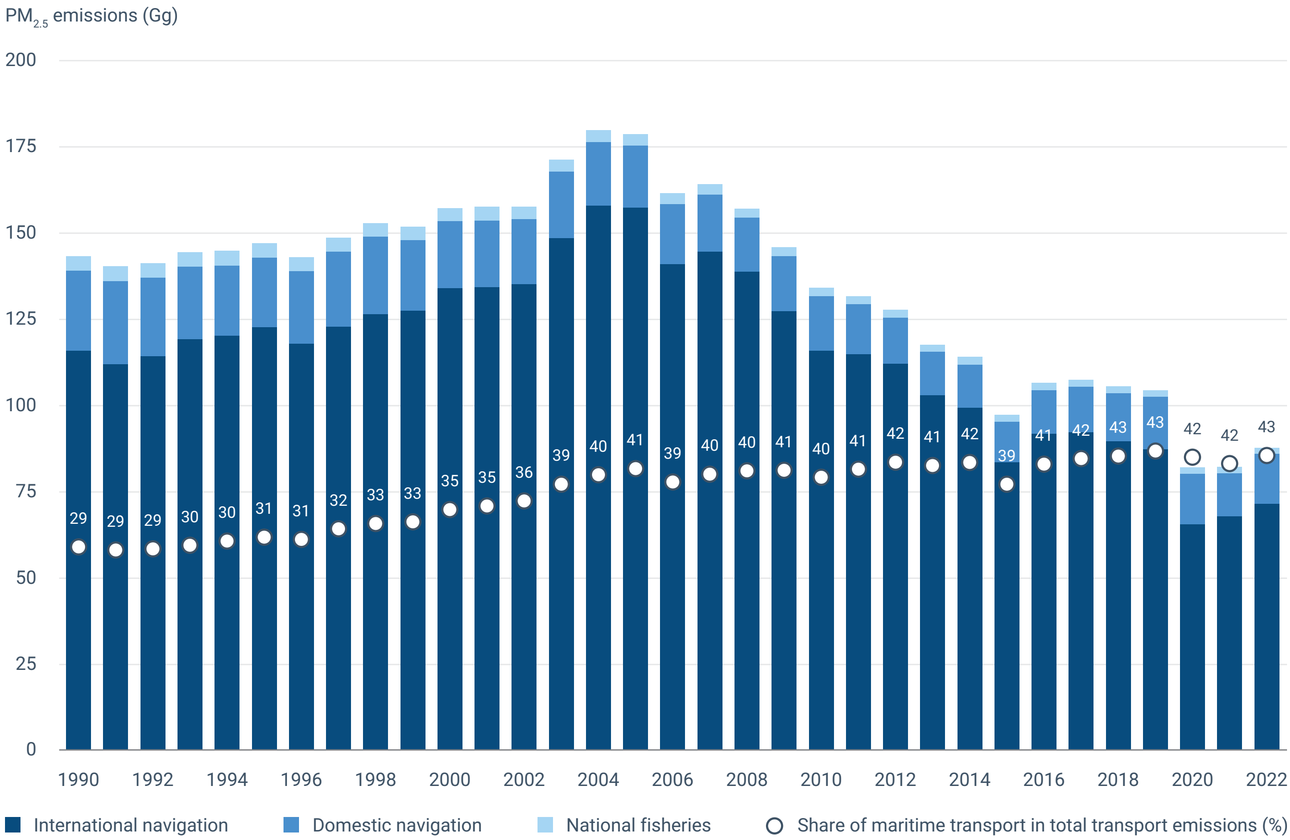
Cruiser ships emitted 7kg/km during this period, approximately 11 times more than conventional passenger ships in the same region (0.7kg/km).

Finally, the average emissions per ship of fishing vessels decreased by 2% from 2015 to 2023. In 2023, an average fishing vessel was emitting approximately 7,461kg of NOx per year. The fishing fleet has meanwhile slightly decreased in size over the same period (by 15%). Absolute NOx emissions decreased by 17%.

Particulate matter (PM)
The contribution of the maritime sector to the overall $PM_{2.5}$ in transport emissions has slightly increased over time, peaking in 2019 (43%) and reaching approximately the same share in 2022 (Figure 2.14). In 2022, $PM_{2.5}$ emissions from the sector reached 88Gg.

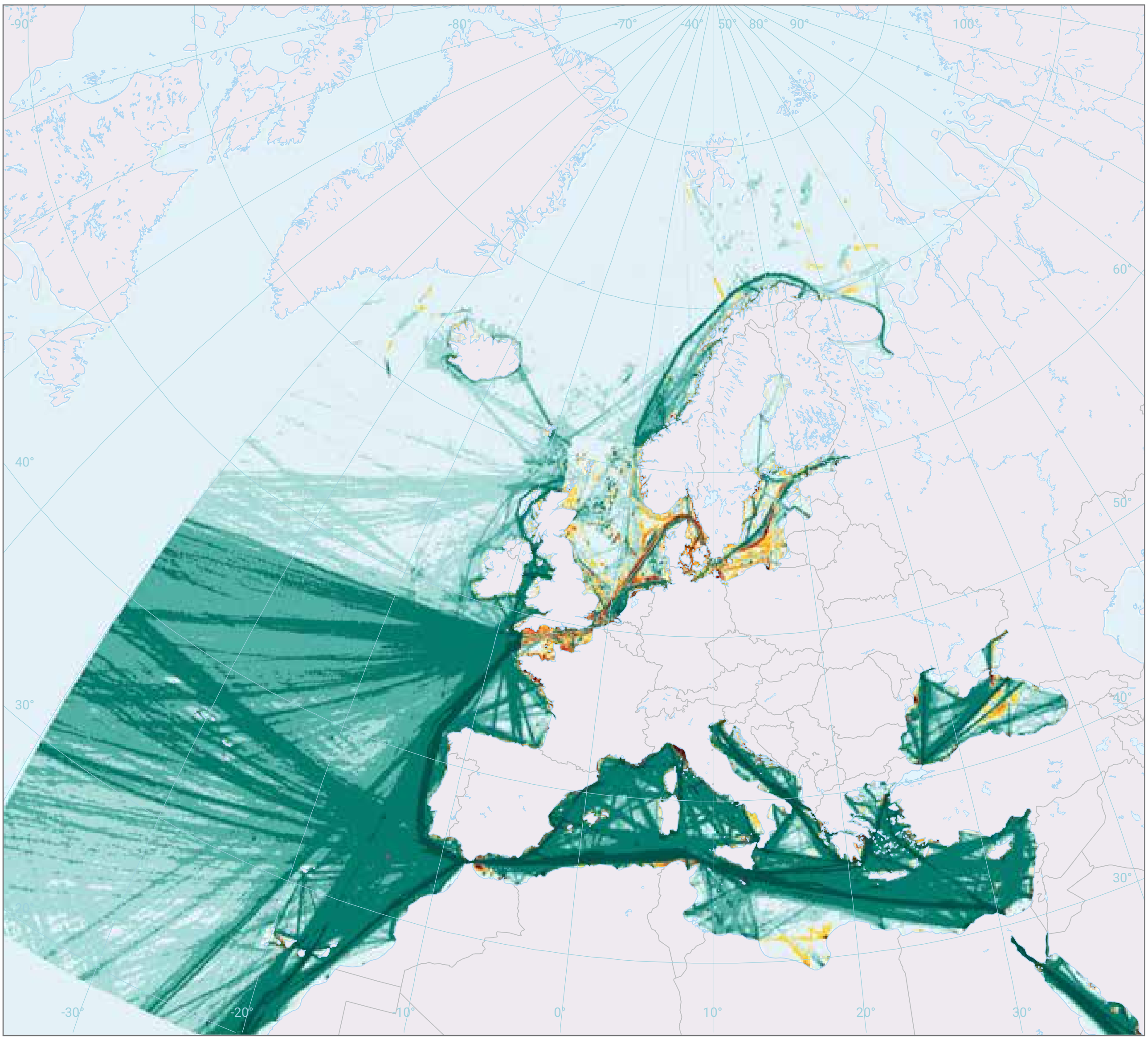
LTRAP inventory data also show that in 2022, fisheries and domestic navigation constituted approximately 2% and 17% of the total maritime emissions. Overall emissions from the sector decreased by 21% from 2019 to 2020, in line with the reduction of activity caused by the COVID-19 pandemic.

Figure 2.14 **$PM_{2.5}$ emissions from the maritime sector and their share in total transport emissions in the EU-27**



Notes: Gg, gigagrams.
Source: LRTAP (EEA, 2024).

Map 2.6 **Difference in $PM_{2.5}$ emissions in European shipping areas**



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Difference in $PM_{2.5}$ emissions in European shipping areas between 2015 and 2023

Tonnes of $PM_{2.5}$

-2,500 | -250 | -100 | -25 | 25 | 100 | 250 | 500 | 1,000

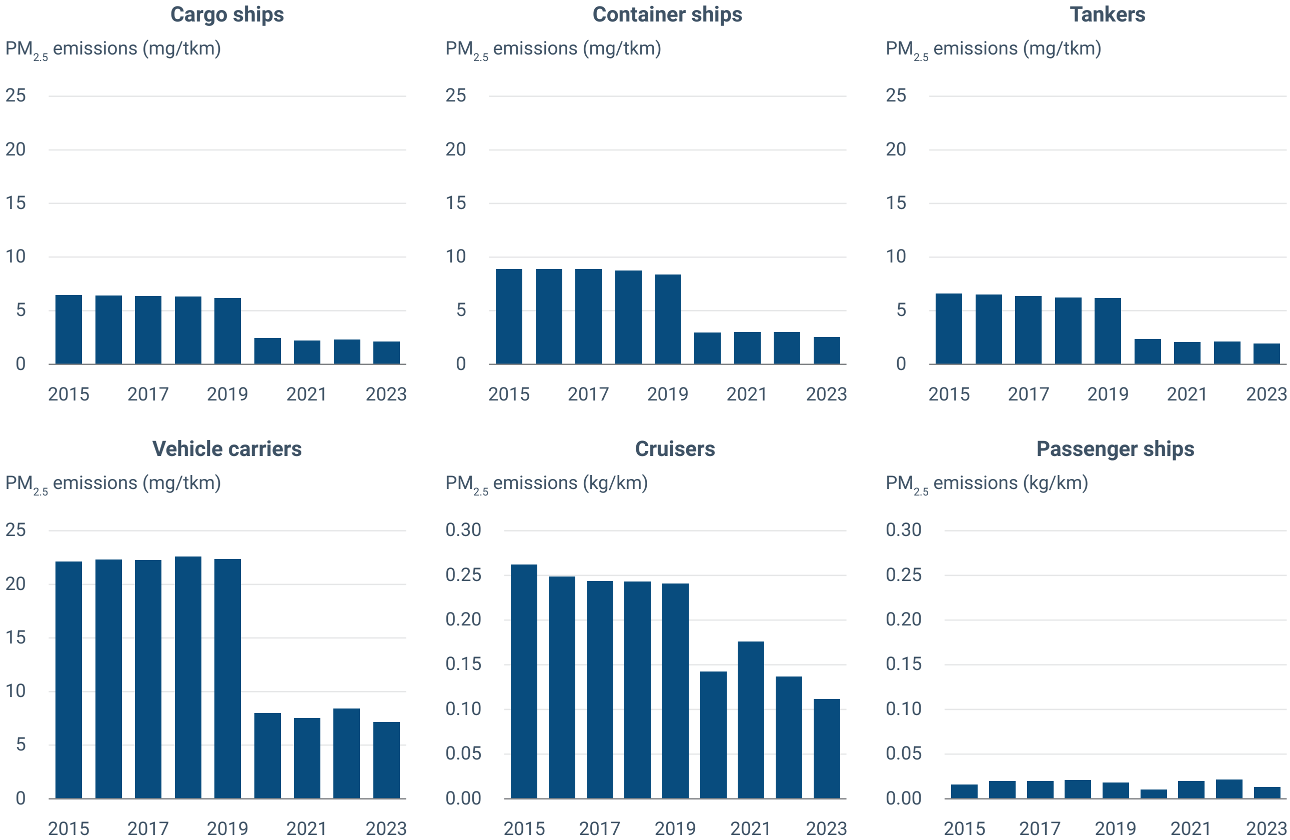
0 500 1,000 1,500 km

Source: STEAM (FMI, 2024).

STEAM data allows us to visualise the uneven distribution of $PM_{2.5}$ emissions across Europe (see Map 2.6). During the period considered, the Mediterranean had the highest average yearly $PM_{2.5}$ emissions equal to 53Gg/year, followed by the Atlantic with 27Gg/year and the North Sea with 8Gg/year.

$PM_{2.5}$ emissions decreased respectively over this period by 61%, 58%, 58% and 9%, in the Mediterranean Sea, Atlantic, Black Sea and North Sea regions. While emissions increased by 6% in the Baltic Sea, this can be aligned with the implementation of the SECAs that will directly have an effect on other pollutants and even outside those areas. Distances travelled in these regions varied by 19%, 45%, -12%, -7% and 7%, respectively. In the Arctic region, $PM_{2.5}$ emissions decreased by 38%, while the distance travelled increased by 48%.

Figure 2.15 $PM_{2.5}$ specific emissions from selected freight and passenger ship types in the EU-27



Notes: Measurements in (mg/tkm) or (kg/km) for freight and passenger ships, respectively.
mg/tkm, milligrammes per tonne-kilometre; kg/km, kilogrammes per kilometre.

Sources: STEAM (FMI, 2024).

Tankers, cargo ships and container ships had the lowest yearly emissions with 4mg/tkm, 5mg/tkm and 6mg/tkm, respectively. By comparison, vehicle carriers emitted up to 16mg/tkm (Figure 2.15).

$PM_{2.5}$-specific emissions have declined for all ship types considered during the period. Specifically, cargo decreased by 67%, containers by 71%, tankers by 71% and vehicle carriers by 68%. This relates to a combination of factors, including the increased average payload transported, yet especially the introduction of new policies such as the IMO Global Sulphur cap, which has an indirect effect on the formation of PM. For reference, the payload carried increased respectively by 34%, 25%, 57% and 10%. Nevertheless, the emission of $PM_{2.5}$ saw an absolute decrease of 56%, 64%, 54% and 64% respectively, showing the important role of cleaner fuels and aftertreatment technologies.

Specific emissions of cruisers in Europe fell by 57%, while the distance travelled grew by 17%, and in absolute terms, emissions decreased by 50%. The situation is similar for passenger ships: emissions increased by 16%, while the distance travelled grew by 4%, with emissions in absolute terms falling by 19%.

However, passenger ships have considerably lower specific emissions compared to cruisers, which emitted 0.212kg/km per year on average between 2015 and 2022. This is approximately 11 times more than conventional passenger ships, which emitted 0.018kg/km on average in the same location and period.

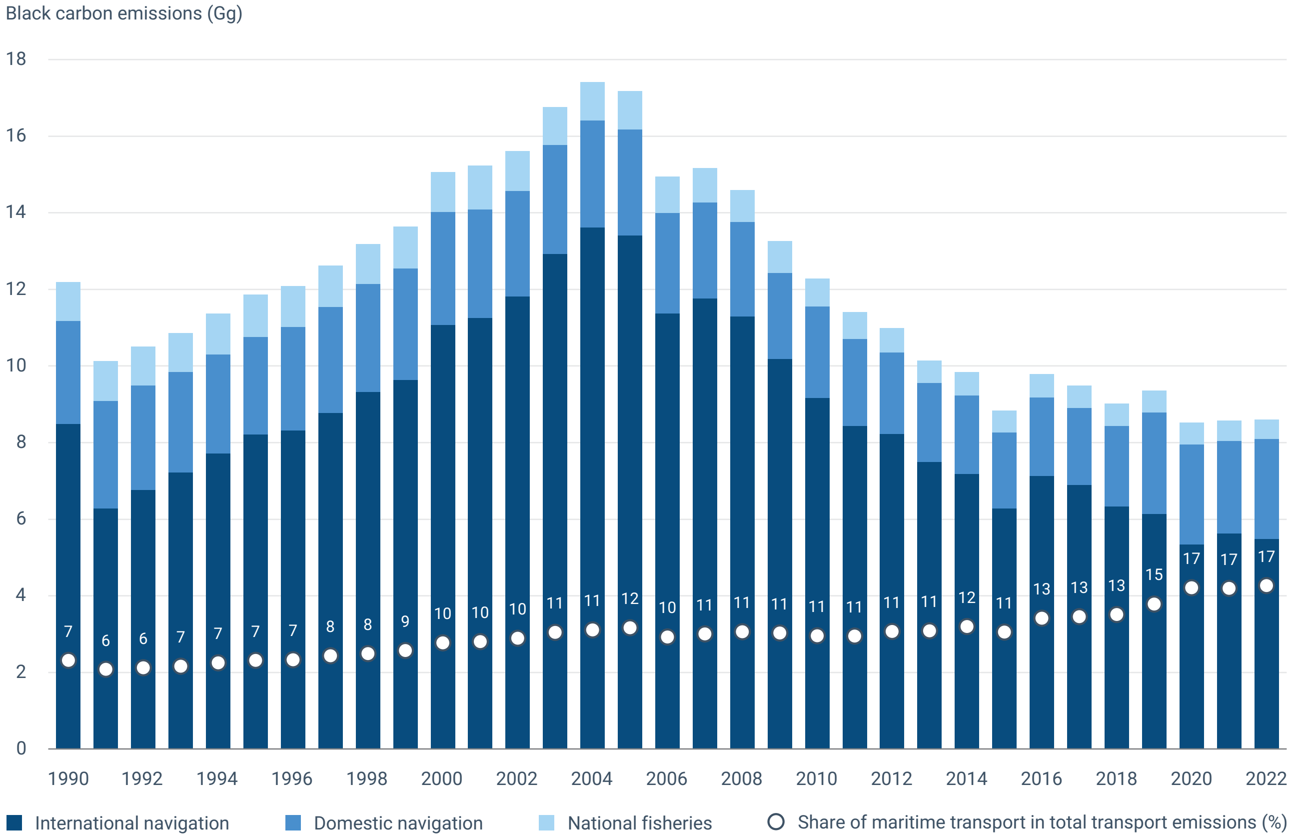
Finally, the average emissions per ship of fishing vessels decreased by 29% from 2015 to 2023. An average fishing vessel emitted approximately 191kg of $PM_{2.5}$ per year in 2023. It should be noted that even though the fishing fleet decreased only slightly (by 15%), absolute $PM_{2.5}$ emissions fell by 39%.

Black carbon (elemental carbon)

Black carbon (BC) is both an air pollutant and a climate forcing compound. Indeed, it is estimated that BC emissions were responsible for 6.85% of the global warming contribution from shipping in 2018, the second most significant contribution for voyage-based international emissions after CO_2 (IMO, 2020a).

The contribution of the maritime sector to overall BC emissions in the EU-27 transport sector has steadily increased over time, reaching approximately 17% in 2022, with BC emissions from the sector reaching 9Gg (Figure 2.16). In 2021, fisheries and domestic navigation constituted approximately 6% and 30% of the total maritime emissions, respectively. From 2019 to 2020 the overall emissions from the sector decreased by 9%, in line with the reduction of activity caused by the COVID-19 pandemic.

Figure 2.16 **Black carbon emissions from the maritime sector and their share in total transport emissions in the EU-27**



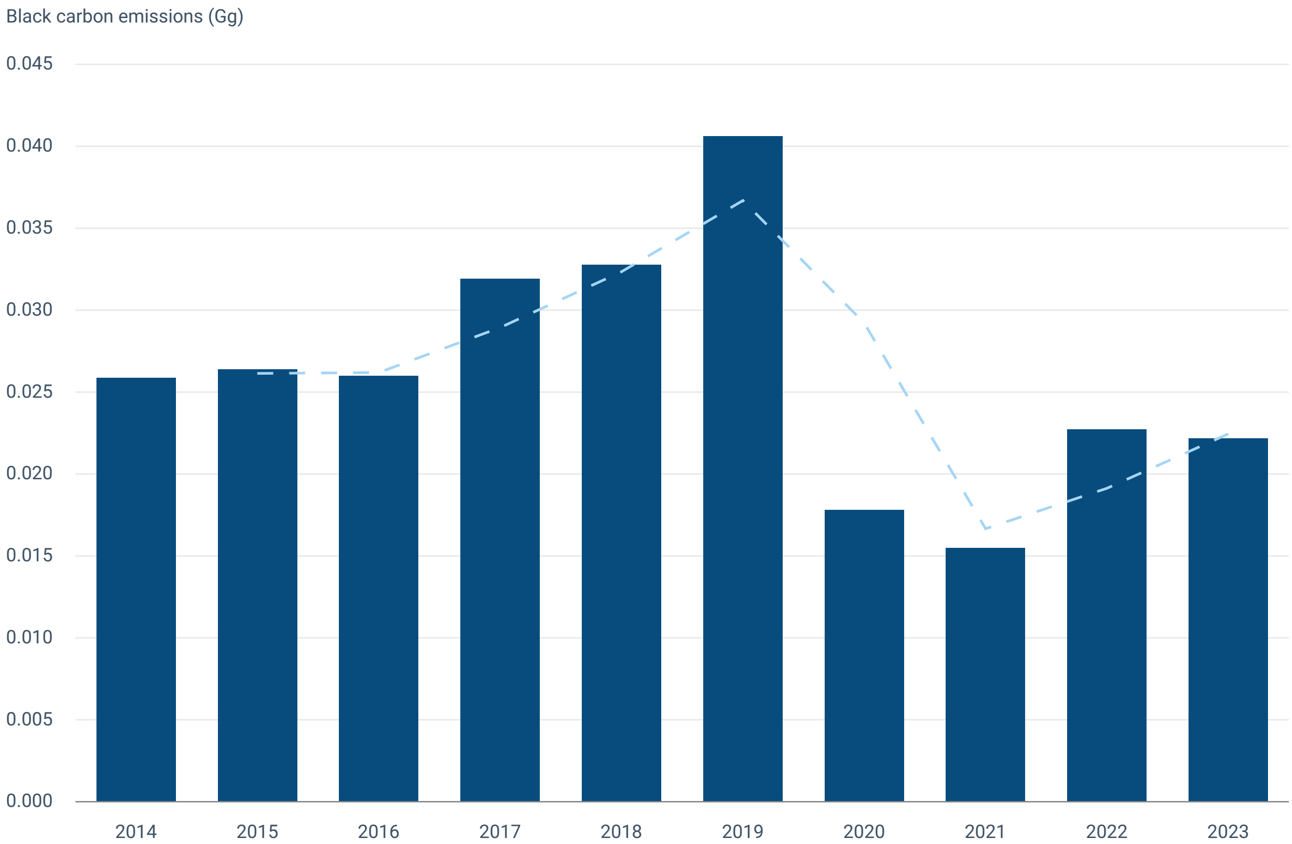
Note: Gg, gigagrams.
Source: LRTAP (EEA, 2024).

In the period considered, the Mediterranean Sea had the highest average yearly BC emissions, equal to 1.61Gg/year, followed by the Atlantic with 0.7Gg/year and the North Sea at 0.47Gg/year.

Data obtained from the STEAM model shows that between 2015 and 2023, BC emissions increased by 21% in the Baltic Sea, while they decreased respectively by 48%, 48%, 36% and 5% in the Mediterranean, Black, Atlantic and North Seas. The variation in distance travelled was 7% in the Baltic Sea, 19% in the Mediterranean Sea, -12% in the Black Sea, 45% in the Atlantic and -7% in the North Sea.

The major impacts of BC emissions relate to its presence and deposition in the Arctic region. The deposition of BC in Arctic snow and ice sheets darkens the ice and reduces the surface albedo, thus increasing heat absorption and melting. BC emissions in the Arctic amounted to 0.022Gg in 2023. Peak emissions came in 2019 with 0.041Gg. Between 2015 and 2023, Arctic BC emissions decreased by 16% while the distance travelled in the area increased by 48% (see Figure 2.17).

Figure 2.17 Black carbon emissions for the Arctic Ocean



Note: Gg, gigagrams.
Source: STEAM (FMI, 2024).

Tankers, cargo ships and container ships had the lowest yearly emissions with 0.127mg/tkm, 0.14mg/tkm, 0.228mg/tkm, between 2015 and 2023. By comparison, vehicle carriers emitted up to 0.323mg/tkm (see Figure 2.18).

BC specific emissions have been declining for all ship types. They decreased by 56% for cargo, 60% for containers, 60% for tankers and 53% for vehicle carrier vessels. This is related to a combination of factors, including the increased average payload transported as well as possibly the introduction of new policies such as the Global Sulphur Cap. For reference, in the same region and timeframe, the payload carried increased respectively by 34%, 25%, 57% and 10%.

Figure 2.18 **BC specific emissions from selected freight and passenger ship types in the EU-27**

Notes: Measurements in (mg/tkm) or (kg/km) for freight and passenger ships, respectively. mg/tkm, milligrammes per tonne-kilometre; kg/km, kilogrammes per kilometre.

Source: STEAM (FMI, 2024).

Specific emissions of cruisers in Europe have been decreasing by 58% during the period considered, with an increase in the distance travelled of 17% and a decrease of absolute emissions of 51%. The situation is similar for passenger ships, for which emissions have decreased by 11% with a relatively modest decrease in the distance travelled (4%). In absolute terms, passenger ships black carbon emissions decreased by 14%.

Finally, the average emissions of black carbon per ship of fishing vessels decreased by 30% from 2015. The fishing fleet slightly decreased its emissions by 15%, while absolute BC emissions fell by 40%.

Estimates suggest low-sulphur fuels could reduce the emission of black carbon by 30-80% when compared to conventional high sulphur fuels (Lack and Corbett, 2012). However, although sulphur in fuels contributes to the creation of particulate matter, studies have shown that reducing sulphur content may not necessarily always reduce black carbon emissions. Low-sulphur fuel blends, while reducing sulphur oxides emissions, may actually produce more black carbon (ICCT, 2019). Some new fuel blends such as Very Low Sulphur Fuel Oils (VLSFOs) designed to meet IMO's 2020 0.50% sulphur regulation (IMO, 2020) have aromatic contents similar to the former HFOs, which also result in higher black carbon emissions when burned, than low-aromatic distillate fuels such as marine gas oil. A Finland-Germany joint study confirmed a correlation between higher aromatics and higher black carbon emissions (IMO, 2019b).

Additional information on how the maritime sector emissions compare with emissions from other non-transport sectors/activities in Europe can be found on the EEA's interactive data viewer (EEA, 2023c).

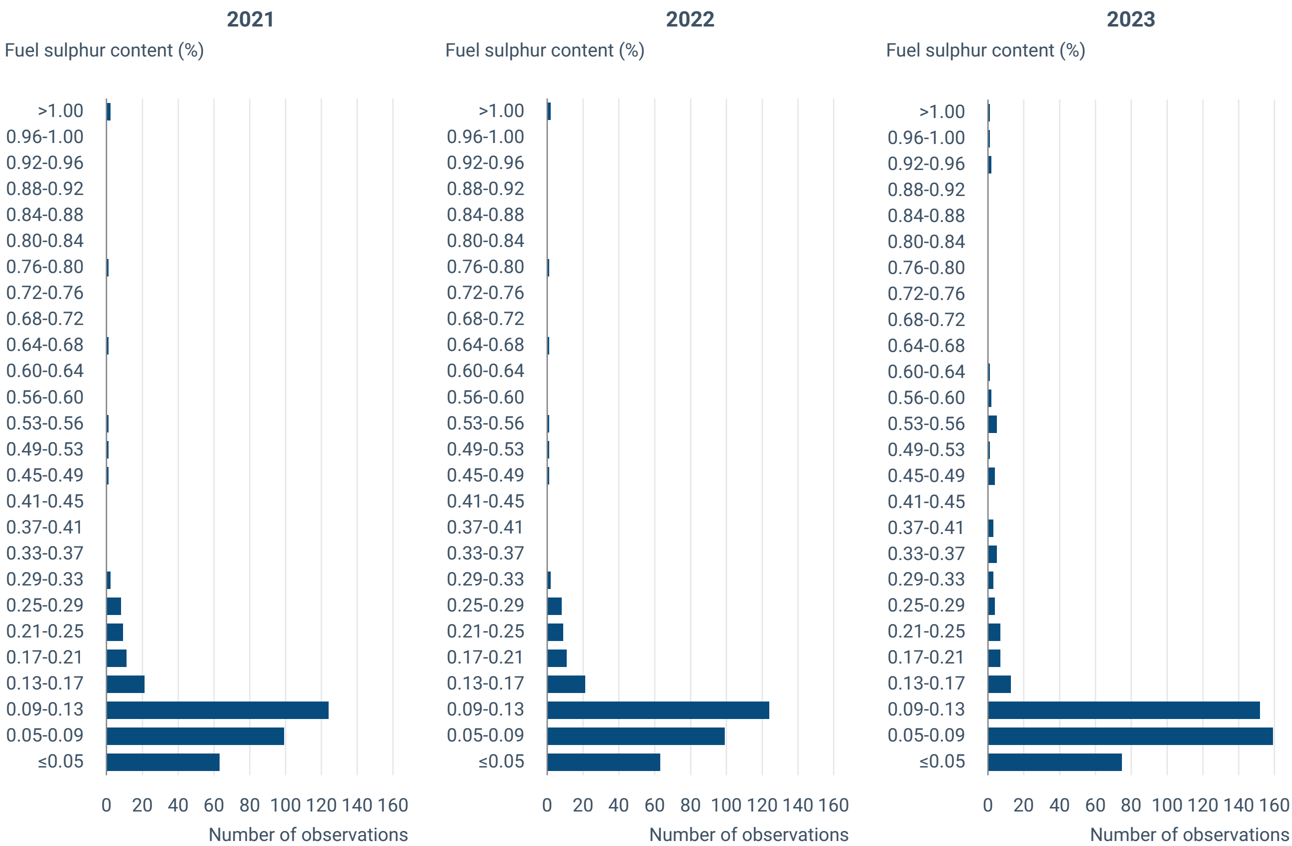
Observations from Remote Piloted Aircraft Systems

SOx Observations from Remote Piloted Aircraft Systems

During EMSA's 2021 Remote Piloted Aircraft Systems (RPAS) emission monitoring campaigns, 624 exhaust gas plume observations were acquired in EU waters in the North Sea, Baltic Sea and North Atlantic. In 2022, the total number of observations rose to 901, with campaigns extended to the Western Mediterranean Sea.

In 2023, RPAS emission monitoring campaigns conducted in the North Sea and Baltic Sea collected 434 observations (note that observation in 2023 took place only within SECA regions). Figure 2.19 provides histograms representing the distribution of the fuel sulphur content values (percentage) derived from the RPAS observations collected during 2021, 2022 and 2023 in Sulphur Emission Control Areas (SECA)and port areas where the emission limit is 0.10%. Figure 2.20 provides instead the values for the RPAS observations collected during 2021 and 2022 outside SECA and port areas where the limit is defined by the global sulphur cap (0.50%) (no observations took place outside SECA areas in 2023).

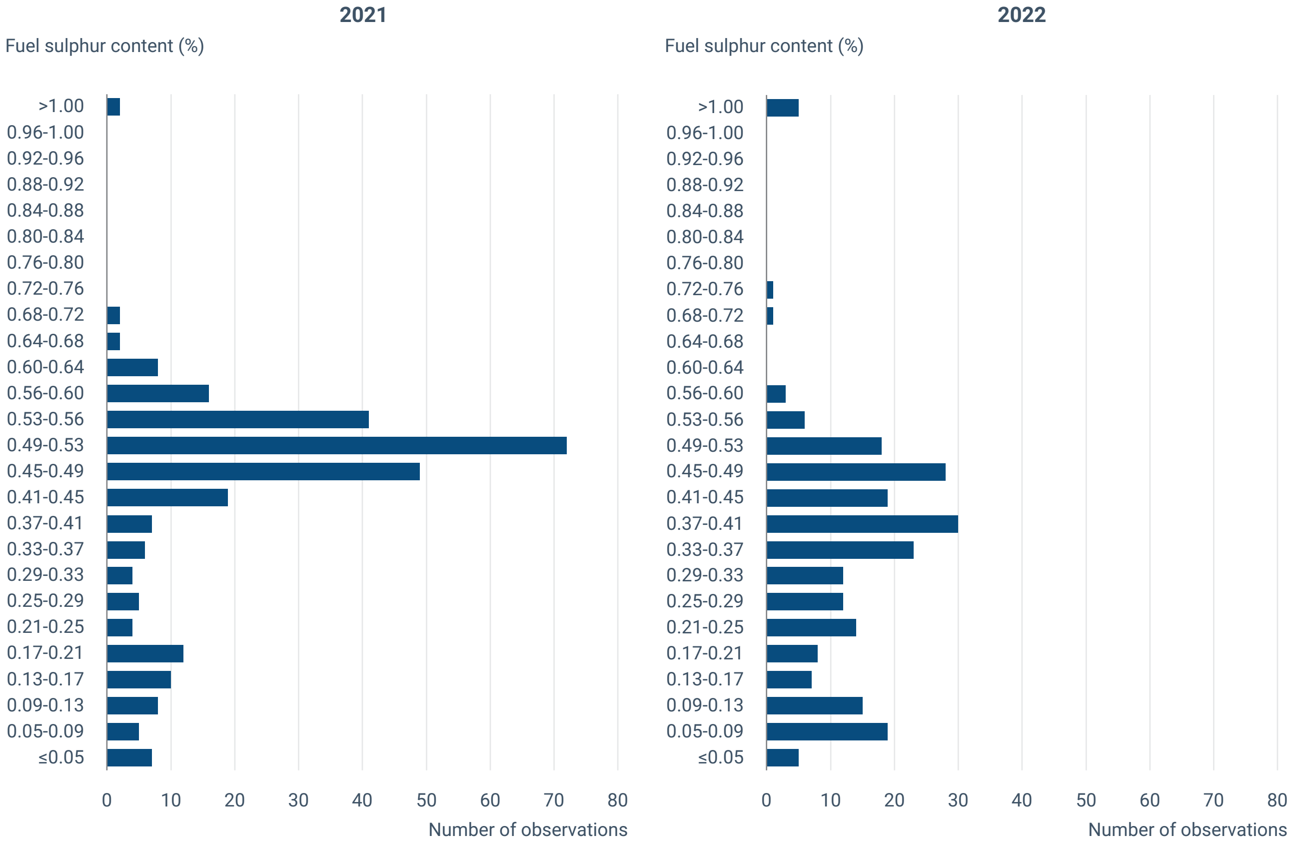
Figure 2.19 Distribution of sulphur emissions obtained through RPAS aerial measurements acquired in SECA and port areas during 2021 (left), 2022 (centre) and 2023 (right)



Notes: Distribution is divided into 26 classes. For 2021 and 2022 the values range from <0.05% to >1% FSC, for 2023 the values go up 0.94% FSC, the highest value measured in that year.

Sources: EMSA internal data; RPAS (2024).

Figure 2.20 **Distribution of sulphur emissions obtained through RPAS aerial measurements acquired outside SECA and port areas during 2021 (left) and 2022 (right)**



Note: No data outside SECA areas was acquired in 2023.

Sources: EMSA internal data; RPAS (2024).

In general terms, the distribution of the measurements shows concentrations around the limit of the respective areas (0.10% and 0.50%), although in non-SECA areas (for the period 2021-2022) there is a more even distribution towards the lower values. This might be due to possible mixture with low-sulphur fuels available in the tanks of the vessels. This is more evident in 2022 than 2021.

In areas where the sulphur emission limit is 0.10%, the average fuel Sulphur content (FSC) derived from RPAS aerial observations was fairly stable, with values of 0.11% FSC in 2021, 0.09% FSC in 2022 and 0.10% in 2023. In areas where the limit is 0.50%, the average FSC derived from RPAS aerial observations was 0.43% FSC in 2021 and 0.36% FSC in 2022. As previously stated, no data outside SECA is available for 2023.

From an air quality perspective, it is evident that the establishment of a SECA may reduce the overall SOx emissions from vessels. Therefore, a reduction of emission limits from 0.50% to 0.10% FSC in the Mediterranean Sea from 2025 can reduce SOx emissions from shipping in the region and hence improve air quality.

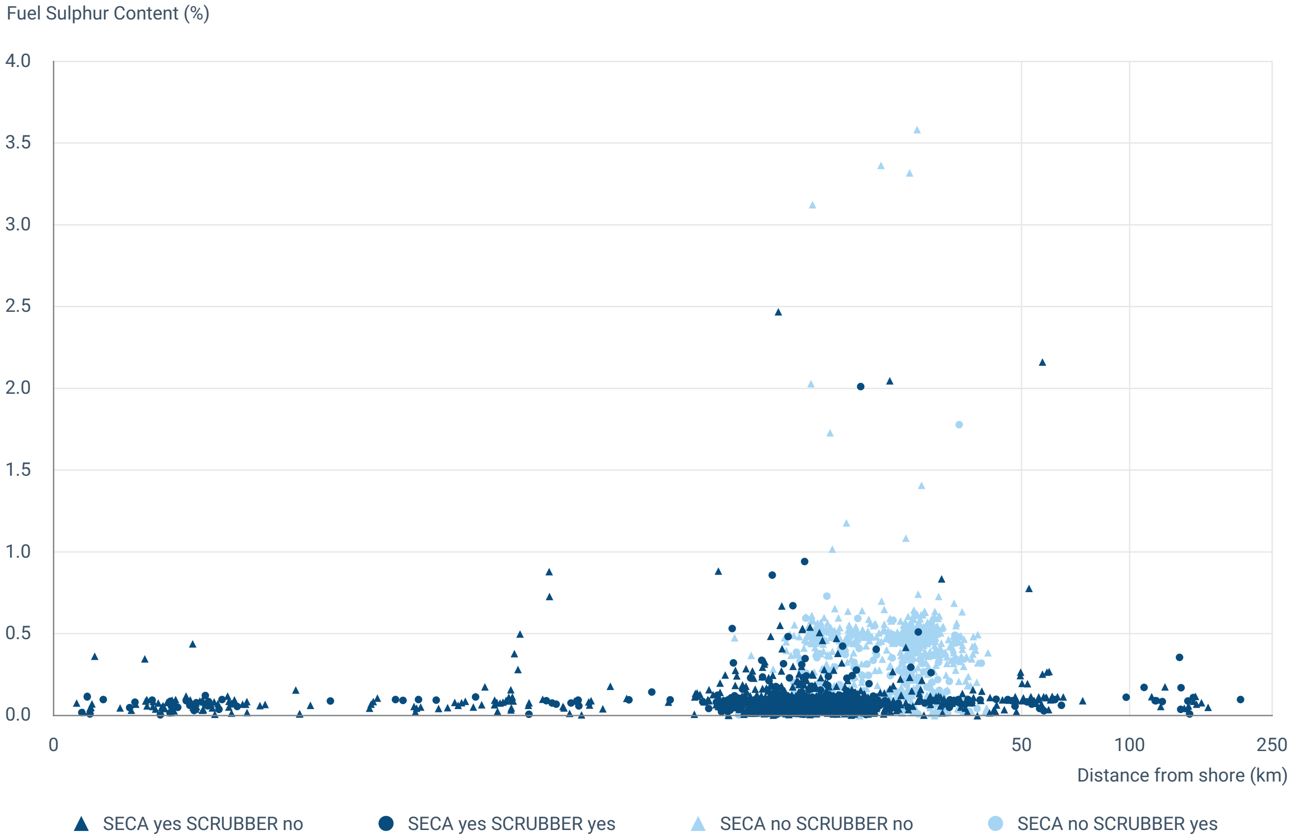
In areas where the sulphur emissions limit is 0.10% FSC, the percentage of observations above the threshold, accounting for measurement uncertainty, was 17% in 2021 and 11% in 2022 and 2023. In areas with a 0.50% FSC limit, the percentage of observations exceeding the threshold, including uncertainty, was 8% in 2021 and less than 4% in 2022. Surveillance and inspections in areas with more stringent limits (e.g. 0.10% FSC) are crucial to ensure vessels adhere to regulations. This is also due to the higher costs for ship operators to comply with the limits in those zones and the increased likelihood of infringements. The combination of port inspections — where infringements can be fully confirmed via laboratory tests of fuel samples — and the use of remote sensing emission monitoring technologies, which can target potentially violating ships in both coastal and open ocean, paves the way for a powerful tool that can enforce regulations.

The RPAS gas observations include geographic coordinates marking where each measurement was taken. This data was analysed to identify spatial trends and patterns within the available fuel sulphur datasets. Interestingly, the percentage of values exceeding permissible limits (accounting for measurement uncertainty) within a 500km radius of the SECA border was 12% in 2021, 11% in 2022 and 15% in 2023. In contrast, the percentage of measurements surpassing limits (including instrumental uncertainty) collected beyond 500km from the SECA border was under 5% for 2021 and 2022 and 3% in 2023. Considering that most vessels were monitored while entering a SECA, this discrepancy suggests that vessels might be delaying their switchover to low-sulphur fuel (albeit the dataset does not allow a statistically significant conclusion).

It is, however, not possible to say if a similar behaviour may happen when the vessels are leaving the SECA, due to the small number of measurements under these conditions. Large vessels typically have multiple tanks, storing fuels with varying sulphur content. When the switch from high sulphur fuel to SECA-compliant low-sulphur fuel is made, remnants of the non-compliant fuel could remain in the pipelines, resulting in elevated emissions for several hours. Thus, if vessels switch fuels too late upon entering the SECA, they could emit more sulphur than permitted until the fuel transition (also known as 'change-over procedure') is complete. More comprehensive studies and targeted monitoring campaigns will clarify this behaviour.

The geographical location of measurements can also be used to plot FSC values against the distance from the shore, as illustrated in Figure 2.21. Given that numerous maritime shipping routes are in close proximity to the shore, vessel emissions can affect air quality on land. As previously noted, this is especially pertinent in areas where emission limits are higher, such as regions where the global sulphur cap is enforced. The datasets were gathered along shipping routes and within port areas, meaning this data distribution might not provide an accurate depiction of whether there is a correlation between sulphur values and the distance to the port of call. Therefore, further targeted data collection is required in this regard.

Figure 2.21 **Distribution of FSC values obtained in RPAS deployments vs distance to shore**



Note: Logarithmic scale, for different areas (in/out SECA or port areas) and vessels (with/without scrubber)

Sources: EMSA internal data; RPAS (2024).

RPAS deployments evaluated 479 vessels equipped with exhaust gas cleaning systems (EGCS) between 2021 and 2023. The FSC was derived from these measurements (represented as circle marks in Figure 2.21). Of these vessels, 47 (accounting for 9.8% of the observations) had FSC exceeding the permissible limits considering uncertainty, with some displaying exceptionally high values (greater than 1% FSC). Five of these vessels with excessive FSC were detected in non-SECA areas (between 2021 and 2022), while the rest (42 vessels) were found in SECA and Port Areas, giving exceedances of 5.1% and 12.1%, respectively.In these instances, it is possible that the scrubbing system might have been malfunctioning, though it might also have been switched off intentionally. It is crucial to conduct careful monitoring and control of vessels fitted with EGCS to analyse the FSC values collected through RPAS.

NOx Observations from Remote Piloted Aircraft Systems

The regulation and enforcement of NOx is more complex than that of SOx. As mentioned above, limit values are tiered depending on keel laying date and defined by the rated engine speed. Moreover, the limits in place represent an average of four different engine loads with different weighting factors (E3 cycle: 100% load with weighting factor 0.2; 75% load with weighting factor 0.5; 50% load with weighting factor 0.15; and 25% load with weighting factor 0.15). The regulation follows an approach based on engine certification. Considering the environmental and health impacts of NOx, discussions are ongoing on the effectiveness of the current regulations in achieving the anticipated reductions in air pollution from marine diesel engines, as well as the potential shortfalls in the compliance approach to detect possible violations during real operations. As highlighted at the beginning of this section, gas sensors equipped on EMSA's RPAS can also measure NOx levels. However, due to the complexity of determining exactly the engine load at the time of the measurement, as well as the specific fuel consumption to convert the measured NOx-CO_2 ratio to an emission factor in g/kWh, these measurements are currently not considered mature enough to be used for monitoring NOx emissions from ships.

Notwithstanding, the SCIPPER project, funded by the EU's Horizon 2020 programme, remotely collected and analysed, recordings of NOx emissions from vessels in the Baltic and North Seas during 2022 (SCIPPER, 2022a). Although the most stringent Tier III requirements apply only to ships built on or after 1 January 2021, from the analysis of the ships under the scope, it appears that many of the ships measured were above the Tier III limit by more than 50% (SCIPPER, 2023a, 2023b).

Additional monitoring approaches
In addition to observations from Remote Piloted Aircraft Systems, it is important to highlight that a suite of other platforms are also used to provide very relevant and insightful SOx and NOx measurements (SCIPPER, 2019, 2022b). For example, Belgium is very active in the use of airborne monitoring techniques (more specifically through the use of sniffer sensors onboard Belgian coastguard aircrafts) to monitor air quality in the North Sea Emission Control Area (Van Roy, et al., 2022; Van Roy et al., 2023a; 2023b).

Further to this, some Member States also operate fixed sensing stations.For example, Sweden operates two sensing stations for the control of sulphur oxides emissions by vessels in Swedish waters and ports, one station located on the Øresund bridge and the other is located on an island close to the entrance to the port of Gothenburg.

These stations carry out automatic measurements and calculate fuel sulphur content from SO_2/CO_2 observations and NOx emissions per kWh from NOx/CO_2 observations and send the data to a database, which communicates with different instruments and identifies the ship. When the measurements show a fuel sulphur content exceeding limits (0.10% sulphur content in this case), the database sends an alarm with the sulphur content measurement and ship information to relevant recipient users by e-mail. These stations take between 1,600 and 1,900 valid measurements per year on average. No alerts occurred in 2021 or 2022.

Germany is also conducting ship plume measurements from three fixed stations located in Wedel/Hamburg, Bremerhaven and Kiel. The fraction of measurements above the sulphur limit at these stations was 0.19% in 2021, 0.11% in 2022 and 0.19% in 2023. A total of 9,189 ship plumes were analysed in 2021, 9,644 in 2022 and 8,609 in 2023 (Bundesamtes für Seeschifffahrt und Hydrographie (BSH),personal communication, 25.03.2024).

2.1.3 Air quality in ports

Monitoring air quality in ports and nearby cities will become more important in the coming decades, to better understand the role of emissions from all port activities (e.g. road traffic, non-road machinery, bulk unloading and industrial installations), including from shipping. The relative contribution from international shipping to NO_2 annual mean concentrations in European ports is 22% on average, 5% for $PM_{2.5}$ and 3% for PM_{10} (Concawe, 2023). Future emission projections indicate that the amount of road traffic emissions contributing to high NO_2 concentration exposure in the population will decrease significantly. Meanwhile, shipping emissions could become the main transport related contributor to adverse health impacts in coastal European cities by 2030 (EC, 2022). Nevertheless, as identified in the first EMTER, there is a gap in monitoring the contribution of shipping emissions to air pollution in ports as the availability of monitoring points in and around port areas is limited while ports are inherently complex environments with industrial activities often taking place within or very near their perimeter. There is a need for increased and more accurate monitoring of emissions in these areas to better determine the contribution of each sector. Further research in this field is required to support improved monitoring. Among the 23 ports analysed (ETC HE, 2024), only five had at least one air quality sampling point ([11]) for NO_2 and PM_{10} located inside the port area ([12]). Almost all ports had at least one monitoring point in the vicinity of the port area (within 1km distance). In addition, only a few of the identified monitoring points are located downwind of the prevalent wind direction of the port areas.

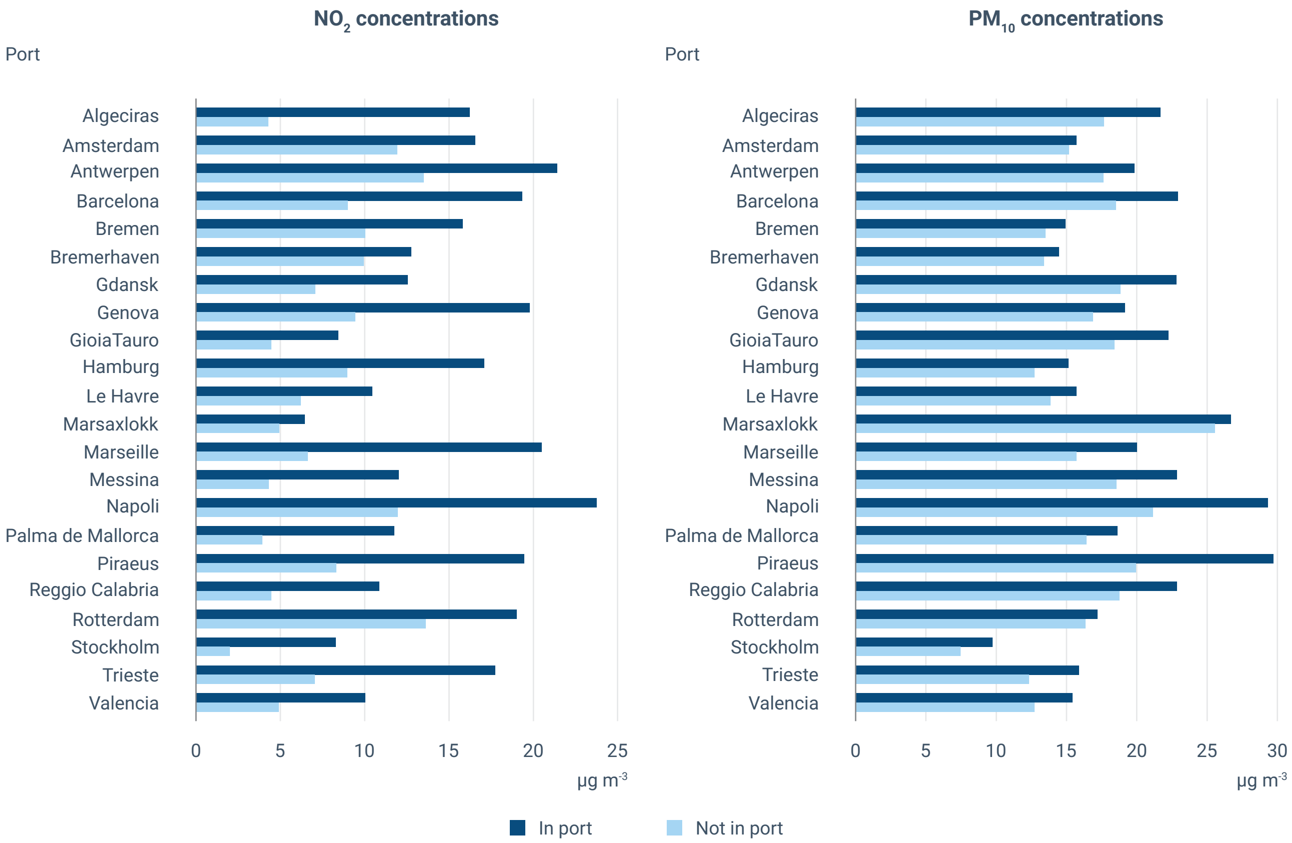
Air quality in port areas compared to the surrounding regions and nearby cities
Due to the scarcity of monitoring points in ports and surrounding areas, it is difficult to assess the differences between air pollutant concentrations in ports and the nearby cities and regions solely on monitoring data. Therefore, the EEA's air quality maps ([13]) for 2021 were used to estimate the distribution and differences of air pollutants in ports and the surrounding regions.

Annual mean NO_2 concentrations in port areas in 2021 were higher than the mean concentrations in the surrounding regions, ranging between 1.5µg/m^3 (Marsaxlokk) to more than 10µg/m^3 (Algeciras, Barcelona, Genova, Marseille, Napoli, Piraeus and Trieste). In relative terms, the annual mean NO_2 concentrations in port areas were higher: from 28% (Bremerhaven) to more than 100% in 11 ports (Figure 2.22a). In Antwerpen, Marseille and Napoli the annual mean NO_2 concentrations in ports were above the limit value of 20µg/m^3 for the protection of human health to be attained by 1 January 2030 of the Ambient Air Quality Directives.

Also, annual mean PM_{10} concentrations in 2021 were higher in port areas compared to the surrounding regions. The difference was below 5 µg/m^3 for almost all the ports analysed, except for Napoli and Piraeus (Figure 2.22b). In relative terms, the concentration differences between port areas and surrounding regions ranged from 3% (Amsterdam) to 49% (Piraeus). In nine ports (Algeciras, Barcelona, Gdansk, Gioia Tauro, Marsaxlokk, Messina, Napoli, Piraeus and Reggio Calabria) the annual mean PM_{10} concentrations were above the limit value of 20 µg/m^3 for the protection of human health to be attained by 1 January 2030 of the Ambient Air Quality Directives.

([11]) Evaluation based on year 2021 data, which was, at the time of performing the study, the latest air quality validated data available from the European e-reporting database: https://aqportal.discomap.eea.europa.eu.
([12]) 'Port area' defined as the polygon classified as 'Port areas', CLC code 123, in CORINE Land Cover 2018. We refer to in and around port as the area within 1km distance from the Port areas polygon.
([13]) https://sdi.eea.europa.eu/catalogue/datahub/eng/catalog.search#/metadata/82700fbd-2953-467b-be0a-78a520c3a7ef.

Figure 2.22 Annual mean concentrations of NO_2 (a) and PM_{10} (b) in 2021 inside and in the vicinity of port areas compared to the surrounding region



Note: Data from European Environment Agency air quality maps at 1km x 1km resolution.

Source: EEA, 2024.

As meteorology plays an important role in air quality, the sampling points must be located downwind (based on the prevailing wind direction) of the port to monitor the impacts on air quality in the surrounding region. An analysis using meteorological data ([14]) assessed the change in pollutant concentrations during downwind conditions (the wind coming from the port) and compared to all other observations. It found a significant increase in NO_2 median concentrations at several sampling points around ports in different cities, up to 100%. The same analysis showed increases in median PM_{10} concentrations at some of the sampling points around ports, up to 74%. These differences are not consistent for all wind sectors around the port and may be influenced also by other pollution sources in the cities.

([14]) Hourly data of wind directions at 10m from ECMWF reanalysis data for year 2021.

2.2 Water pollution

2.2.1 Oil spills

Key messages

- There is a higher detection of possible oil spills in the North Sea and Mediterranean Sea compared to other areas due to high traffic, which increases the likelihood of illegal discharges and accidents.
- Although there is a decline from 2018 to 2022 in the rate of detected pollution incidents, in 2023 the average number of possible pollution incident detections increased by more than 58% compared to 2022.
- In 2023, 62% of detected possible pollution incidents by the CleanSeaNet service were lower than 2 km^2 and 87% were lower than 7 km^2. When compared with previous years, there was an increase in the detection of small to medium-sized possible pollution incidents (i.e., less than 15 km^2). The more extensive use of higher spatial resolution imagery from commercial satellite missions has enhanced CleanSeaNet's capability to identify smaller possible spills.

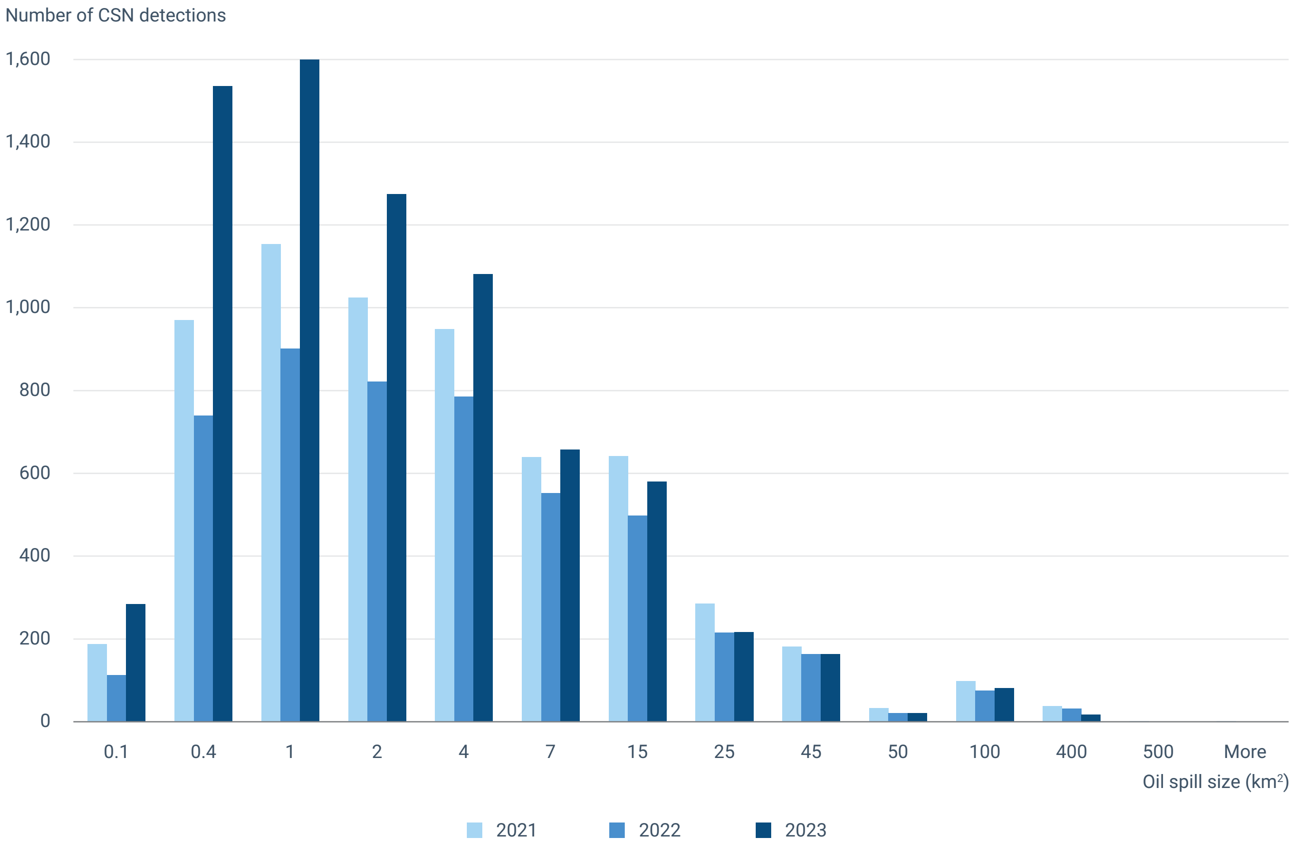
In 2023, EMSA's CleanSeaNet service detected a total of 7,513 possible oil spills. The CleanSeaNet service uses a two-level classification system, namely Class A and Class B, to indicate the likelihood that a feature detected in a satellite image is a spill. Class A suggests that the detected possible spill has a higher (more than 50%) detection confidence level, implying that it is more likely to be an oil spill. Conversely, a Class B classification indicates a lower (less than 50%) detection confidence level, suggesting that it is less likely to be an oil spill. This two-level classification system helps Member States prioritise their response efforts accordingly.

The analysis of the geographic distribution of the possible oil spills suggests a higher incidence probability in the North Sea, southwest Iberian Peninsula and Mediterranean Sea compared to other areas. This is attributed to heavy maritime traffic in these areas, where a significant number of ships transit daily, heightening the risk of illegal discharges and accidental spills. Furthermore, the North Sea's status as one of the largest offshore oil and gas production regions in the world, populated with numerous platforms and drilling rigs, may increase the occurrences of accidental and operational spills in the area and contribute to the high volume of possible oil spills detected by CleanSeaNet. Similarly, there is an amplified risk of pollution in the highly industrialised Mediterranean Sea, characterised by numerous and extensive ports, refineries and petrochemical plants along its coastlines. Research indicates that approximately 35% of oil entering this sea originates from routine shipping operations, 45% from land-based sources, including municipal and industrial effluents and regular oil rig operations, 10% from accidents involving oil tankers, and 5% from natural sources. The remaining 5% remain undefined (World Ocean Review, 2014).

Figure 2.23 presents the distribution of possible oil spills according to their size. In 2023, 62% of the possible pollution incidents detected by CleanSeaNet were smaller than 2km^2 and 87% were smaller than 7km^2. The detection of small to medium-sized possible pollution incidents (i.e. possible oil spills covering less than 15km^2)

increased compared to previous years, which points to an enhanced capability in detecting small oil spills with higher resolution satellite imagery. The detection of possible pollution incidents covering an area equal to or larger than 25km², however, remains stable.

Figure 2.23 CleanSeaNet possible oil detections according to size (km²)

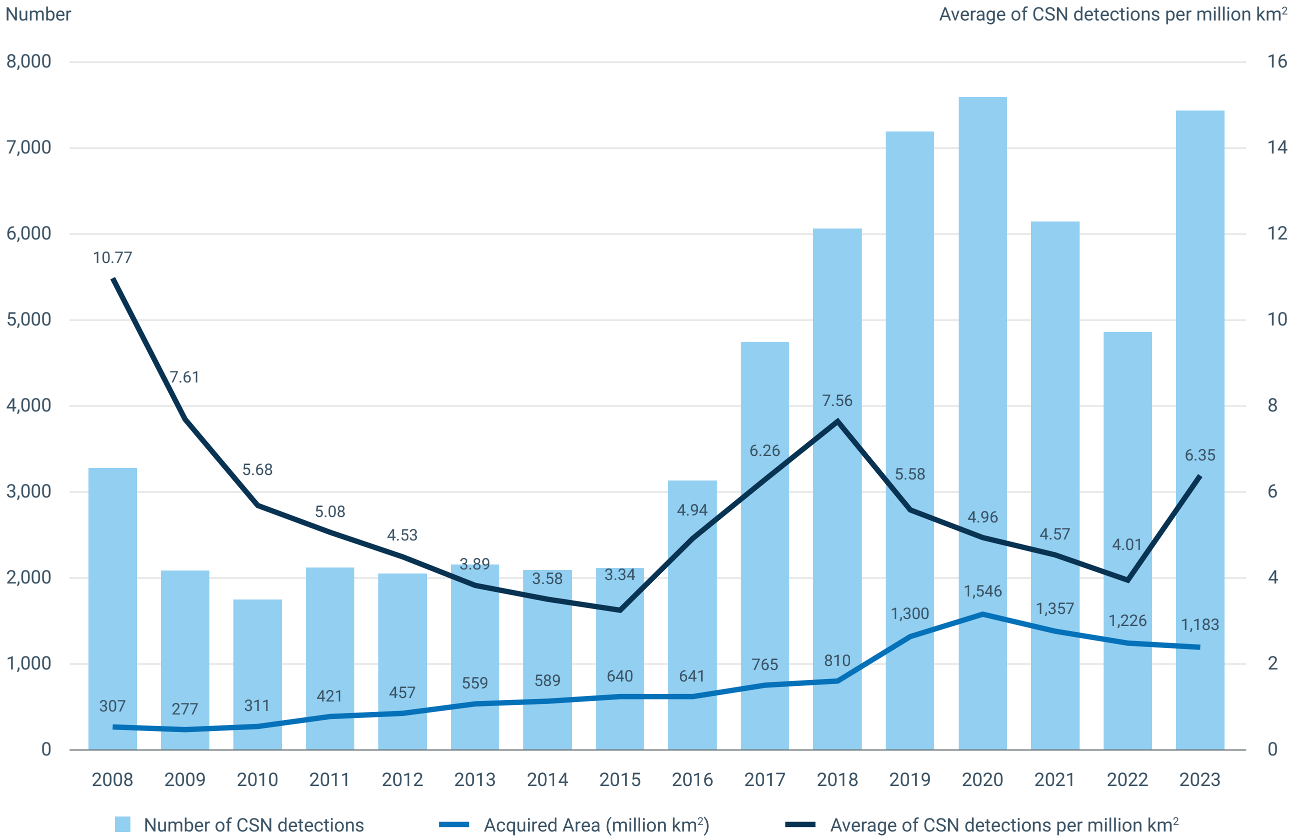


Note: CSN, CleanSeaNet.
Sources: EMSA internal data; CleanSeaNet, 2024.

By analysing the CleanSeaNet data in Figure 2.24, it is possible to identify a decreasing trend in the number of possible pollution incidents detected per million km² between 2008 and 2015. This coincides with an increased awareness of maritime pollution prevention and improvements in the provision of port reception facilities across the EU (UNCTAD, 2011).

The number of possible pollution incidents detected per million km² increases between 2015 and 2018, possibly due to the enhanced capabilities of satellite surveillance tools used by EMSA in the CleanSeaNet service. Subsequently, there is a decline in the rate of possible pollution incidents detected per million km², with a downward trend commencing in 2019 and persisting through 2022, with a reduction of over 12% in the average number of possible pollution incidents detected per million km² compared to the previous year (decreasing from 4.57 in 2021 to 4.01 in 2022). In contrast, 2023 saw a reversal of this trend, with the average number of possible pollution incident detections per million km² climbing to 6.35, an increase of more than 58% relative to 2022. Although this surge moderates to roughly 16% when considering only Class A detections, it signifies a heightened use of higher spatial resolution imagery from commercial satellite missions, enhancing the capability to identify smaller spills.

Figure 2.24 **Trend in annual number of possible pollution incidents detected by CleanSeaNet and average number of possible pollution incidents per million km²**



Notes: Acquired area is the number of km² which have been monitored through the acquisition and subsequent analysis of satellite imagery.
CSN, CleanSeaNet.

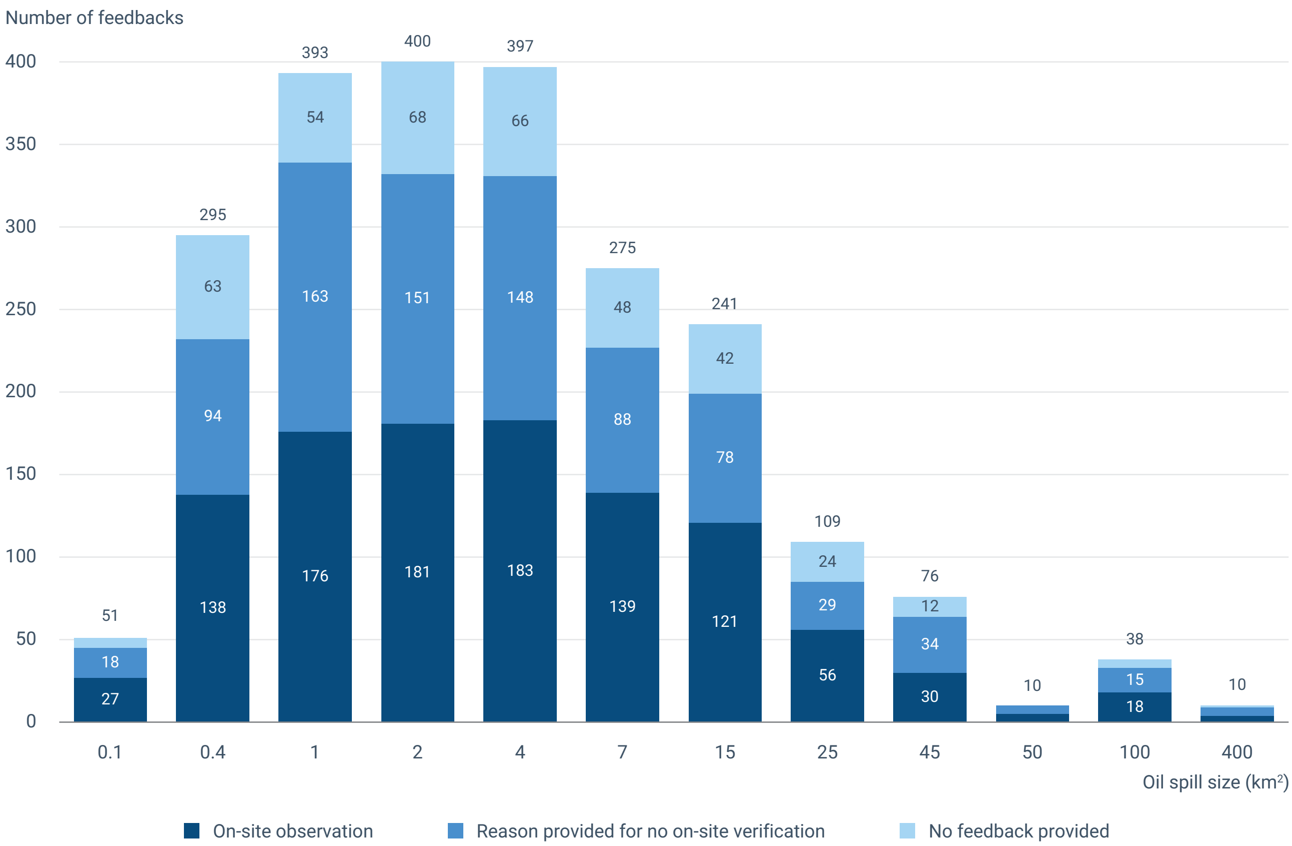
Sources: EMSA internal data; CleanSeaNet, 2024.

In addition to identifying possible oil spills, CleanSeaNet promptly alerts the concerned Member State. Upon detection of a possible spill, an alert report is dispatched in near real-time to the Member State, typically within 20 minutes following the satellite's observation. This enables responsible authorities to initiate follow-up actions, which may include on-site checks by patrol boats, aerial surveillance monitoring, along with other measures such as port inspections.

In 2023, a total of 2,464 possible pollution incidents within Exclusive Economic Zone (EEZ) areas were verified on-site, accounting for 41% of detections. Among these, 133 (5%) were confirmed as 'mineral oil', 399 (16%) as 'other substance', 377 (15%) as 'unknown feature' and 65 (3%) as 'natural phenomena'. Notably, a significant portion of the follow-up activities, 60% (equating to 1,490 detections), reported 'nothing observed'.

Figure 2.25 illustrates that in 2023, the majority of the Class A possible pollution incidents were between 0.4km² and 15km² in size. Furthermore, as the size of the spill enlarged, the percentage of possible pollution incidents confirmed on-site increased. There was a simultaneous decrease in the percentage of spills that were not verified on-site, for reasons such as unavailability of assets or operational irrelevance. This suggests a prioritisation by Member States towards the on-site verification of larger spills.

Figure 2.25 **Feedback to CleanSeaNet detections of Class A, according to size (km²) of possible pollution incident in 2023**



Sources: EMSA internal data; CleanSeaNet, 2024.

Statistical data on oil tanker spills made available by the International Tanker Owners Pollution Federation (ITOPF) shows that in 2023 the percentage of spills from oil tankers in the EU was 12% (out of the total that took place worldwide), compared to 13% in 2019. More specifically, this decline is more noticeable for the large spills which have decreased to 13% in 2023, compared to 17% in 2019 (ITOPF, 2024).

Table 2.2 **Number and percentage of oil spills from tankers inside and outside the EU by spill size, 2010-2023**

	Oil Spill Size		
Location	Large	Medium	Total
	>700 Tonnes	7-700 Tonnes	
EU	3	8	11
Outside	20	59	79
Total	23	67	90
Percentage in EU	**13%**	**12%**	**12%**

Note: Note that the unit used by ITOPF to report and identity the size of an oil spill is tonnes, while in previous figures it is km^2.

Source: ITOPF, 2024.

Despite the steady decrease in the number of oil tanker spills in Europe and the increased surveillance and enforcement efforts, illegal discharges of oil and other polluting substances persist in European waters (EC, 2023e).

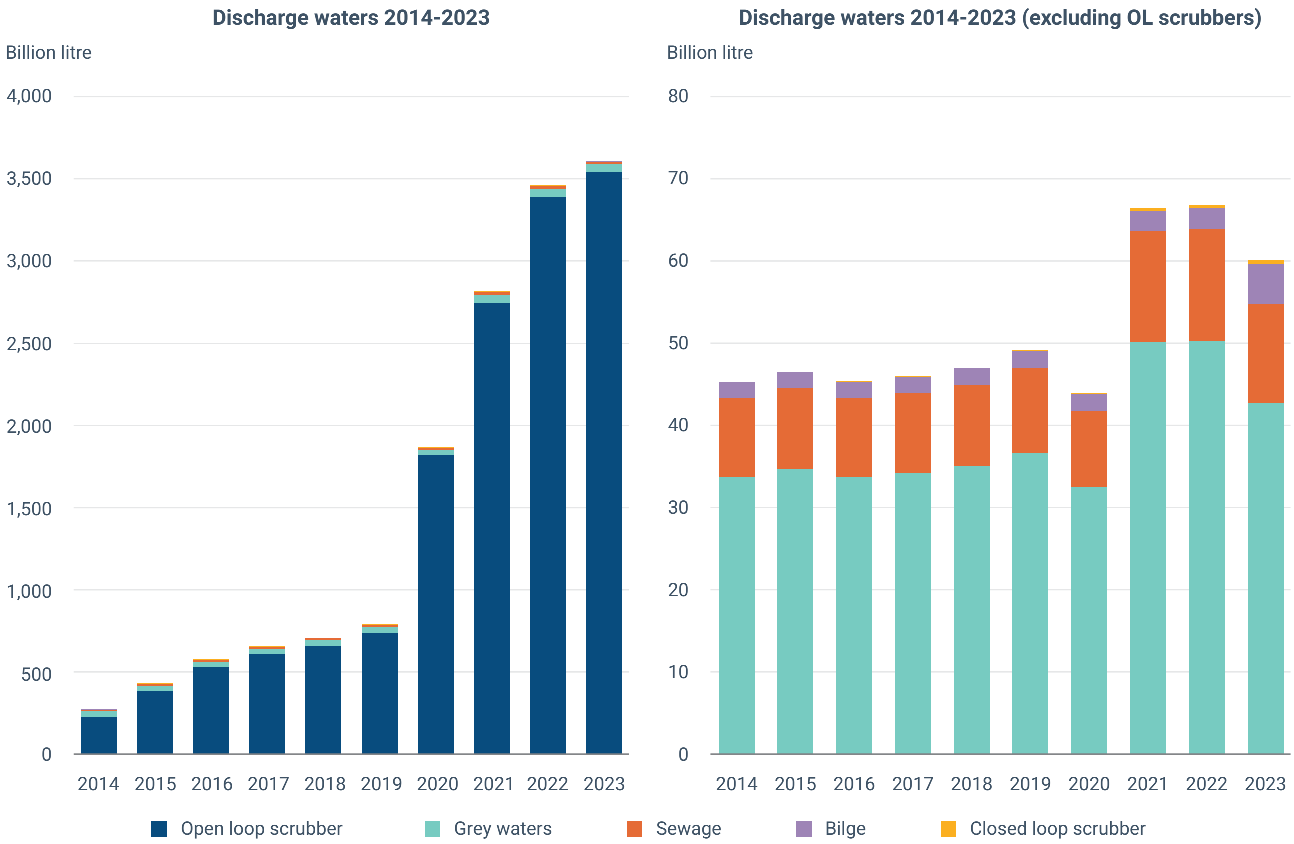
2.2.2 Discharge waters and contaminants

Key messages

- 98% of water discharge volumes consist of wash waters mostly from open-loop Exhaust Gas Cleaning Systems (ECGS) (74% of the scrubbers are open loop). The remaining 2% comprises primarily grey water (1.4%) and sewage (0.4%).
- Since 2020, water discharges from open-loop scrubbers have remained stable in previously established Sulphur Emission Control Areas (SECAs) and increased in the Atlantic Ocean, Black Sea, and Mediterranean Sea. This increase is due to compliance with the EU and IMO sulphur emission regulations by using low-sulphur fuel or installing scrubbers.
- Water discharges from grey waters from cruise ships increased by 41% from 2014 to 2023, while the highest discharge volumes on the freight side come from tankers with an increase of 25% since 2014.

Analysis of the discharge waters data from the STEAM model reveals that from 2014 to 2023 their overall volume has constantly increased, while the composition of discharge waters remained the same (Figure 2.26).

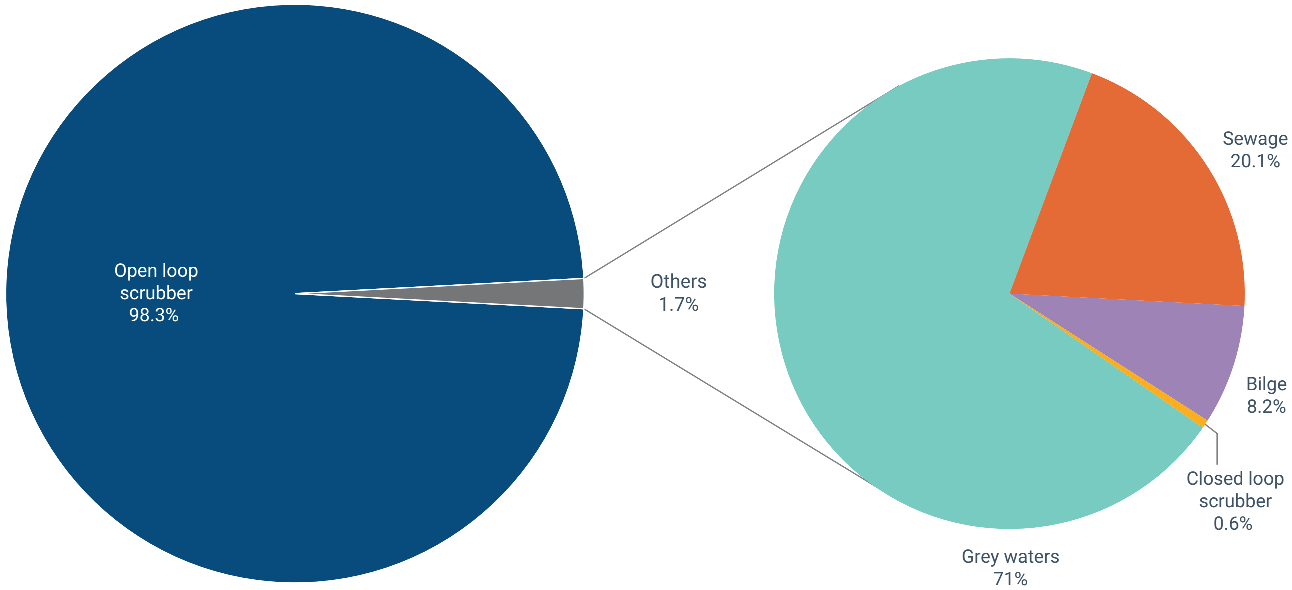
Figure 2.26 Total discharge waters 2023 (left with ECGS open loop discharges and right without)



Source: STEAM (FMI, 2024).

Most discharge waters come from container ships, mostly from open loop scrubbers. Over the same time period, the major type of discharge water for both passenger ships and fishing vessels was grey water, not open loop scrubber discharges from an EGCS. Passenger ships (excluding cruisers) contribute on average only to 1% of the total discharges with the majority stemming from grey waters (>76%). Fishing vessel EGCS discharges contribute on average around 20%, while grey waters average 40%.

Figure 2.27 **Water discharges composition in European waters in 2023 (left) and a close-up of the composition of discharges excluding open loop scrubbers (right)**



Source: STEAM (FMI, 2024).

Data from 2023 excluding open loop scrubbers shows more than 70% of discharge waters from all ship types originate from grey waters (see Figure 2.27). STEAM analysis highlights that cruise ships discharge the highest volume of grey water among the various ship types. In 2023, cruise ships discharged a total of 14 billion litres of grey water (equivalent to an average of 47.6 million litres per ship/year), an increase of 41% since 2014 and a decrease of 29.6% from 2022. When analysing the freight sector, tankers discharged a total volume of 1.84 billion litres in 2023 (equivalent to an average of 0.23 million litres per ship/year), reflecting a 24.6% increase since 2014 and a decrease of 4.4% from 2022.

The use of EGCS as an abatement technology rose in the past years as a technological shift in the maritime sector, especially after the implementation of limits to the amount of sulphur in marine fuels. As shown in Figure 2.27, discharges from open loop scrubbers in European waters represent 98% of the total maritime water discharges. A more in-depth analysis is therefore hereby provided.

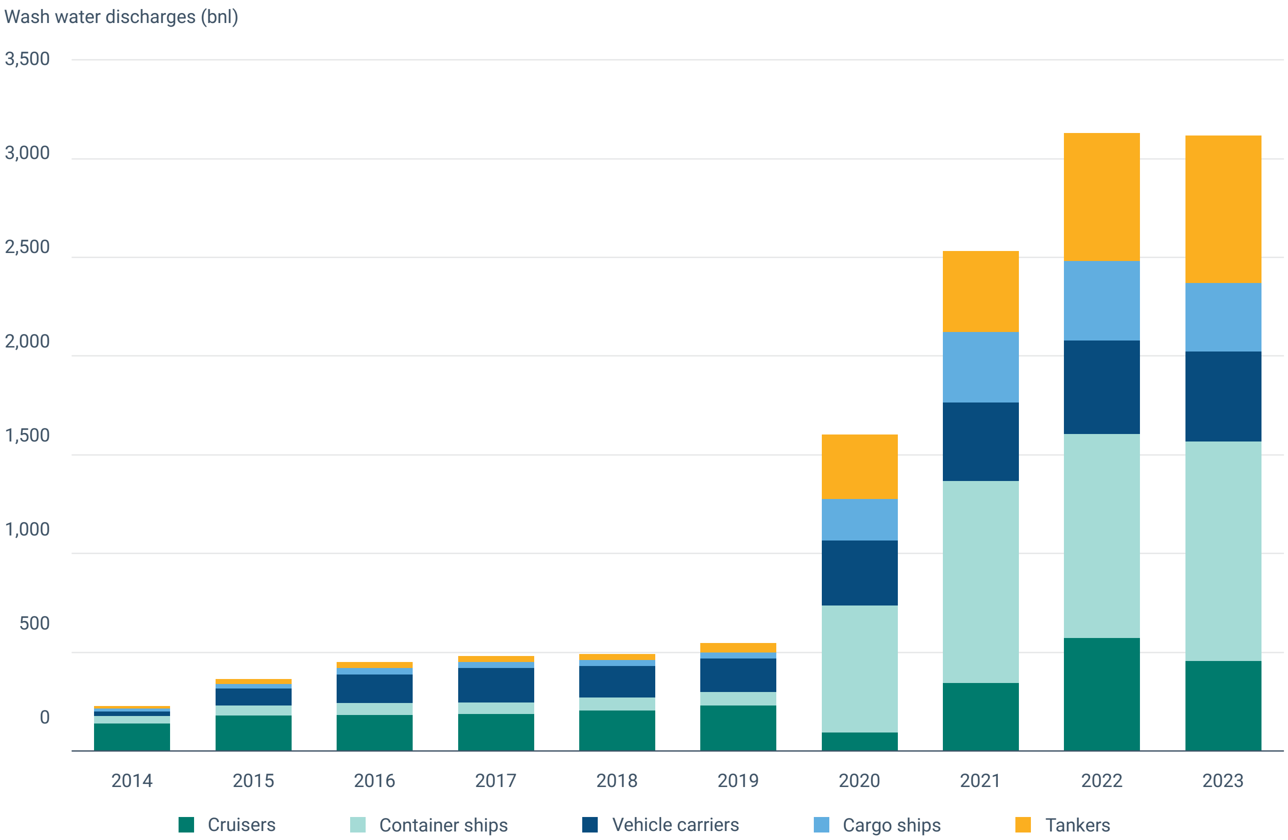
The IMO 2020 global sulphur cap, the introduction of Sulphur ECAs, as well as the implementation of the Sulphur Directive, have been successful in reducing SOx emissions to the atmosphere. However, as described by a comprehensive set of studies, the risk of displacement of pollution from air to water, for example through the release of discharge waters from EGCSs in the marine environment, is real and may directly impact marine life, affecting mortality levels of zooplankton due to the variety of pollutants discharged (Hassellöv et al., 2020; OSPAR, 2022). A recent study (Faber et al., 2021) acknowledges that EGCS discharges contribute to the presence of hazardous contaminants in the environment, although the increase in metals and polycyclic aromatic hydrocarbons (PAH) in water due to EGCS discharge waters remains limited and within the thresholds established in the Environmental Quality Standard (EQS) Directive (EU, 2008) and the Water Framework Directive (WFD) (EU, 2000) for marine waters. Nevertheless, this study also highlights limitations in methodology and sampling protocols across different studies, as well as in the potential impacts of these discharges. Furthermore, environmental toxicity testing of the effluent demonstrates that the toxic effects vary depending on the species and the developmental stage of the organisms. (Jalkanen et al., 2024; Magnusson et al., 2018; Marin-Enriquez et al., 2024; Picone et al., 2023). Other impacts on the marine environment, such as bioaccumulation, acidification and eutrophication are also highlighted.

Regarding the market share of EGCS technologies, EMSA's database reports a total of 5,613 ships currently equipped with scrubbers ([15]). This number is higher compared to the total EGCS installations considered in the STEAM model, where a total of 4,593 ships are reported to have scrubbers installed in 2022 (FMI, 2022). Data extracted from EMSA's database notably shows that 75% of the scrubbers are open loop systems, 14% hybrid systems, 1% closed loop systems and 10% unknown. These numbers are similar to the information reported by the ImpEx study in 2022 through the IMO GISIS database, which reported a total of 3,729 ships, with 86% of the registered ships having open loop scrubbers, 13% hybrid and 1% closed loop (Marin-Enriquez et al., 2023). According to EMSA's database, the installation of scrubbers is predominant in bulk carriers (around 35%), oil/chemical tankers (28%) and containerships (22%), which aligns with the IMO GISIS data.

Through the STEAM model, it is possible to estimate the volume of water discharges from scrubbers and the associated mass flows of pollutants. The modelling work done for this report is in accordance with the most recent scientific literature regarding discharge volumes of effluent per megawatt hour, respectively 90 and 0.45 cubic meters of effluent per megawatt hour used for open and closed loop systems, and provides an estimate of the volumes being discharged to the marine environment (Teuchies et al., 2020). When analysing the STEAM data on discharge waters from EGCS in the EU waters, a clear increase in open loop discharges can be noted from 2020 (Figure 2.28) and for closed loop scrubbers a clear increase is only noticed after 2021. The increase of the discharges from open-loop scrubbers is observed in all ship types and can be attributed to the IMO Global Sulphur Cap that entered into force in 2020, which lead to a sudden and significant increase of EGCS installations in the global fleet. Data from passenger ships (excluding cruiser ships) is not shown in the graphic per ship types due to inconsistencies in the data for some years.

([15]) Data extracted on 17/01/2024.

Figure 2.28 Wash water discharges from open loop scrubbers per ship type in EU waters

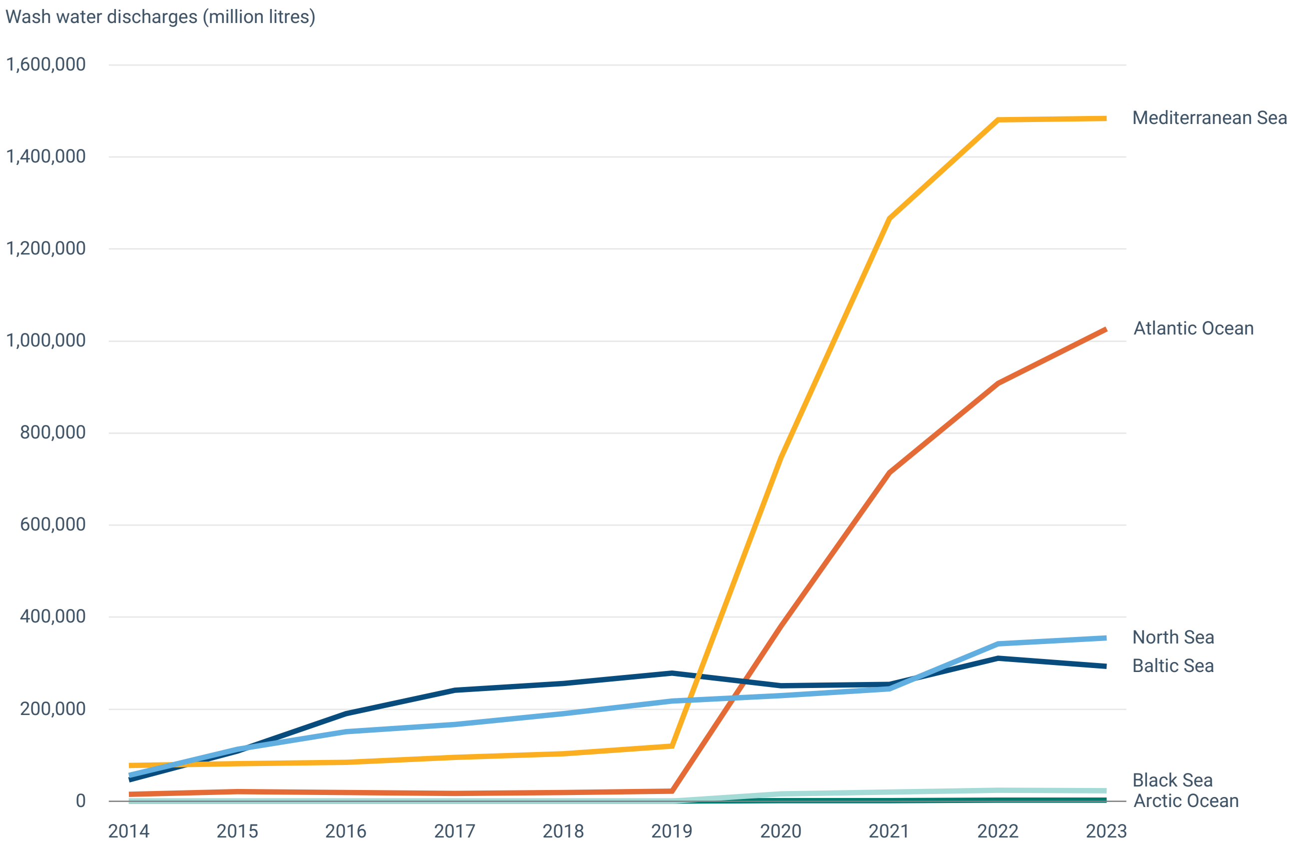


Note: Figures are in bnl, billion litres.
Source: STEAM (FMI, 2024).

Data analysis at the regional level (Figure 2.29) reveals two different dynamics: (1) a stable trend for the existing SECA areas (i.e. North Sea and Baltic Sea), where ships were already either using low-sulphur fuel or were equipped with EGCSs, and (2) an increasing trend for those areas who had to comply to the measures of the IMO global sulphur cap and the EU Sulphur Directive (i.e. Atlantic Ocean, Black Sea and the Mediterranean), where vessels had to systematically adapt to comply with the requirements of sulphur emissions by using low-sulphur fuel or installing scrubbers.

Furthermore, the Port Reception Facility (PRF) Directive (EU, 2019) includes the reception of EGCS residues as part of the MARPOL Annex VI - Air Pollution. Preliminary analysis from the PRF data (information extracted from the electronic waste receipts notified to SafeSeaNet) shows that in 2023, approximately 6,800m^3 of EGCS residues were delivered to ports in Europe (see Section 2.3.2 on waste reception at ports for details).

Figure 2.29 **Wash water discharges from open loop scrubbers per region in EU waters**



Source: STEAM (FMI, 2024).

2.2.3 Ballast waters and non-indigenous species (NIS)

Key messages

- The share of NIS introduced by shipping was 60%, whereas the share for invasive alien species (IAS) was 56% in 2017. The International Ballast Water Management Convention entered into force in 2017, and by 2023, 31% of the ships held International Ballast Water Management Certificates, while 23% had compliant ballast water management systems.
- While the number of non-indigenous species (NIS) keeps increasing, the introductions of IAS peaked in 2000-2005 and has since decreased. Only 18-21% of the MSFD assessed marine areas are in a good state regarding NIS.

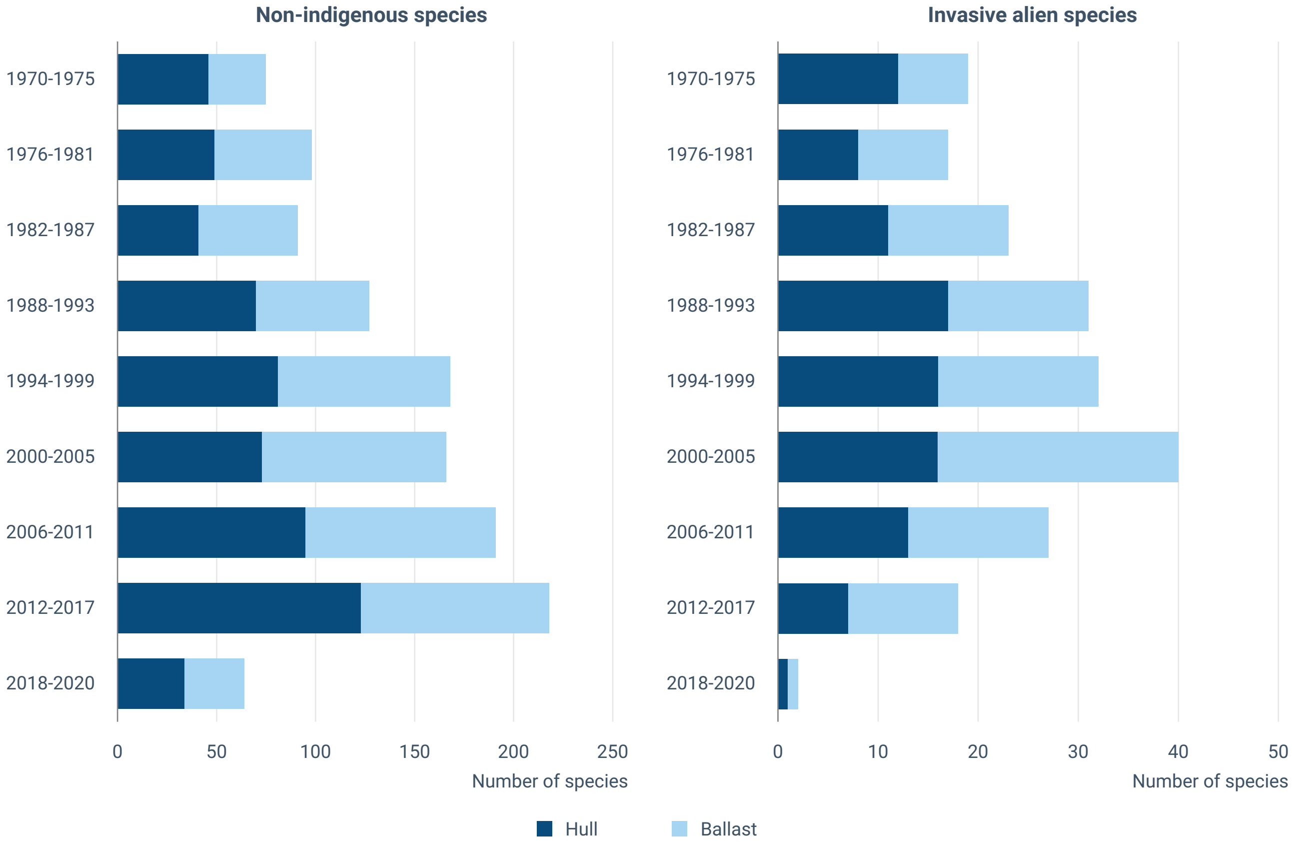
Ballast water and biofouling are the main vectors for introduction of harmful aquatic organisms in the regional seas. The problem with ballast water is that many organisms have a free-swimming phase in their reproductive cycle. Additionally, phytoplankton, zooplankton, bacteria and viruses can be found permanently in the water column. All these organisms can be taken up in the ballast water and moved around the world, so when the ballast is discharged, they can create non-indigenous communities in the new environment. If these communities become detrimental to the local ecosystem, they are considered invasive alien species (IAS). Examples include invasions of the North American comb jelly (*Mnemiopsis leidyi*) in the Black Sea and Caspian Sea, the zebra mussel (*Dreissena polymorpha*) in the Great Lakes of North America and the Asian kelp (*Undaria pinnatifida*) in Australia and New Zealand. With respect to biofouling, organisms with a sedentary part of their lifestyle can settle on the hull of ships and be carried round the world. Free-swimming larvae can then depart in new habitats which they can colonise. Mobile organisms such as macrozoobenthic or fish species are also often found in biofouling communities, traveling within the niches of these communities around the world.

Shipping is responsible for 60% of all the non-indigenous species (NIS) in the marine environment and 56% of the NIS which have become invasive in Europe (i.e. spread aggressively and cause adverse effects) (EEA, 2023). NIS introductions from maritime transport have increased for decades, despite international efforts to curtail them. Ballast water is controlled through the IMO's International Ballast Water Management Convention (IMO, 2004) and biofouling by IMO guidelines that can be found in Resolution MEPC.378(80).

The introduction of NIS through biofouling and ballast water has gradually increased over the past several decades, with higher numbers of NIS introduced over successive six-year cycles since the 1970s (Figure 2.30, left). However, the introduction of IAS increases until the early 2000s and is followed by a significant decrease in the periods following (Figure 2.30, right; note the last cycle consists of only 3 years (2018-2020).

Not all NIS cause damage to the ecosystems they become established in or become IAS, although the same NIS species can be invasive in one area and effect the local ecosystem whilst in others their presence is not detrimental. There is also a slight shift in shares between biofouling and ballast water pathways for IAS (Figure 2.30, right). From around the turn of the century, the majority of IAS were introduced by ballast water, in contrast to previous decades. This shift is not apparent for all NIS (Figure 2.30, left).

Figure 2.30 **Number of non-indigenous species (NIS - left) and invasive alien species (IAS - right) introduced by biofouling and ballast water in European regional seas, over six-year periods**

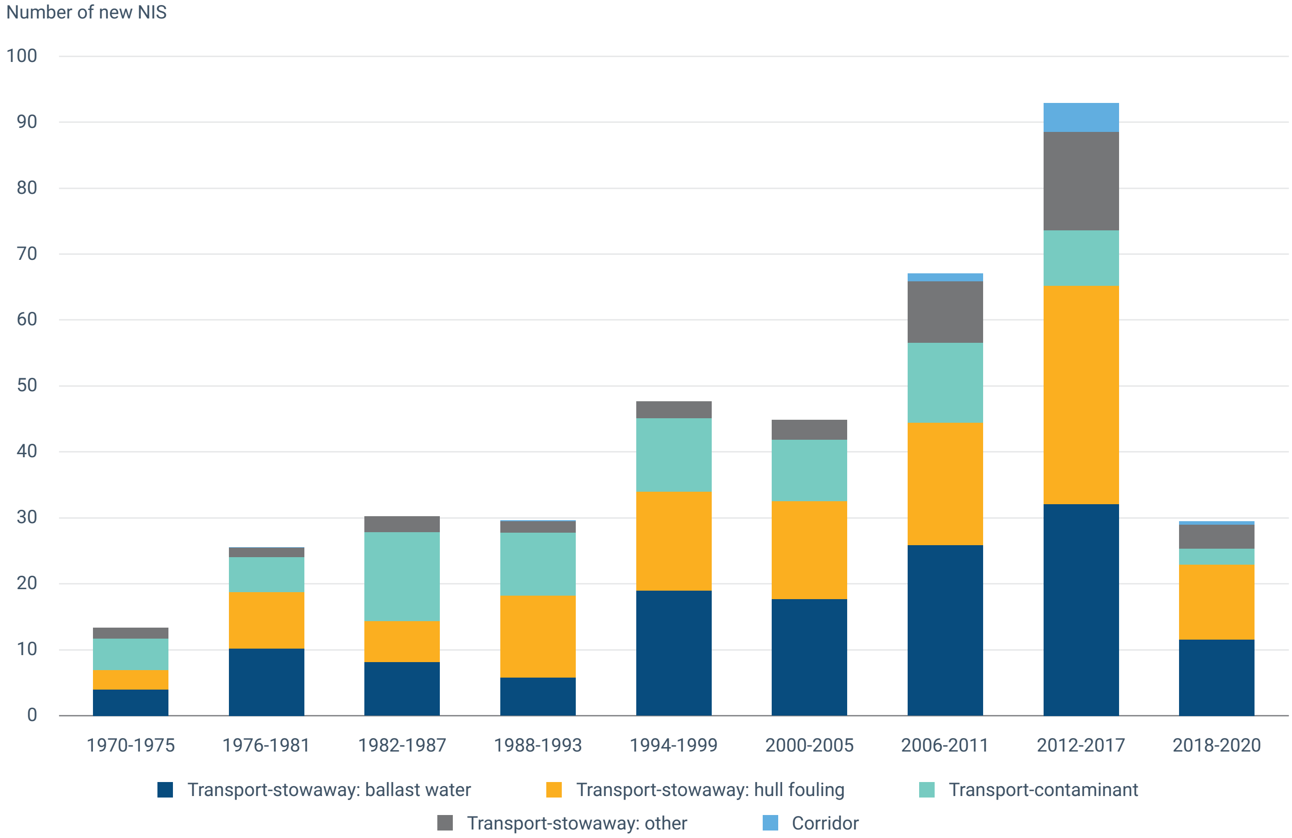


Note: The last period is shorter (three years).

Sources: EEA, based on Teixeira et al., 2019 ETC ICM technical report (EEA, 2023).

The two subregions with the highest numbers of NIS and IAS in Europe's seas are the Bay of Biscay and Western Mediterranean Sea. The balance of introduction pathways also shifts away from ballast water towards biofouling in these two regions.

Figure 2.31 Number of new non-indigenous species (NIS) in European regional seas introduced by maritime transport, over six-year cycles



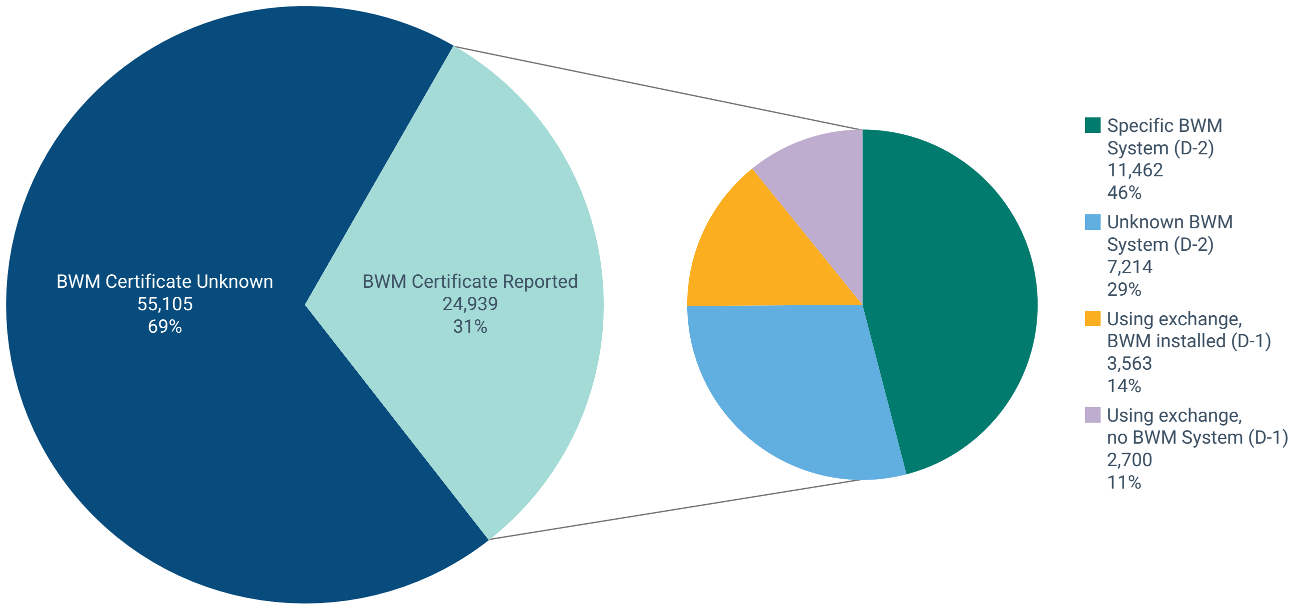
Notes: Key to categories: 'ballast water': with ships' ballast waters; 'hull fouling': attached to ships' outer hulls; 'contaminant': carried with another species in a ship; 'Corridor': via man-made shipping canals; 'other': any other ship-related means. The last period is shorter (three years).

Source: EEA, 2023.

The major introduction vectors for NIS are the ship hull- and niche areas, along with ballast water (Figure 2.31). With the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM) coming into force in 2017, an International Ballast Water Management Certificate is required for vessels of 400GT and above, which certifies that the vessel carries out ballast water management in accordance with the BWM Convention and specifies which standard (D-1 or D-2) the ship is complying with (IMO, 2004). Based on available data, approximately 80,000 vessels worldwide may need to carry this certificate. Some of these ships operate in national waters however and do not need to comply with the BWM Convention, while some parties to the convention do require their flagged vessel to apply the whole BWM Convention even if they only operate in national waters. Therefore, the available and reliable data on certificate status and related BWM Convention standard is scarce, as the ballast water management status of a vessel and whether a vessel only works in national waters is compiled by every flag state and there is no mandatory reporting of this data to a central database under the BWM Convention. The worldwide datasets utilised in this analysis rely on voluntary reporting and are not complete.

Out of 80,000 vessels (> 400GT) from global fleet, approximately 25,000 vessels (31%) have reported an International Ballast Water Management Certificate (Figure 2.31). 18,676 (75%) of these vessels have installed a ballast water management system and are compliant with the D-2 BWM Convention standard (23% of all vessels > 400GT), while 6,263 (25%) vessels (8% of all vessels) either do not have BWM system installed or do not use it. These vessels therefore only comply with D-1 standard. Based on this BWM Certificate analysis, it is assumed that around 15% of all vessels have not yet started to comply with the standards set by the BWM system, while around 10% are yet to install one. In conclusion, around 90% of vessels are ready to conform with the D-2 standard which could significantly impact the spread of non-indigenous species by ballast waters in European, as well as global seas.

Figure 2.32 Reported Ballast Water Management (BWM) Certificates and BWM standard compliance of global vessel fleet (> 400GT)



Notes: Figures refer to vessels globally, as fleet regionalisation (to EU or European Economic Area) is difficult and not meaningful since vessels from all over the world are present in European Seas. Only a small share (< 4,000 vessels) with a BWM Certificate is registered in European Economic Area countries.

Source: EMSA internal data, 2023.

Studies indicate that under future climate conditions (e.g. increased water temperature and decreased salinity), NIS are in a favourable position compared to native species (McKnight et al., 2021). Climate change may promote further expansion of NIS towards higher latitudes and increase the risk of introductions originating from warmer climate regions (Carlton, 2000). Climate change not only facilitates the introduction of NIS originating outside Europe but also NIS introduction from within regional seas. For example, a warmer Black Sea allows Mediterranean species to colonise, causing endemic species to relocate and retreat (Rotter et al., 2020).

2.2.4 Underwater radiated noise

Key messages

- The areas that currently have the highest underwater radiated noise (URN) sound pressure level (SPL) values in Europe include parts of the English Channel, the Strait of Gibraltar, parts of the Adriatic Sea, the Dardanelles Strait and some regions in the Baltic Sea. The lowest values are recorded in the north-west part of the North-East Atlantic Ocean, particularly around the Denmark Strait and the Irminger Sea, and the southern part of the Mediterranean Sea.
- Tankers and cargo ships emerge as primary contributors to URN, particularly at lower frequencies. However, the contribution of specific ship types varies across regions and frequency bands, highlighting the complex interplay of factors influencing URN distribution.
- Foresight analysis indicates that the implementation of technical and operational URN and GHG mitigation measures may lead to a substantial reduction in URN for all ship types and in all regions by 2050. In specific cases, this reduction could be as much as 70% compared to the business-as-usual scenario.

While underwater radiated noise (URN) has received comparatively less attention than other pollutants, it is now gaining important focus at both the international and European level, as reflected in the IMO's recent *Revised Guidelines for the Reduction of URN from Shipping to Address Adverse Impacts on Marine Life* (IMO, 2023) and addressed by the EU Marine Strategy Framework Directive (MSFD). Under the MSFD, it was agreed that no more than 20% of a given marine habitat area, should be exposed to high levels of continuous underwater noise over a year (TG NOISE, 2022). The EU Zero Pollution Action Plan also requires the monitoring of underwater noise levels and its adverse effects in EU marine waters (EC, 2021g).

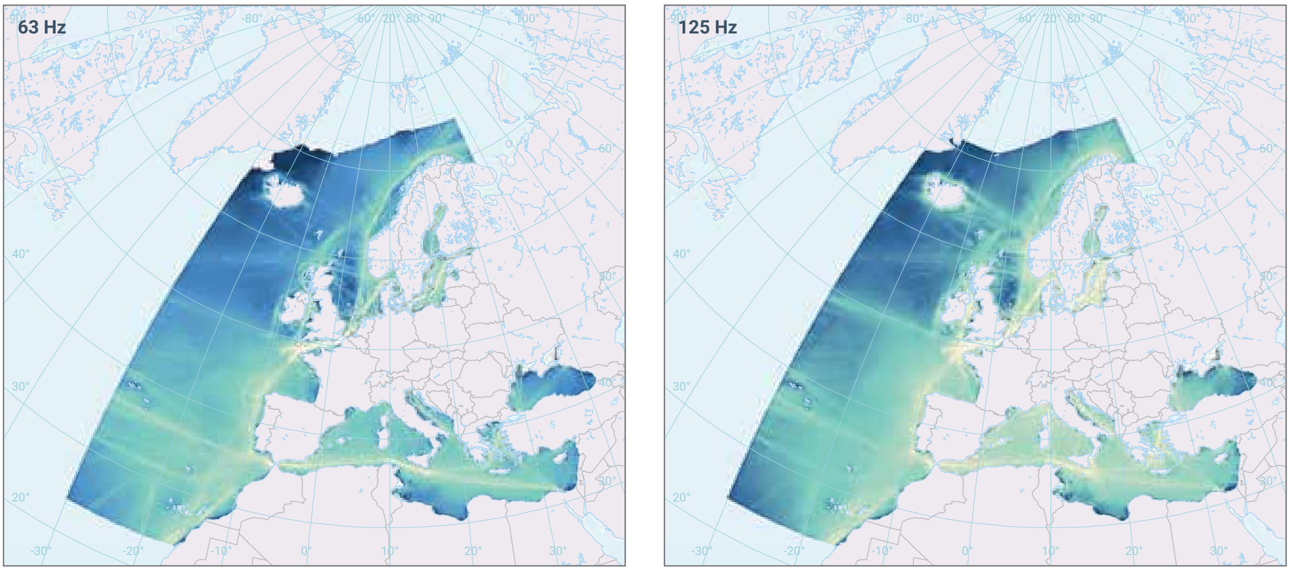
Given that the major source of continuous URN derives from propeller cavitation and on-board engine/machinery, substantial work has been performed in the last years on both the monitoring and estimation of the maritime transport sector contribution, its impacts on the environment, as well as the relationship between URN GHG emissions and energy efficiency compliance measures (Cruz et al., 2021; ICS, 2023; IMO, 2023; JRC, 2023; Sertlek et al., 2019; Thomsen et al., 2021; Vard Marine, 2023). Both measurements and modelling of ship noise are important for effective mitigation. The standardisation of terminology and procedures, as well as uncertainty quantification, are the focus of recent and ongoing work at EU, regional and global level (BLUES, 2021; DEMASK, 2024; JOMOPANS, 2018; PIAQUO, 2021; quietMED2, 2019; SATURN, 2020).

One new element to highlight is the EMSA-financed project '*Navis Sonus*' (NAVISON), which derives soundscape maps from a state-of-the-art parametric source model for continuous broadband URN (EMSA, 2024a). It encompasses ship characteristics with ship traffic and an acoustic propagation model and aims to quantify the URN produced by ships in all EU waters. By using the same approach for the entire EU sea basin, NAVISON permits for the first time like-with-like consistent comparison between regions over long time scales.

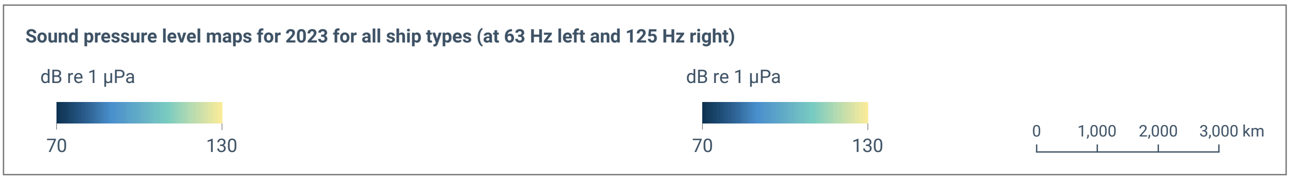
In NAVISON, two parameters accounted for the level of URN in regional seas: sound pressure level (SPL) and sound energy density (SED). SPL ([16]) represents the spatially and temporally distributed/propagated sound sources (the soundscape). The SED, which is equivalent to the total sound energy over the volume of the sea water (and thus can be calculated for any sea region as well as for the total regional seas), provides a parameter independent of the spatial and temporal observation window, which may thus be used to compare URN between regions as well as identify the contribution of different ship types.

The areas that currently have the highest underwater radiated noise SPL values in Europe include parts of the English Channel, the Strait of Gibraltar, parts of the Adriatic Sea, the Dardanelles Strait, and some regions in the Baltic Sea.The lowest values are recorded in the north-west part of the North-East Atlantic Ocean, particularly around the Denmark Strait and the Irminger Sea, and the southern part of Mediterranean Sea (see Map 2.7).

Map 2.7 Sound pressure level maps for 2023 for all ship types (at 63 Hz left and 125 Hz right)



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO



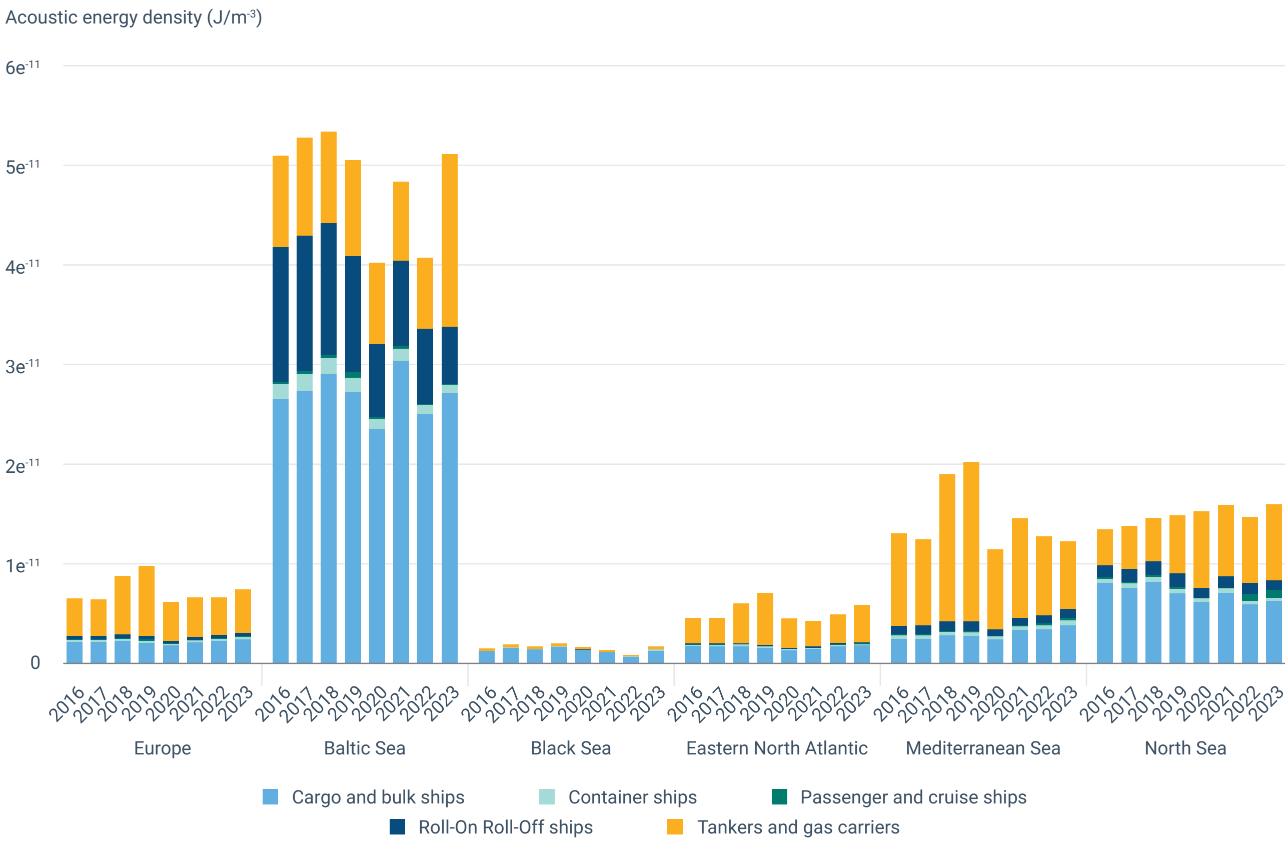
Notes: SPL, sound pressure level; dB re μPa, a decibel relative to 1 micropascal.

Source: NAVISON (EMSA, 2024a).

([16]) SPL calculations are performed for two 1/10- decade (one tenth of a decade or decidecade) bands, with nominal centre frequencies (63 and 125 Hz) corresponding to the EU's Marine Strategy Framework Directive environmental status indicators for low-frequency continuous sound (2008/56/EC).

Even though no significant trend may be highlighted other than the drop registered for the COVID year of 2020, cumulative sound energy densities at the EU level can be observed to increase until 2019, ending abruptly in 2020 (a year affected by the COVID-19 pandemic), thereafter slightly but steadily increasing in the modelled sound maps (note that 2019 levels have still not been reached). Analysing sound energy densities can also reveal the extent and temporal trends of URN at regional levels (see Figure 2.33). The region with the highest sound energy density is the Baltic Sea, due to its shallow water and relatively high shipping density. In the Baltic Sea the sound energy density is dominated by cargo vessels, followed by Ro-Ro and tankers at 63 Hz (Ro-Ro signal increases when looking at the 125 Hz frequency band (data analysed but not shown)). Compared to the North Sea, this same combination of shallow water and high shipping density is found in the south but not in the north. the average for the entire North Sea is therefore lower because of the effect of the deeper water and hence lower energy density in the north. Here a slight increase in energy density can be observed. In the Mediterranean Sea, the sound energy density is dominated by tankers, which contribute more than the sum of the remaining ship types at 63 Hz. Interestingly, in the Mediterranean Sea the sound energy density at 125 Hz is a factor of one to two less than at 63 Hz (data analysed but not shown).

Figure 2.33 **URN sound energy density at 63 Hz (Europe leftmost chart and regional seas) from 2016 to 2023**

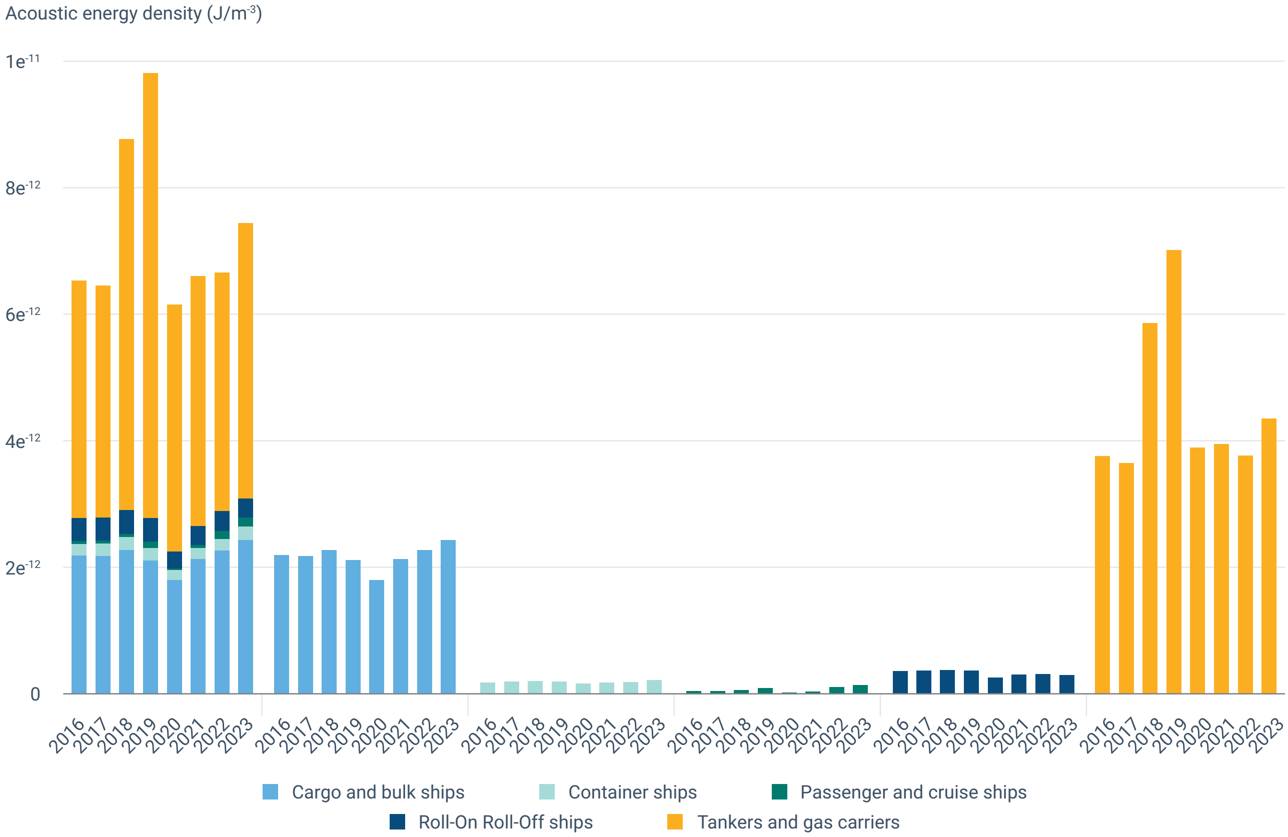


Note: J/m³, Joules per cubic metre.

Source: NAVISON (EMSA, 2024a).

When looking at sound energy densities per ship type (see Figure 2.34) over the regional seas, tankers and cargo ships have the highest contribution at 63 Hz. The modelled temporal trends are, once again, dominated by a steady increase until the COVID 2020 drop and thereafter a smaller increase. Interestingly, the contribution of cargo ships is minimal due to the low frequency of sound generation (even though the number of cargo ships is high). The Ro-ro signal, however, does contribute more significantly when looking at the sound energy densities at 125 Hz (data not shown). This is possibly due to these ships being more likely to use a four-stroke engine and therefore having a higher propeller/engine rotation rate.

Figure 2.34 URN sound energy density at 63 Hz in Europe (total leftmost chart and by ship types) from 2016 to 2023



Note: J/m³, Joules per cubic metre.

Source: NAVISON (EMSA, 2024a).

Underwater radiated noise forecast

Further to the development of hindcasts and nowcasts of EU-wide harmonised soundscape maps, it is important to assess the impact of different combined operational and technical mitigation responses for reducing underwater radiated noise, as these will assist us in determining the net effectiveness (including role and magnitude) of the possible URN mitigation measures on the overall soundscape.

To perform this forecast exercise, the NAVISON project worked on four scenarios, designed for the years 2030, 2040 and 2050, looking at how URN may evolve under the following scenarios: (1) business as usual (BAU) scenario; (2) considering the effect of the IMO GHG emission reduction roadmap on URN, but without applying URN mitigation measures (the GHG scenario); (3) URN management including technical and operational URN mitigation measures, but without considering the IMO GHG emissions reduction roadmap (the URN scenario); and (4) URN management in addition to the IMO GHG emissions reduction roadmap (the U&G scenario) (EMSA, 2024a).

These scenarios are based on applying six different URN and GHG mitigation measures with time-varying penetration rates within the fleet to 'baseline sound map layers', which are calculated based on AIS track data from 2022. Each scenario assumed changes in the adoption levels of several different mitigation measures over time — the so-called penetration rate. Up to six mitigation measures were included in each scenario, with the selected measures representing possible options for GHG and/or URN abatement, covering both technical and operational measures (see ICS, 2023). These were: speed reduction ([17]), more efficient propellers, quieter propellers, air injection systems, optimised hull form, and hull and propeller cleaning.

The resulting sound map layers are determined by combining the results for different mitigation measures using a novel probabilistic approach, based on the assumed penetration rates. The resulting sound map layers are determined by combining mitigation measures according to their joint probabilities (some measures are mutually exclusive and others are independent of each other). The aforementioned four scenarios were run for the five different EU basins and six ship types.

Preliminary results indicate that the impact of mitigation measures varies across different vessel categories, resulting in significant differences in sound pressure levels across the four scenarios. The main overall conclusion is that for U&G (possibly the most realistic scenario) URN reduces for all ship types by 2050. The GHG scenario shows lower reductions (and in some cases increases) in URN since the 'more efficient propeller' measure is assumed to increase ship source levels.

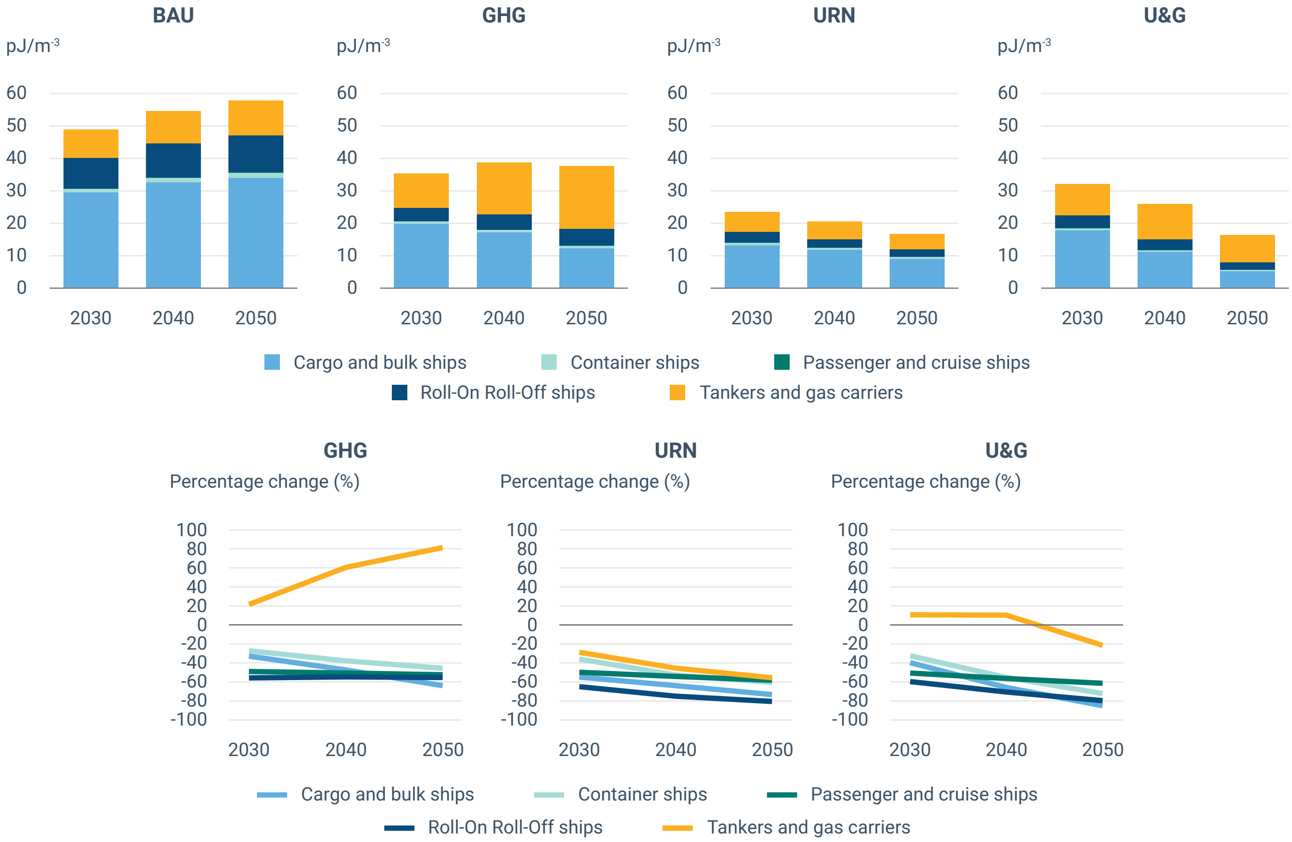
The trends per ship type within this (and other) scenarios depend on the effectiveness of each mitigation measure modelled and the penetration rates. For tankers and gas carriers, there is a large increase in SPL at 63 Hz (larger than most other ship types) in the Baltic Sea, North Sea and North-East Atlantic, due to the 'more efficient propeller' measure, while other mitigation measures are (on the whole) less effective than for other ship types. These effects combine to give the observed increase (or smaller decrease) in sound energy density.

These results further highlight the relevance of considering URN in the application of the GHG reduction strategy. The effects of ship type and regional behaviour on scenario output become clear when analysing sound energy densities as well as mitigation performance, measured as the percentage change of the difference between the sound energy density of one specific scenario (GHG, URN or U&G) and

([17]) Assumed as 75% of design speed.

the BAU ([18]). Figures 2.35 and 2.36 indicate how the sound energy density varies between ship types and forecast scenarios within the Baltic Sea and Mediterranean Sea. This provides relevant information for the implementation of mitigation measures. Interestingly, mitigation measures on tankers will take some time to take effect within the Baltic Sea, even in a U&G scenario.

Figure 2.35 URN forecast scenarios Sound Energy Density (top) and Mitigation Performance (bottom) for the Baltic Sea



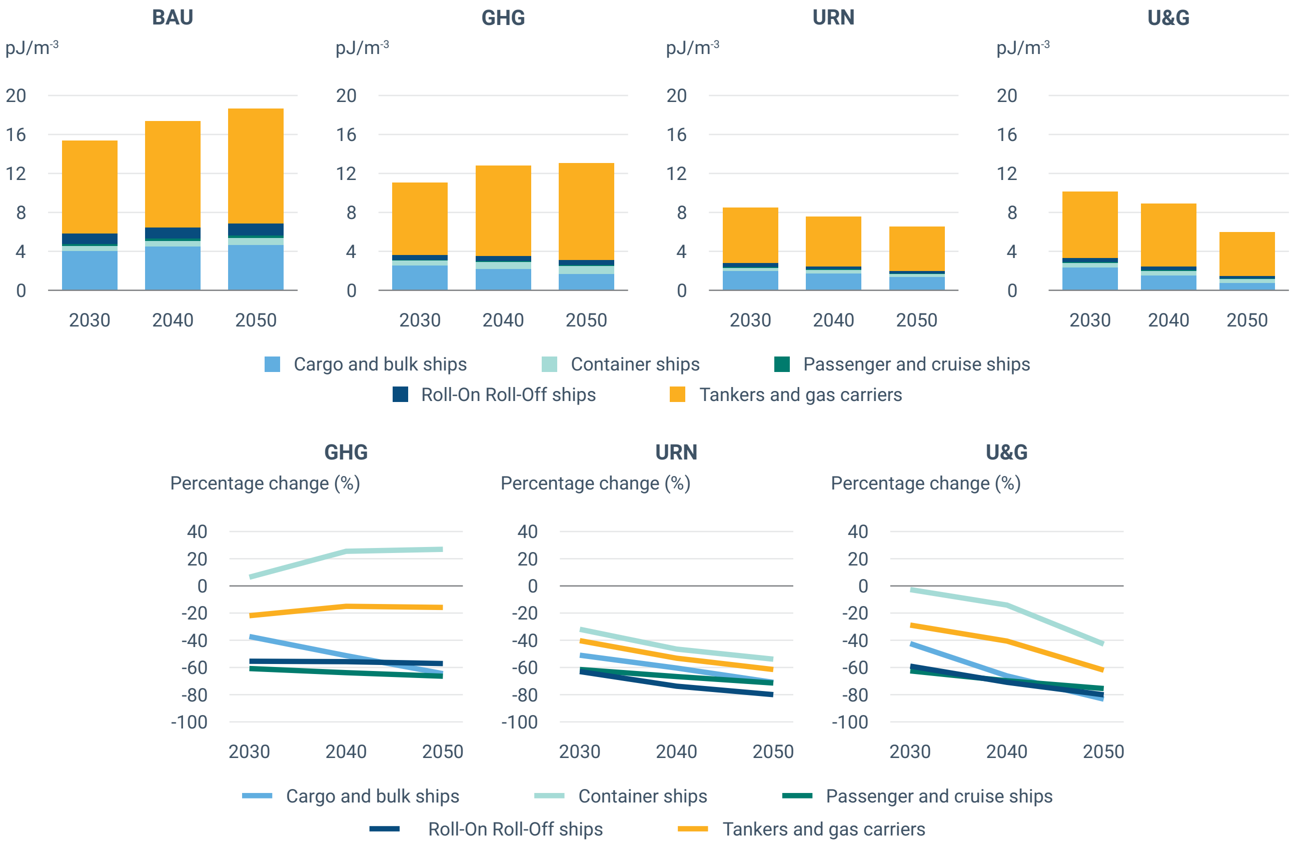
Notes: pJ/m³, picojoules per cubic metre.

See text for scenario explanation.

Source: NAVISON (EMSA, 2024a).

([18]) $\text{Percentage change} = 100\% \left(\frac{E_{GHG,URN\ or\ U\&G} - E_{BAU}}{E_{BAU}} \right)$

Figure 2.36 URN forecast scenarios Sound Energy Density (top) and Mitigation Performance (bottom) for the Mediterranean Sea



Notes: pJ/m³, picojoules per cubic metre.
See text for scenario explanation.

Source: NAVISON (EMSA, 2024a).

This dependency is reflected within the IMO's revised *Guidelines for the Reduction of URN from Shipping to Address Adverse Impacts on Marine Life* (see Chapter 7, (IMO, 2023)) as well as in the Marine Environment Protection Committee endorsed draft action plan for the reduction of underwater noise from commercial shipping, developed by the Sub-Committee on Ship Design and Construction in its 10th meeting ([19]). It is also apparent when analysing the difference in sound pressure level maps between the BAU scenario and the GHG, URN and combined U&G (EMSA, 2024a).

([19]) https://www.imo.org/en/MediaCentre/MeetingSummaries/Pages/SDC-10.aspx

2.3 Marine litter and waste delivery at ports

2.3.1 Marine litter, passively fished waste, and container loss.

Key messages

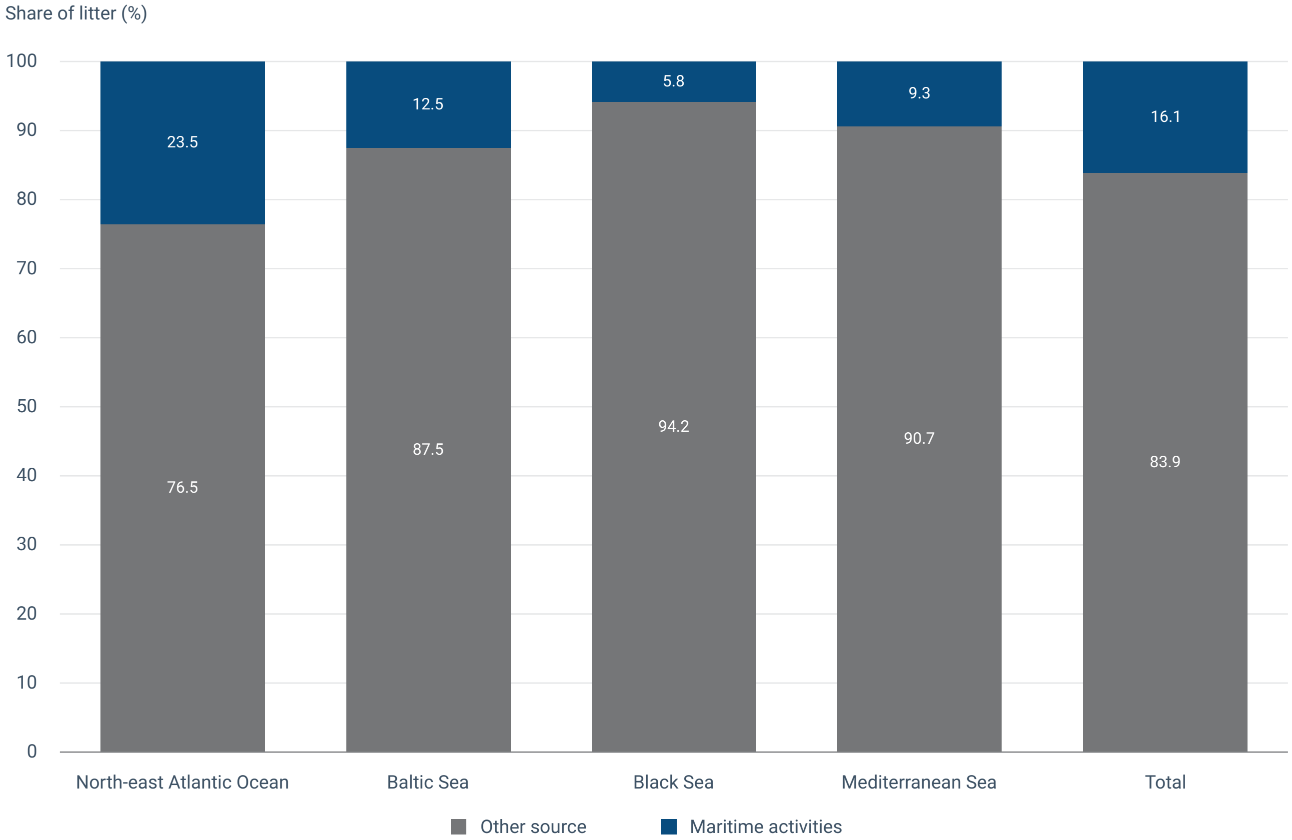
- Marine litter from fisheries represent 11.2% and from shipping 1.8%, together contributing to over 13% of total marine litter in the regional seas around Europe. Beach litter attributed to shipping and fisheries is decreasing, with a reduction by half within a decade.
- In 2022, 62% of the waste collected in nets as passively fished waste was reported as non-classified, 26% as plastics and the remainder was split between metal, rubber, and wood/textiles. Efforts to engage fishers in collecting, delivering to ports, and reporting waste caught in their nets during regular fishing activities are key and are being implemented.
- Data suggests that the shipping sector contributes between 141 and 279 tonnes to annual pellet losses from European industries. These losses can have immediate and long-term environmental, socioeconomic, and health impacts. For example, the CSAV TOCONAO incident in late 2023 resulted in the release of approximately 26 tonnes of plastic pellets, causing significant environmental damage, and prompting extensive clean-up efforts along the Galician coastline.
- While the number of reported lost containers is relatively small compared to the total number of containers shipped, notable incidents of container loss have had a considerable impact on the coastal and marine environment, such as the release of plastic pellets and other types of marine litter.

Marine Litter

Among all the marine litter affecting the regional seas, 16% likely originates from maritime activities ([20]) (see Figure 2.37).

([20]) The methodology for analysing marine litter involves examining three main compartments: beach, seafloor and water column, with beach surveys being the most documented. Standard methodologies established in 2013 have produced consistent data sets from 2013 to 2022. Therefore, beach litter data was used for the analysis. For beach litter analysis, the primary data source is the 'EMODnet European beach litter' dataset, supplemented by 'MarineLitterWatch' data due to limited surveys in certain areas. The analysis of the current state uses data from 2018-2022, involving 4,801 surveys across 548 beach sites, while trend analysis covers 2013-2022 with data from 4,532 surveys at 146 beaches. Litter origin likelihoods are categorised based on literature and expert input, distinguishing between maritime activities, shipping, fisheries and other sources and are used to attribute litter in survey data to these categories.

Figure 2.37 **Share of litter items likely originating from maritime activities, by regional sea**

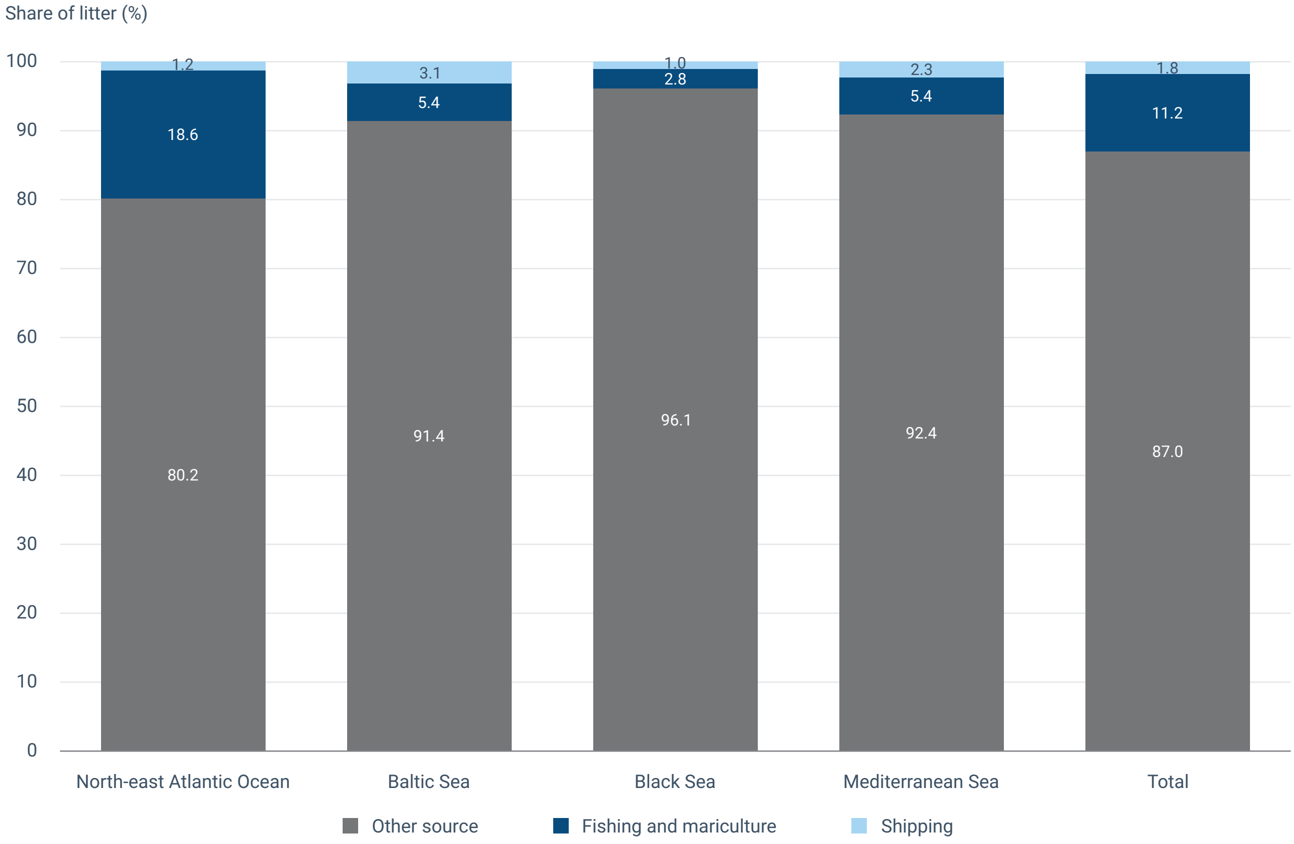


Notes: Compiled survey data of EMODnet European beach litter standardised, harmonised and validated datasets 2001/2022 v2023 and EEA MarineLitterWatch v2023. Monitoring events of the recent most recent available five years 2018–2022 are included. The share is calculated based on the number of items, not the volume/weight.

Source: EEA, 2024.

More specifically, 1.8% of European beach litter can be attributed to shipping and 11.2% to fisheries and mariculture (see Figure 2.38). Litter from shipping varies in share between 1% (Black Sea and North-East Atlantic Ocean) and 3% (Baltic Sea). Fisheries and mariculture-originating litter is the most abundant in the North-East Atlantic Ocean with 19% share; it is the least abundant in the Black Sea with 3% share.

Figure 2.38 **Share of litter items likely originating from shipping and fisheries and mariculture in relation to the total litter recorded on beaches, by regional sea**

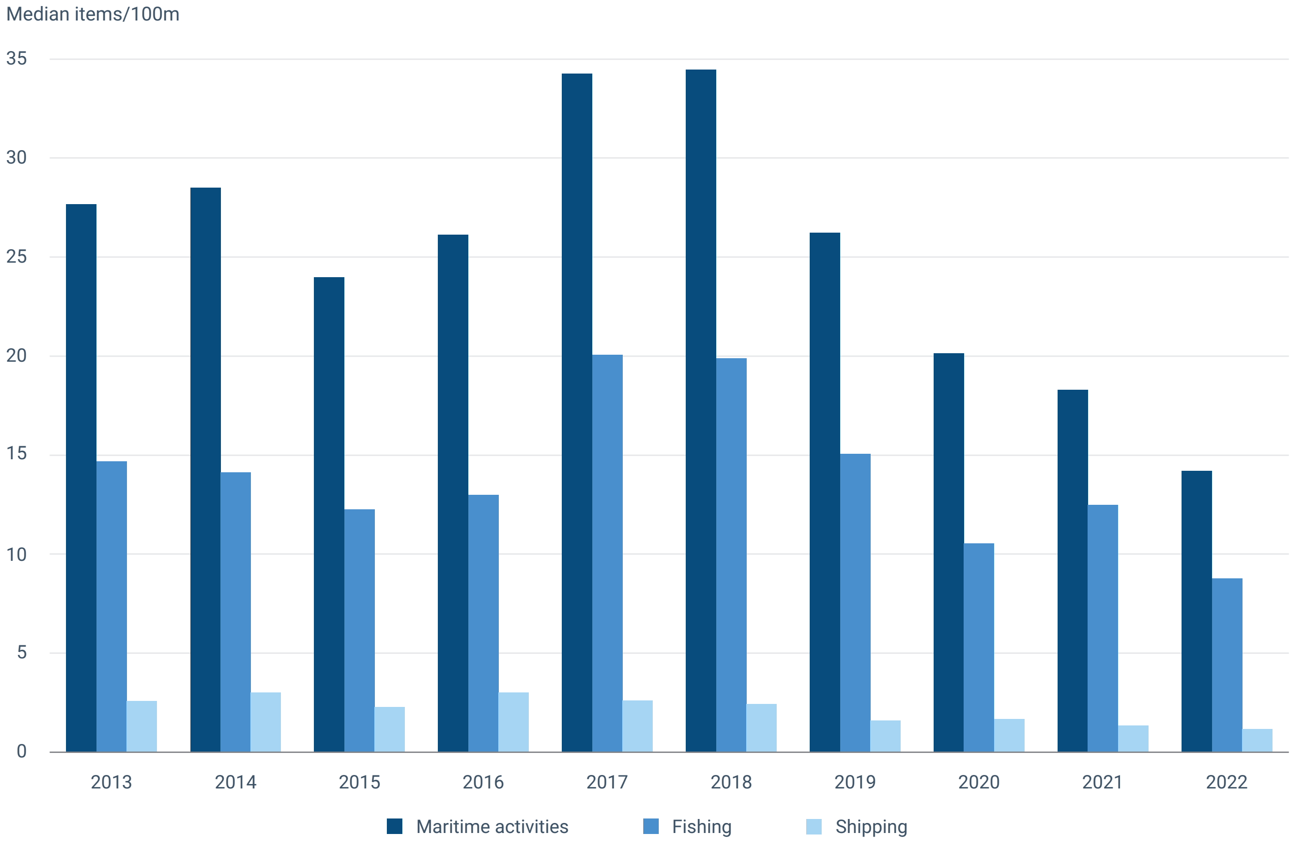


Notes: Compiled survey data of EMODnet European beach litter standardised, harmonised and validated datasets 2001/2022 v2023 and EEA MarineLitterWatch v2023. Monitoring events of the recent most recent available five years 2018-2022 are included. The share is calculated based on the number of items, not the volume/weight.

Source: EEA, 2024.

Temporal trends are detected in the abundance of beach litter originating from maritime activities (see Figure 2.39). In a decade, the abundance of such litter has more than halved from 28 items per 100m in 2013 to 14 items per 100m in 2022. This decreasing trend has been particularly pronounced since 2018. These figures follow general trends of decreasing beach litter abundance, as detected by the MSFD beach litter monitoring.

Figure 2.39 Temporal distribution of litter items likely originating from all maritime activities, shipping and fisheries and mariculture, in regional seas around Europe



Notes: Compiled survey data of EMODnet European beach litter standardised, harmonised, and validated datasets 2001/2022 v2023 and EEA MarineLitterWatch v2023. Monitoring events of the period 2013-2022 are included.

Source: EEA, 2024.

Microplastic pollution

In shipping, microplastics are created after routine ship hull cleaning, mishandling of cargo comprising plastic items or accidental spills of either industrial plastic resin pellets (GESAMP, 2021) or plastic polymers in solution (Suaria et al., 2018). While the data suggests that shipping contributes the smallest fraction to the total annual pellet loss from various European industries, ranging between 141 and 225 tonnes, these losses can have immediate and long-term environmental, socioeconomic, and health impacts (Perkins et al., 2023).

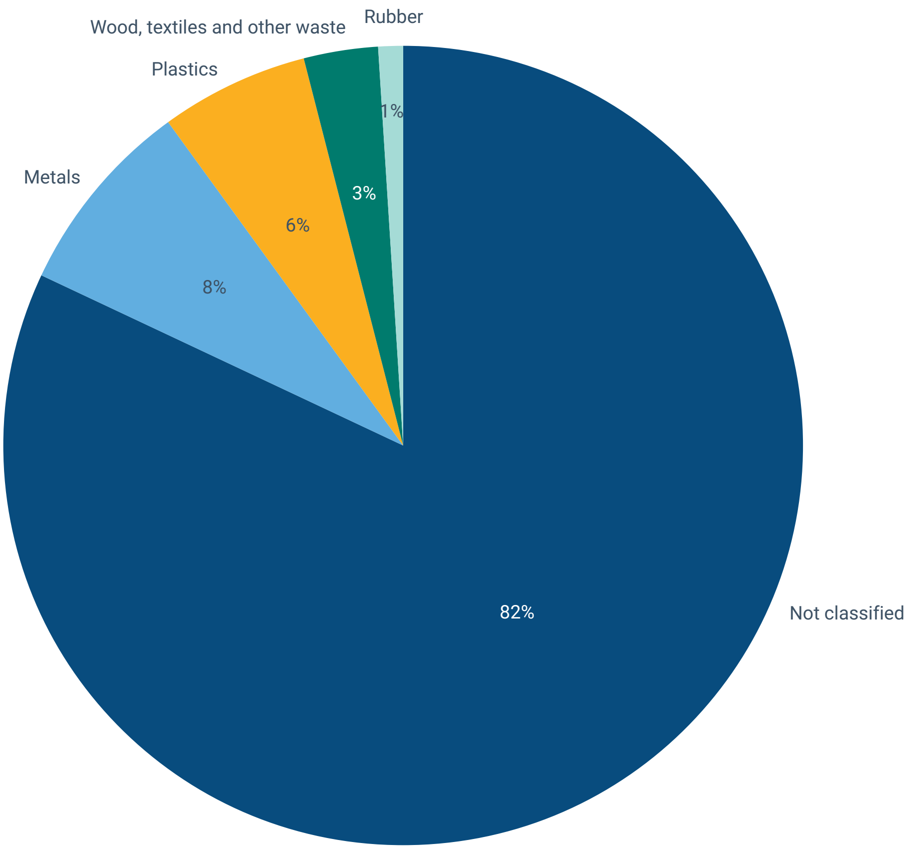
Other studies estimate that the EU plastic industry transports approximately 70% of all pellet imports and exports through shipping. According to the latest available Eurostat data, the EU imports 13.4 million tonnes of pellets and exports 18.4 million tonnes (EC, 2023g). Multiplying the percentage carried through shipping by the total amounts imported and exported, while applying the estimated lost container factor over the period 2008-2021 from the World Shipping Council (see section on Lost Containers further on), the approximate annual loss of pellets from lost containers reaches the equivalent of 289 tonnes per year.

Recent findings indicate that marine paint is a significant source of microplastics from shipping. In 2019, the global use of plastic in marine paint amounted to 1,374 kilotonnes (kt), with 66% of this eventually leaking into the environment, totalling 911kt of plastic. Out of this amount, 816kt is estimated to leak into oceans and waterways, with 65% of the leakage coming as microplastics (Earth Action, 2022). Notably, 29% of the leakage from marine paint is attributed to wear and tear, with most losses occurring during a ship's end-of-life (34%) and paint removal during surface preparation in dry docks (26%). While most of this leakage takes place in the Asia-Pacific region, where 96% of commercial ships are dismantled, the European environment is also pressured by leakages directly from the hull exteriors. Moreover, 56% of the global commercial ship fleet is owned by European countries. This means European enterprises contribute significantly to this type of plastic input into the sea (Earth Action, 2022). Additional studies suggest a notably reduced influence of marine paints on the generation of microplastics (Boucher and Friot, 2017; Turner, 2021; Turner et al., 2022). Grey water from ships also emerges as a significant source of microplastics from shipping (Peng et al., 2022).

Passively Fished Waste

This section presents data on marine litter and waste collected during EU fishing operations and delivered to EU ports under the auspices of the PRF Directive [21]. A total of 1,220m^3 of waste was collected by 10 Member States in 2021. This fell to 932m^3 in 2022, with additional information provided: 4% was classified as 'ALDFG' (Abandoned Lost and Discarded Fishing Gear), 14% as Other Marine Litter and 82% was not classified in terms of origin. Figure 2.40 shows the distribution of passively fished waste (PFW) waste type in terms of classification per composition of the collected materials in 2022.

Figure 2.40 Total reported volume of passively fished waste per waste type in 2022



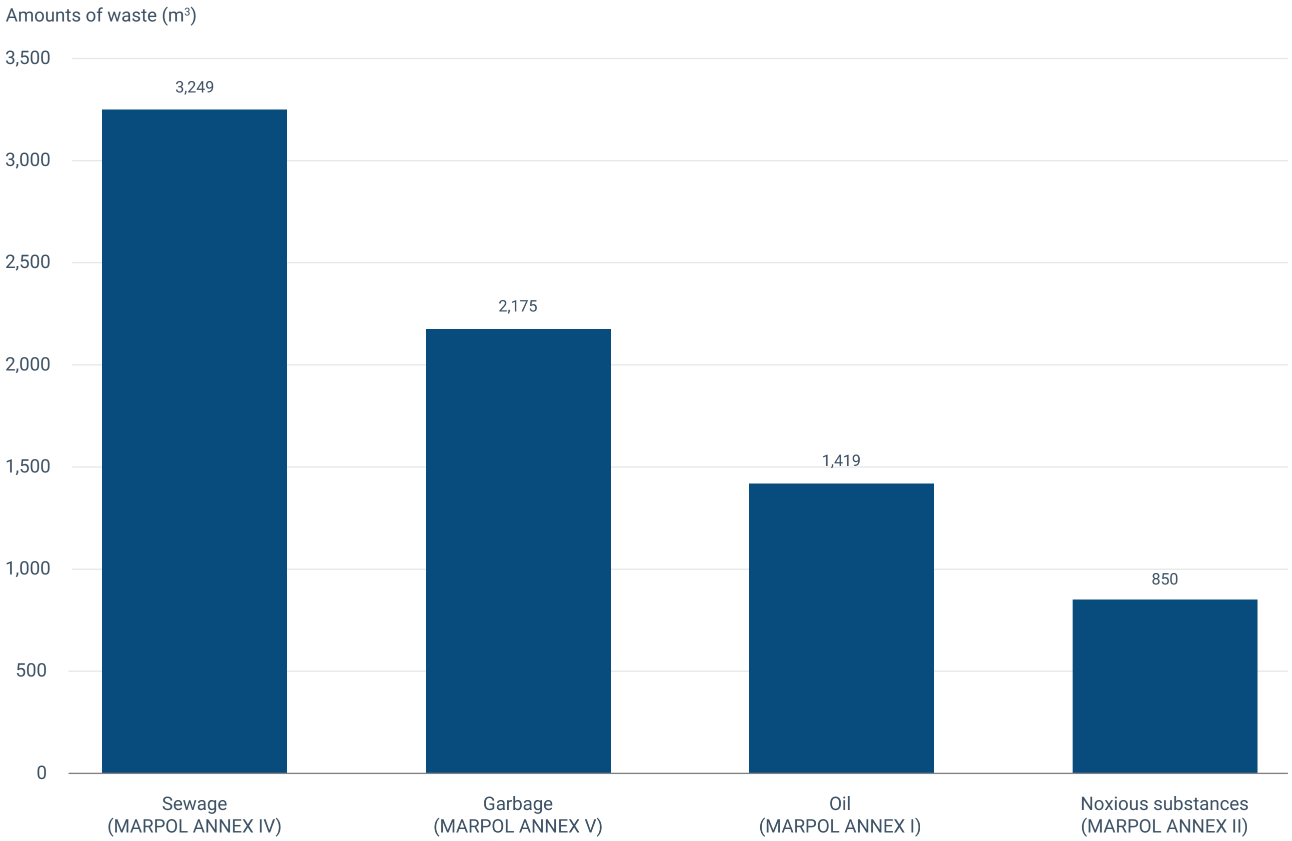
Sources: EMSA internal data; DONA (2024).

([21]) Not all the Member States have yet reported under the PRF Directive for the first and second obligatory reporting period.

Legal discharges at sea

From the inspection records it is also possible to assess the amounts of waste that have been reported to have been legally discharged at sea in line with the MARPOL legislation ([22]). Figure 2.41 displays these amounts in absolute volume, as recorded in THETIS-EU (EMSA, 2023e) for 2023 ([23]).

Figure 2.41 Waste discharged at sea in 2023 as reported by inspectors



Source: THETIS (EMSA, 2023e).

Lost containers

According to the World Shipping Council's (WSC) annual survey (addressed to companies that operate more than 90% of the global containership capacity),a total of 221 containers were reported as lost at sea in 2023 (Figure 2.41). While this number represents a small percentage (0.0000884%) of the 250 million packed and empty containers currently shipped globally in 2023 (WSC, 2024), such incidents may have significant environmental impacts, especially if the lost containers contain plastic pellet cargo.

Considering the 14-year period surveyed (2008-2021), during which the WSC estimates that there were on average a total of 1,629 containers lost at sea each year, this equates to a loss of approximatively 0.0013% of all containers each year.

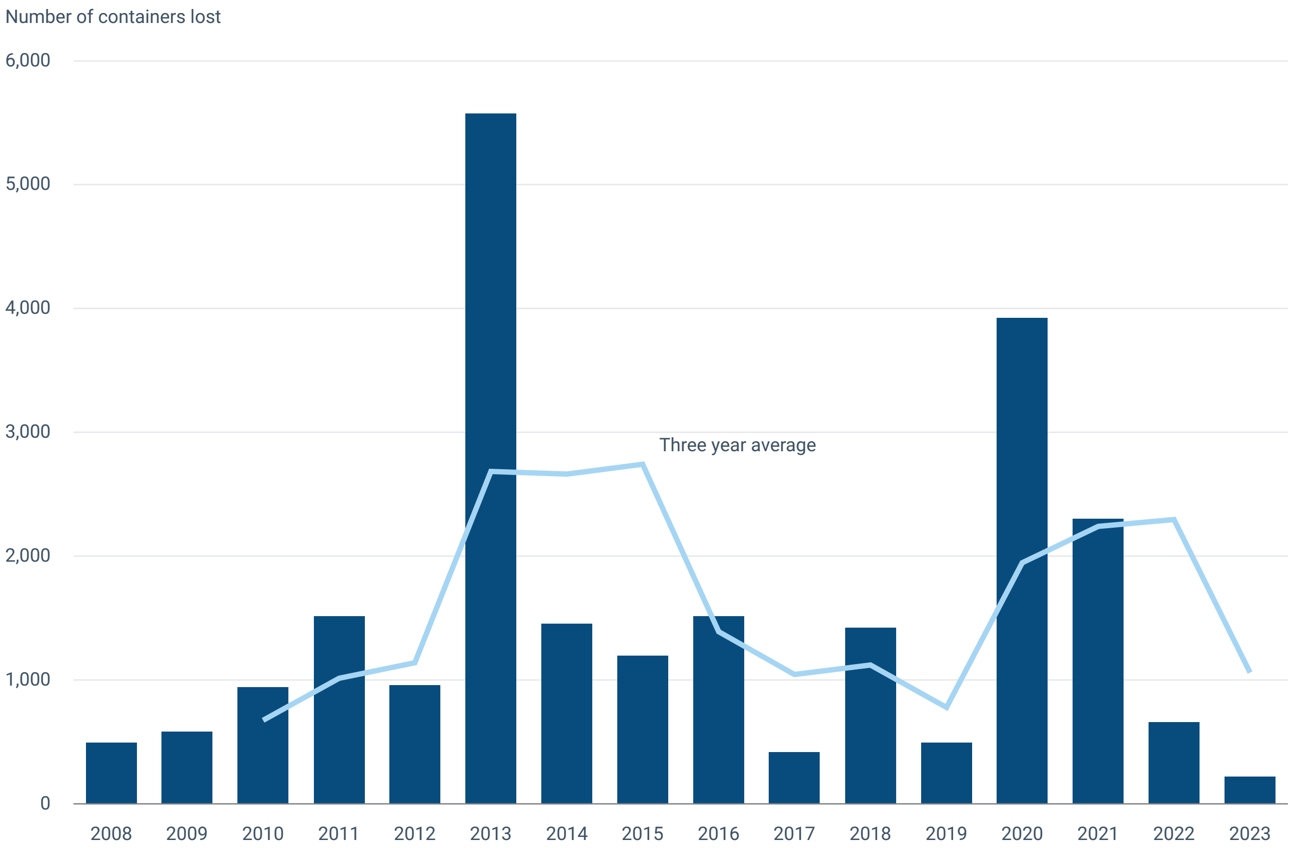
([22]) https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx
([23]) 7,225 PRF Directive inspections were respectively carried out in 2023.

Since 2019 there have been a number of notable incidents involving container loss (numbers of reported lost containers in 2020 and 2021 are sensibly higher than 2022), including the following three, which resulted in considerable impact on the marine environment:

- the MSC Zoe incident in 2019, which resulted in the loss of 342 containers overboard in EU waters;
- the ONE Apus incident in 2020 resulting in more than 1,800 containers overboard in the north Pacific Ocean;
- the Maersk Essen, in 2021 which resulted in a loss of more than 750 containers in the north Pacific Ocean.

The outlying number of containers lost in 2013 (Figure 2.42) is a result of the sinking of the MOL Comfort on 17 of June 2013 in the Indian Ocean. The incident resulted in 4,382 container units (7,041 TEU) lost at sea and is still considered the largest number of containers lost in a single event.

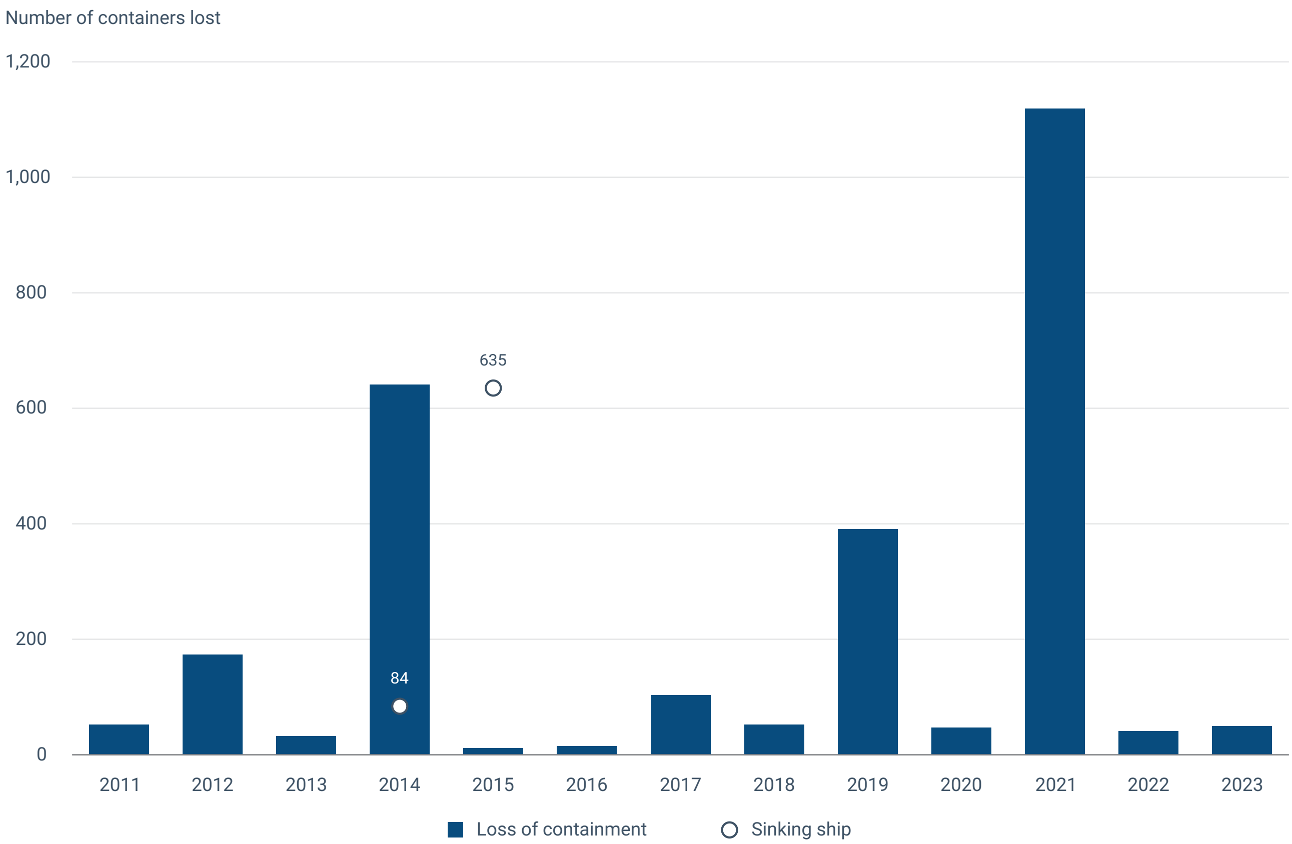
Figure 2.42 **Total number of containers lost at sea at global level per year and 3-year moving average**



Source: WSC, 2024.

From the EU's perspective, data from the European Marine Casualty Information Platform (EMCIP) shows that in the EU, for the period from 2011 until 2023, 86 single occurrences have been reported, resulting in a total of over 3,452 containers lost overboard (see Figure 2.43). Of these, the majority were lost in events that occurred in 2014, 2019 and 2021. 2021 saw four incidents with the loss of over 1,100 containers (including MAERSK ESSEN, MAERSK EINDHOVEN, ZIM KINGSTON and MSC ARIES), while 2019 saw one main incident with the loss of over 340 containers (MSC ZOE). In 2014, another major incident contributed to the loss of over 500 containers (SVENDBORG MAERSK). In 2015, one sunken ro-ro cargo vessel resulted in the loss of 391 containers and 243 trucks with containers in the garage deck (EL FARO). Notably, although not yet reported in EMCIP, the incident involving the CSAV TOCONAO occurred in late 2023. On December 8th, a reported six containers were lost, resulting in the loss of approximately 26 tonnes of plastic pellets at sea. This event caused significant environmental damage, prompting extensive clean-up efforts along the Galician coastline and raising concerns about marine pollution and its long-term effects on local ecosystems.

Figure 2.43 Total number of containers lost at sea events in the EU between 2011 and 2023



Source: EMCIP 2024 (EMSA, 2011).

2.3.2 Waste reception at ports

Key messages

- Oily waste (855,000m^3) and garbage (488,000m^3) are the largest amounts of waste delivered in port reception facilities in Europe, according to data reported in 2023, followed by sewage (250,000m^3).
- Ports in Rotterdam, Antwerp and Copenhagen handle the highest volumes of waste, with respectively 475,000m^3, 210,000m^3,and 132,000m^3 in 2023.

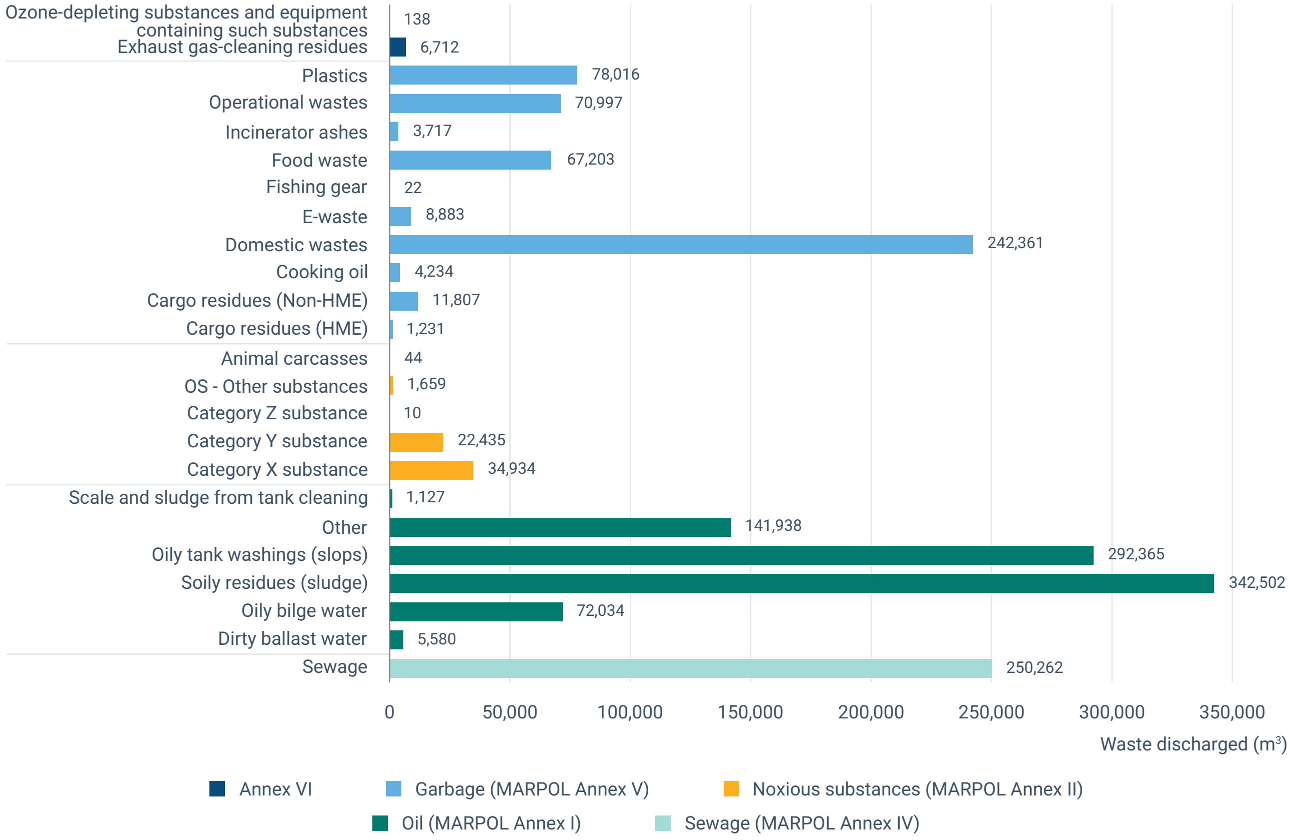
When a ship delivers its waste at a port it receives a receipt to confirm the type and amount of waste collected. Analysis of waste receipts notified electronically by the port reception facilities or ports can provide knowledge about the types and amounts of waste delivered at European ports by ships ([24]). A detailed description of the different types of waste as defined by the MARPOL convention ([25]) is provided in section A1.3.2 (Waste reception at ports).

Figure 2.44 indicates the amount of garbage delivered by ships for all MARPOL Annexes and waste types. Domestic waste, plastics, operational waste and food waste are the most common waste types delivered to port reception facilities (MARPOL Annex V).

([24]) Data should be interpreted with the disclaimer that countries started reporting waste receipts electronically gradually in 2022 and 2023 and are still not doing it for the totality of the waste disposal operations: 12 countries started in in 2022 and by 31 December 2023 a total of 20 countries were reporting. With time, all countries should issue electronic waste receipts and for all waste disposals at ports, in order to have more reliable information and better quality of data.

([25]) https://www.imo.org/en/about/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

Figure 2.44 **Reference waste receipt in EU ports as well as Norway and Iceland in 2023**



Notes: Not all countries reported waste receipts in 2023 electronically and those that reported only did so for part of the disposal operations.

Reference waste receipt: Oil (MARPOL Annex I), noxious liquid substances waste (MARPOL Annex II), sewage (MARPOL Annex IV), garbage (MARPOL Annex V) and air pollution related waste (MARPOL Annex VI) total amounts delivered at port reception facilities.

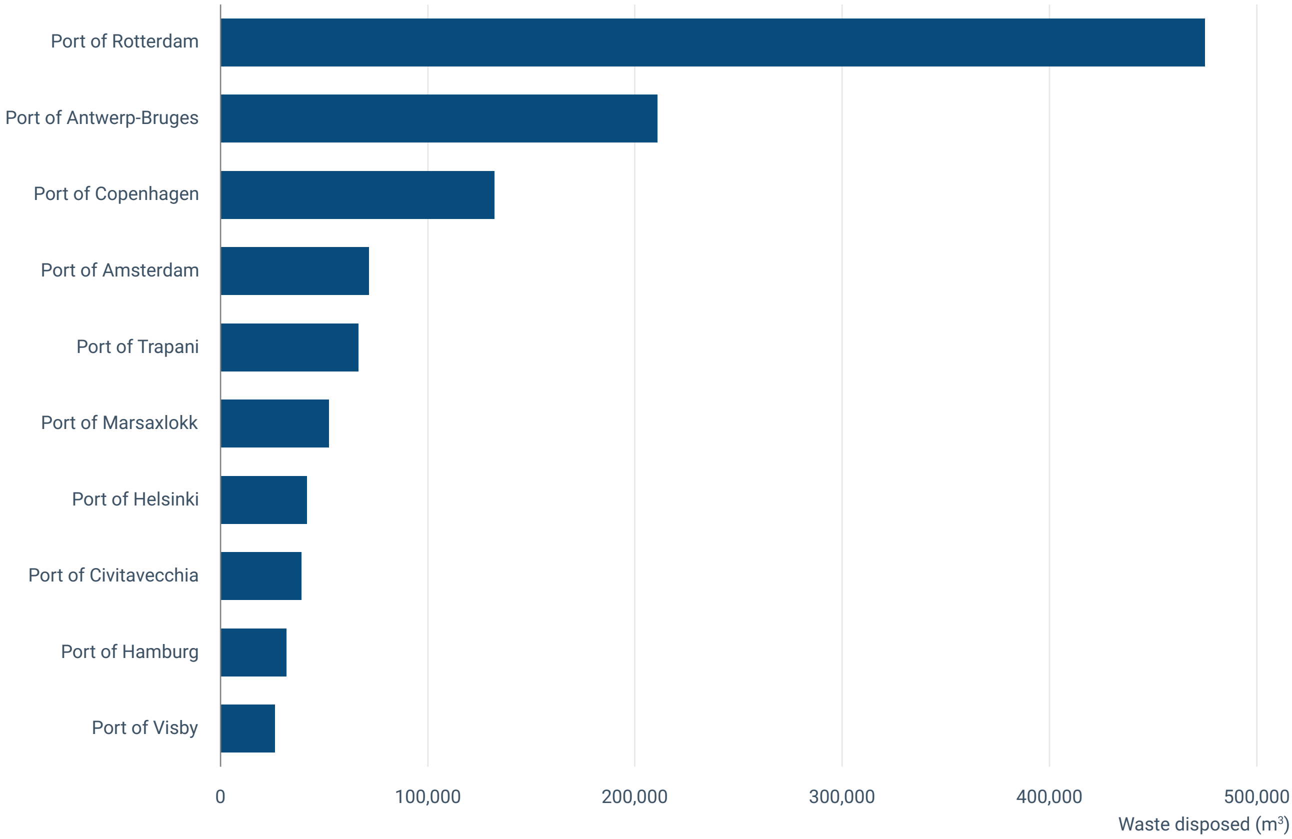
Sources: EMSA internal data; SafeSeaNet (2024).

Approximately 855,000m^3 of oily waste was delivered during 2023 (MARPOL Annex I). Oily residues (sludge) and oily tanks washings (slops) form the majority, followed by oily bilge water. In the same year, 59,000m^3 of noxious liquid substances were reported (MARPOL Annex II), 250,000m^3 of sewage (MARPOL Annex IV) and 6,500m^3 of mainly exhaust gas cleaning residues (MARPOL Annex VI).

The delivery of oily tank washings and cargo residues from Annex II is anticipated to rise in the foreseeable future, particularly with EU legislation encouraging the delivery of residues containing high-viscosity persistent floating substances. Additionally, more delivery of sewage at ports is anticipated, leading to increases in disposal values as Member States expand infrastructures for sewage reception and treatment. Regarding Annex VI, the amounts of Exhaust Gas Cleaning Residues (notably sludge from scrubbers) may experience growth in the coming years, particularly with the entry into force of new SECA areas like the Mediterranean and additional areas in Norway, which will amplify the demand for compliant waste management solutions.

By analysing the total volume of waste from ships from all categories (MARPOL Annex I, II, IV, V and VI) disposed at port reception facilities in European ports according to the waste receipts, it is possible to identify the ports which collect and manage most waste from ships (see Figure 2.45).

Figure 2.45 **Top 10 ports in terms of total volume of waste disposed at port reception facilities in 2023**



Sources: EMSA internal data; SafeSeaNet (2023).

This data highlights how in numerous ports, port reception facilities have evolved into key contributors to the circular economy. In addition, it illustrates the importance of offloading waste at ports with significant capacities for recoveryand recycling as well ensuring the availability of sufficient port reception facilities. In addition, the PRF Directive emphasises the need for Member States to implement appropriate financial incentives in waste fee cost recovery systems at ports, further incentivising compliance.

2.3.3 Ship recycling

Key messages

- EU Member States and Norway reported a total of 90 ships for which a ready for recycling certificate was issued in the period between 1 January 2019 and 31 December 2021, indicating they met environmental and safety standards for being dismantled and recycled in EU approved yards. Of these vessels, 41 completed the recycling process. These vessels were recycled in seven recycling facilities,with Türkiye recycling the highest share (50%).
- In 2022, while the share of vessels flying a flag from an EU Member State was 13.2% of the total world fleet, only 7% of end-of-life vessels recycled were flagged under an EU Member State at the time of recycling. This highlights that the objective of safe and environmentally sound recycling of vessels, as pursued by EU legislation, is still undermined by the practice of re-flagging.

An analysis of the information submitted by the Member States for their first triannual reports under Article 21(1) of Regulation (EU) No 1257/2013 on Ship Recycling (EU, 2013b) shows that a total of 90 ships were issued Ready for Recycling Certificates (RFRC) between 1st January 2019 to 31st December 2021. This is based on 26 reports (25 Member States and Norway), of which 10 Member States (and Norway) identified ships for which they have issued a RFRC. Of these vessels,a Statement of Completion (SOC) has been received for 41 of them (Table 2.3).

Table 2.3 **List of EU countries with Ready for Recycling Certificates and Statement of Completion**

Member State	Number of vessels for which the following document were available	
	Ready for Recycling Certificate	Ready for Recycling Certificate + Statement of Completion
Belgium	2	2
Croatia	1	1
Cyprus	11	5
Denmark ([26])	9 (3 extra vessels were reported where the RFRC has not been received but the SOC has)	8 (including 2 where the RFRC has not been received but the SOC has)
Greece	8	6
Italy ([27])	6	4
Malta ([28])	24	0
Netherlands	7	4
Spain	1	0
Sweden	1	1
MS Total	73 ([29])	31
EFTA Countries Norway	17	10
Total	**90**	**41**

Note: If no data is provided then no documents were issued by that MS.
Source: EMSA internal data, 2023.

These vessels were recycled in seven countries at recycling facilities on the European list of approved recycling facilities, with 51% being recycled in Türkiye (Table 2.4). After analysing the vessel size, vessel type, place of recycling and country of recycling of these vessels it was found that no trends in ship recycling could be identified. This is due to the small dataset of only ten states providing information about certified ships.

([26]) No date provided for the certification.
([27]) Not including Jumeira, which was the centre of an infringement case.
([28]) No dates provided for the Ready for Recycling Certificate and no information provided for the Statement of Completion.
([29]) Including the 3 Danish vessels where a SOC has been received.

Table 2.4 **List of countries where ships were recycled, reported by Member States, Norway and Türkiye between 2019 and 2021**

Country of recycling	Number of vessels where information was reported	Percentage share of recycling
Türkiye	46	51.1%
Denmark	12	13.3%
Norway	8	8.8%
Belgium	4	4.4%
The Netherlands	4	4.4%
Spain	3	3.3%
Italy	1	1.1%
Unknown	7	7.7%
Still trading	2	2.2%
Total	**90**	**100%**

Source: EMSA internal data, 2023.

The dataset provided by these Member States, Norway, and Türkiye was compared with other information available through EMSA's tools. An additional 54 vessels were found to have been registered as recycled between 2019 and 2021 (Table 2.5). Analysis showed that, whilst in 2022, the share of vessels flying a flag from an EU Member State was 13.2% of the total world fleet, only 7% of end-of-life vessels recycled were flagged under an EU Member State at the time of recycling. This highlights that the objective of safe and environmentally sound recycling of vessels, as pursued by EU legislation, is still undermined by the practice of re-flagging.

Table 2.5 List of countries where the 55 additional vessels were recycled from 2019 to 2021

Country of Recycling	Number of Ships
Denmark	14
Norway	9
Belgium	8
Türkiye	6
Unknown	3
The Netherlands	3
Spain	2
Latvia	2
France	2
Lithuania	1
Romania	1
Pakistan	1
India	1
USA	1
Total	**54**

Source: EMSA internal data, 2022.

Analysis of this data shows that although Member States are giving Ready for Recycling Certificates and receiving Statements of Completion, this is not happening in every case a ship has been recycled.

2.4 Hazards and physical disturbance of seabed

2.4.1 Collisions with animals

Key messages

- Eastern parts of the Greater North Sea, the south coast of the Bay of Biscay, the Gibraltar region, and parts of the Aegean Sea are hotspots with significant increases in collision risk for whales and turtles.
- A decrease in collision risk is noticeable in the western coast of the Iberian Peninsula, partially in the Celtic Seas, Adriatic Sea and Black Sea.
- Maritime transport is recognised to have an important impact on red-list species within Natura 2000 sites in marine regions, notably in collision risks, which have seen a significant increase between 2017 and 2022.

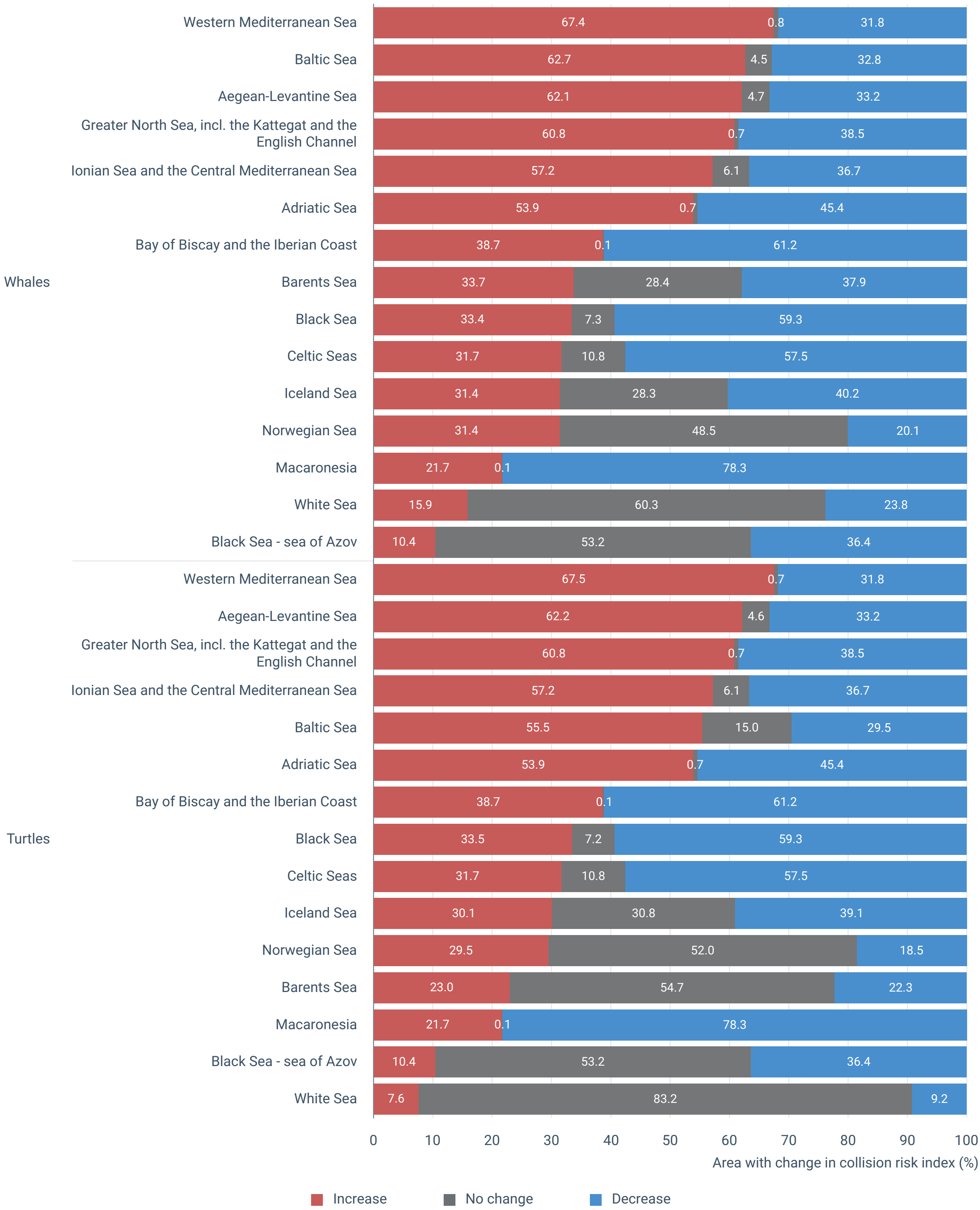
With the increase of maritime traffic and increased vessel speeds over the past decades, the probability of collisions has also increased. However, such events are rarely recorded and often the collision is not even detected by the vessel crew. Quality data on collision events is therefore scarce, so the risk of collisions with animals is assessed by a proxy indicator (i.e. the collision risk index).

In general, the marine subregion with the highest collision risk values for whale and turtle species is the Greater North Sea, including the Kattegat and the English Channel. This subregion is highly affected by intensive maritime traffic due to several important ports and shipping lanes. High collision risk for whales and turtles is also prominent in the Adriatic Sea and the Western Mediterranean Sea, where there is a high occurrence of species (especially turtles, fin whales and sperm whales) and intensive marine traffic (around Gibraltar).

There are four marine subregions in which more than 60% of area has seen an increase in the collision risk index for whales and turtles in 2022, compared to 2017: the Western Mediterranean Sea, the Aegean-Levantine Sea, the Greater North Sea and the Baltic Sea (whales only) (Figure 2.46). Subregions with the largest areas of collision index decrease are Macaronesia (78%), Bay of Biscay, Iberian Coast (61%) and the Black Sea (59%) ([30]).

([30]) Collision index values for 2017 and 2022 were compared (2022 value minus 2017 value) for each raster cell to determine the changes ('increase/decrease/no change'), then the areas of each class were aggregated per marine subregions. Note that the changes (increase or decrease) on a cell basis can be very small (especially in open seas with low traffic density), nevertheless these small changes are also considered in the aggregation. Thus, large areas (e.g. Macaronesia, Bay of Biscay and Iberian coast) register a decrease in the collision index, for example. Global traffic is indeed increasing. However, this probably occurs the most in established corridors along traffic routes. This chart shows aggregated results across entire regions. Thus, Figure 2.46 does not show the significance or magnitude of collision risk index change, only the sum of areas with 'increase/decrease/no change' between 2017 and 2022.

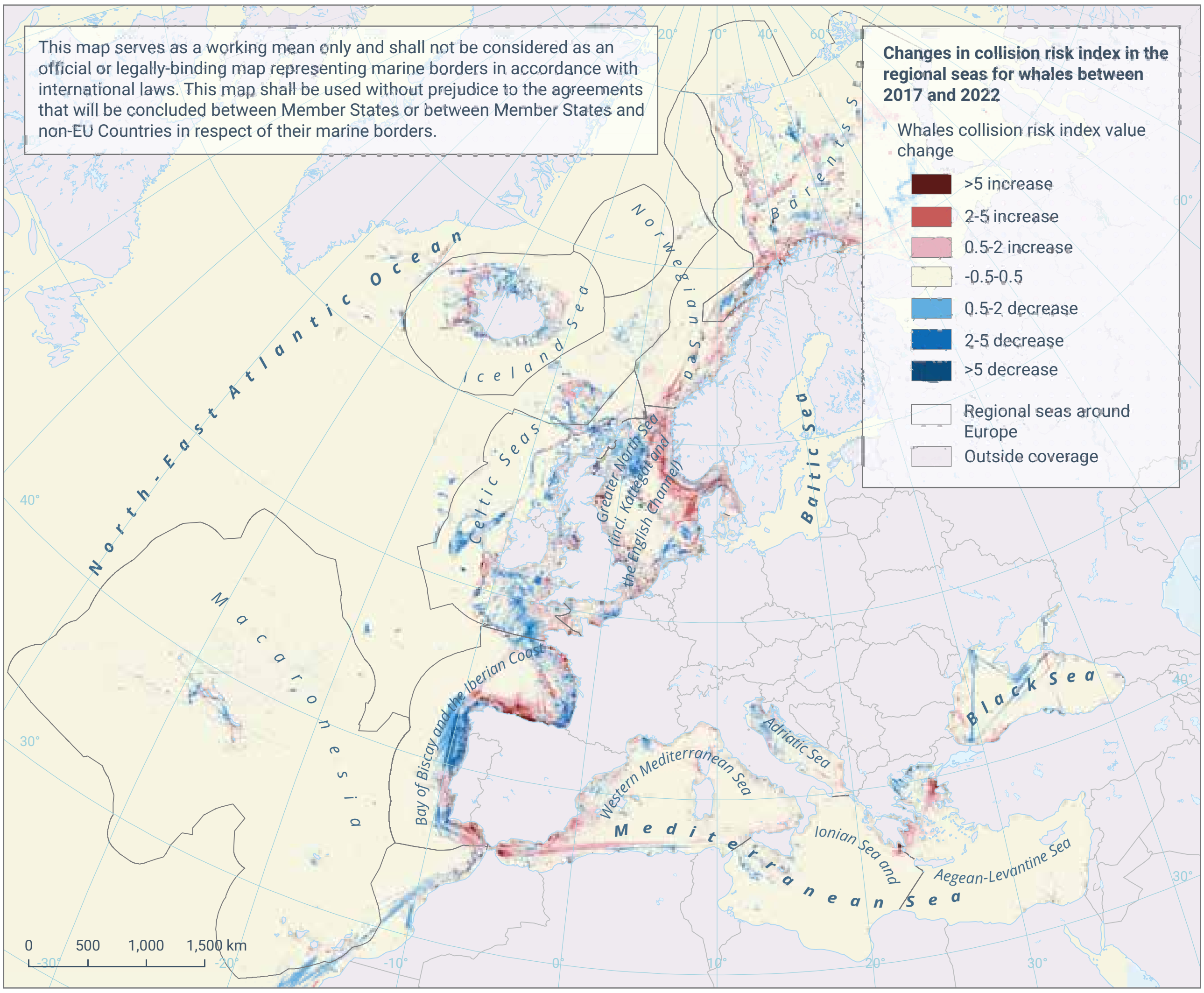
Figure 2.46 **Collision risk (% of area) for whales and turtles between 2017 and 2022, by MSFD marine subregion**



Source: EEA, 2024 (using Aquamaps and EMODnet data).

Some hotspot areas show a significant increase of collision risk between 2017 and 2022 (Map 2.8). These areas are the Greater North Sea (and Norway coast) and the Bay of Biscay with increase of collision index, wider area around Gibraltar and East Mediterranean. On the other hand, there is a noticeable decrease in collision risk on the western coast of the Iberian Peninsula, in the Celtic Seas, partially in Icelandic Sea (whales only), and parts of the Adriatic Sea and the Black Sea (whales and turtles).

Map 2.8 **Changes in collision risk index for whales in European regional seas between 2017 and 2022**



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

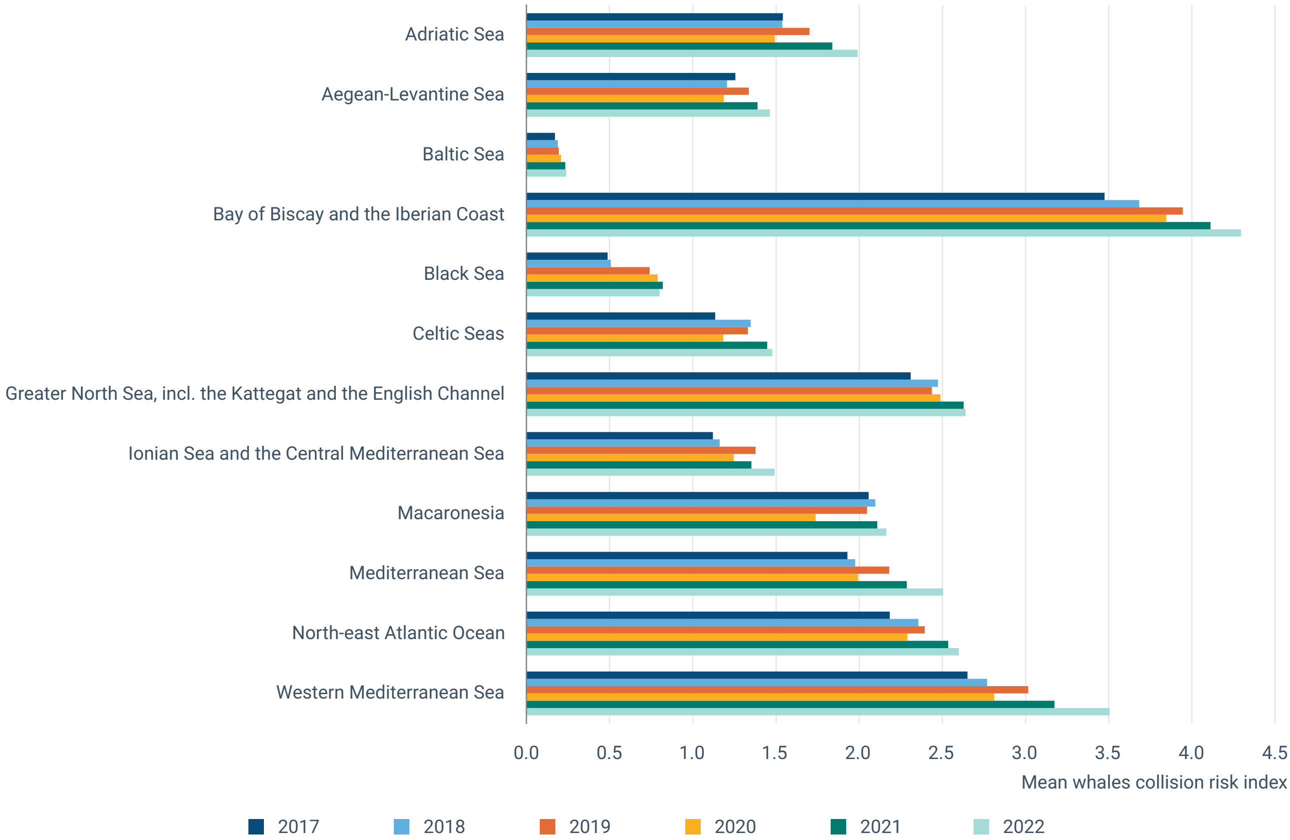
Notes: The collision risk index is designed as a spatial overlay of the animal species distribution and vessel density. In areas where marine species are present (i.e. high occurrence probability) and the density of marine traffic is high, the collision risk index is also high. 23 whales (cetaceans) species and 3 turtle species were included in the calculation of the index. Each species was assigned (weighted by) a strike frequency factor, which indicates the level of susceptibility of the species to collisions with vessels. The factors were developed based on the frequency of a species observed stricken by a ship (Schoeman et al., 2020). Weighted species occurrence probability layers were summed to get the species group (whales, turtles) occurrence probability layer. For more information about methodology see: https://www.eea.europa.eu/en/analysis/maps-and-charts/changes-in-collision-risk?activeTab=265e2bee-7de3-46e8-b6ee-76005f3f434f

Source: EEA, 2024 (using Aquamaps and EMODnet data).

According to the International Whaling Commission (Cates et al., 2017), high-risk areas for ship collisions in Europe are the Canary Islands (especially for sperm whale), the Strait of Gibraltar (for fin and sperm whales), the Balearic Islands (for fin and sperm whales), the Eastern Alboran Sea (for fin whale and sperm whale) and the Hellenic Trench (for sperm whales).

There is a clear increasing trend of higher collision risk index values in Natura 2000 areas (Figure 2.47) in all marine regions. Natura 2000 sites can be designated in near-shore areas, as well as intersect with high intensity shipping lanes.

Figure 2.47 Average whale collision risk index inside Natura 2000 areas, by MSFD marine subregion between 2017-2022 ([31])



Source: EEA, 2024 (using Aquamaps and EMODnet data).

This report considers 23 red-listed cetacean species ([32]), 19 of which are recognised as protected or important species within Natura 2000 areas — and some of this latter group exist in Natura 2000 sites displaying high mean collision indices.

Maritime transport has significant impacts on red-list species within Natura 2000 sites in marine regions (Figure 2.48). There are 171 Natura 2000 sites where 'shipping lanes, ports, marine constructions' are listed as a significant impact to red-list species. More than 80 sites are in the North-East Atlantic Ocean, 15 of these have a

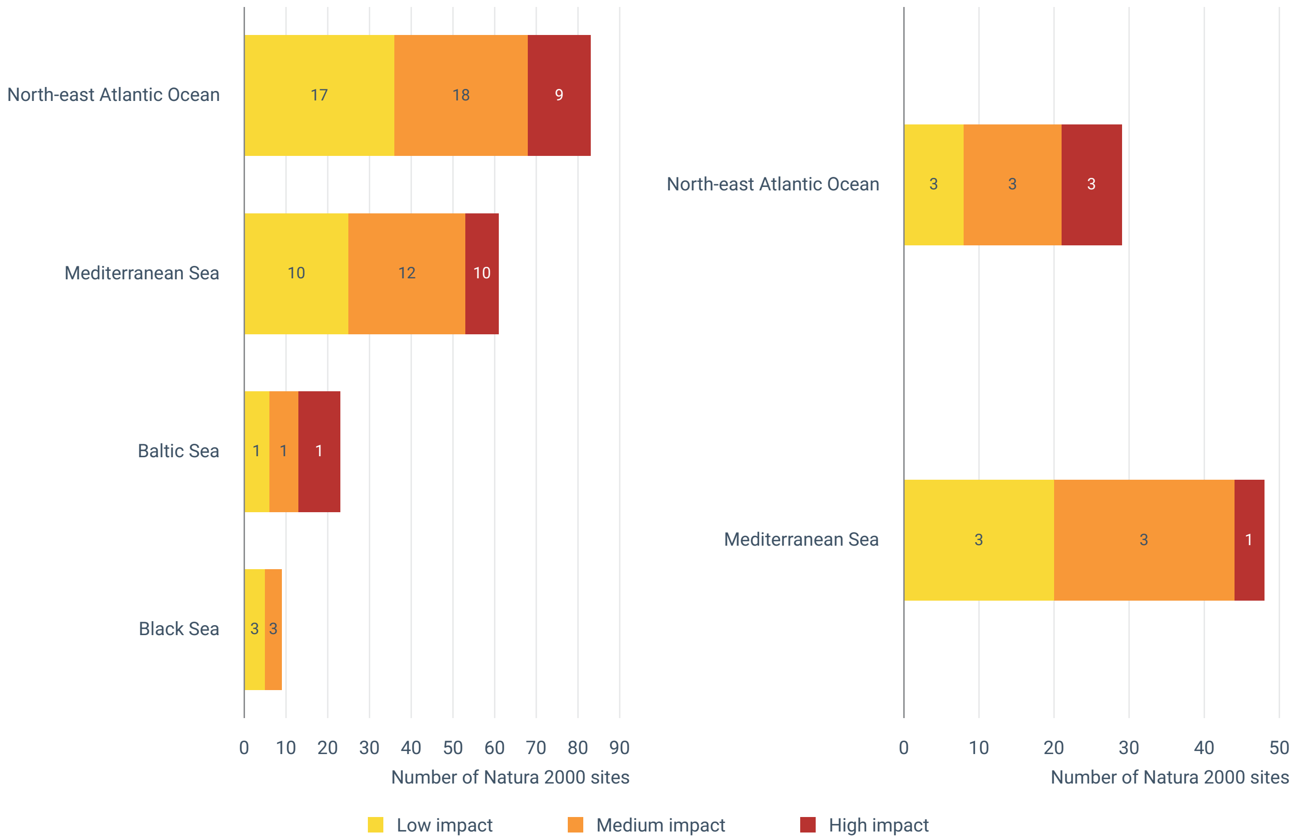
([31]) Natura 2000 areas are calculated first as mean value for each Natura 2000 site and then averaged per marine subregion, whereas mean values for entire marine subregions are calculated as mean values for entire areas.

([32]) Cetacean species include killer whales (*Orcinus orca*), white-beaked dolphins (*Lagenorhynchus albirostris*), humpback whales (*Megaptera novaeangliae*), minke whales (*Balaenoptera acutorostrata*), common bottlenose dolphins (*Tursiops truncatus*), harbor porpoises (*Phocoena phocoena*), long-finned pilot whales (*Globicephala melas*), striped dolphins (*Stenella coeruleoalba*), sperm whales (*Physeter catodon*) and short-beaked common dolphins (*Delphinus delphis*). Sea turtle species include loggerhead sea turtles (*Caretta caretta*), green sea turtles (*Chelonia mydas*) and heatherback sea turtles (*Dermochelys coriacea*). These are the species recognised in Natura 2000 sites most affected by collision risk.

high impact on nine whale species. 32 Natura 2000 sites with 18 whale species are exposed to medium impact of shipping (Figure 2.48, left). In the Mediterranean Sea, there are eight Natura 2000 sites exposed to high impact, with ten whale species present at these sites.

Turtles are more exposed to impacts in the Mediterranean Sea, where 28 Natura 2000 sites have shipping identified as a medium or high risk. In these areas, three red-list turtle species are present (Figure 2.48, right).

Figure 2.48 **Natura 2000 sites in European regional seas with red-list whales (left) and turtles (right) species where 'shipping lanes, ports, marine constructions' are an identified impact**



Notes: Number of sites and impact intensity classes. Values inside bars represent number of species in impact intensity class.

Source: EEA, 2024 (using Aquamaps and EMODnet data).

The overall speed of ships in regional seas has on average increased marginally (by 1%) between 2017 and 2022 (EMSA, 2023a). The impact of increasing ship speed on collision risk is therefore assessed as marginal in this period. Nevertheless, the risk of lethal collisions remains high, especially for coastal areas and NATURA areas.

2.4.2 Physical disturbance of the seabed

Key messages

- 27% of the seabed in near-shore marine waters (one nautical mile from the coastline) experiences physical disturbance, with 5% of the area being subject to high impact.
- The widest seabed physical disturbance is found in the Greater North Sea (10% of sea area), including the Kattegat and the English Channel subregion. Approximately 4.2% of broad benthic habitats in marine reporting units reported by EU Member States are disturbed due to maritime transport.
- The MSFD Good Environmental Status (GES) threshold value for seabed habitat loss is 2% of the marine area. Out of the broad benthic habitats spanning over 405 marine reporting units reported by EU Member States, 0.2% are physically lost due to substantial modification of the seabed attributed to maritime transport.
- Between 2000 and 2018, there has been a 12.5% increase in port areas. The expansion has been the most prominent in the North-East Atlantic Ocean in absolute terms (53 km²) and in the Black Sea in relative terms (17%).
- The habitat types most impacted by ports and port activity-related pressures are sands and muds in the infralittoral biozone (shallow water closest to the shore). These provide homes for various species, including seagrass, microalgae, mangroves, saltmarsh, prawns, bivalves, mud crabs, and fish. Impacts can lead to habitat loss or degradation.

Wake-induced habitat disturbance – turbidity

In the Baltic Sea, Adriatic Sea, Greater North Sea (including the Kattegat and English Channel marine subregions), more than 6% of the total area is impacted by ship-generated turbidity. These seas hold a significant share of the marine area impacted by high shipping traffic waters shallower than 30 metres. Nevertheless, most of the affected areas are subject to low turbidity pressure, causing only minor impact to marine habitats.

Dredging

More than 1,700 dredging activities have been reported in Europe over the past decade. The amount of dredged material during this period exceeded 300 million tonnes. The overwhelming majority (90%) of these activities are associated with maintenance and capital dredging (EMODnet, 2023). The purpose of maintenance dredging is to deepen or maintain navigable waterways or channels which face the threat of silt buildup over time, due to sedimented sand and mud. Capital dredging is used to create a new harbour, berth or waterway, or to deepen existing facilities to allow access to larger ships (IADC, 2023).

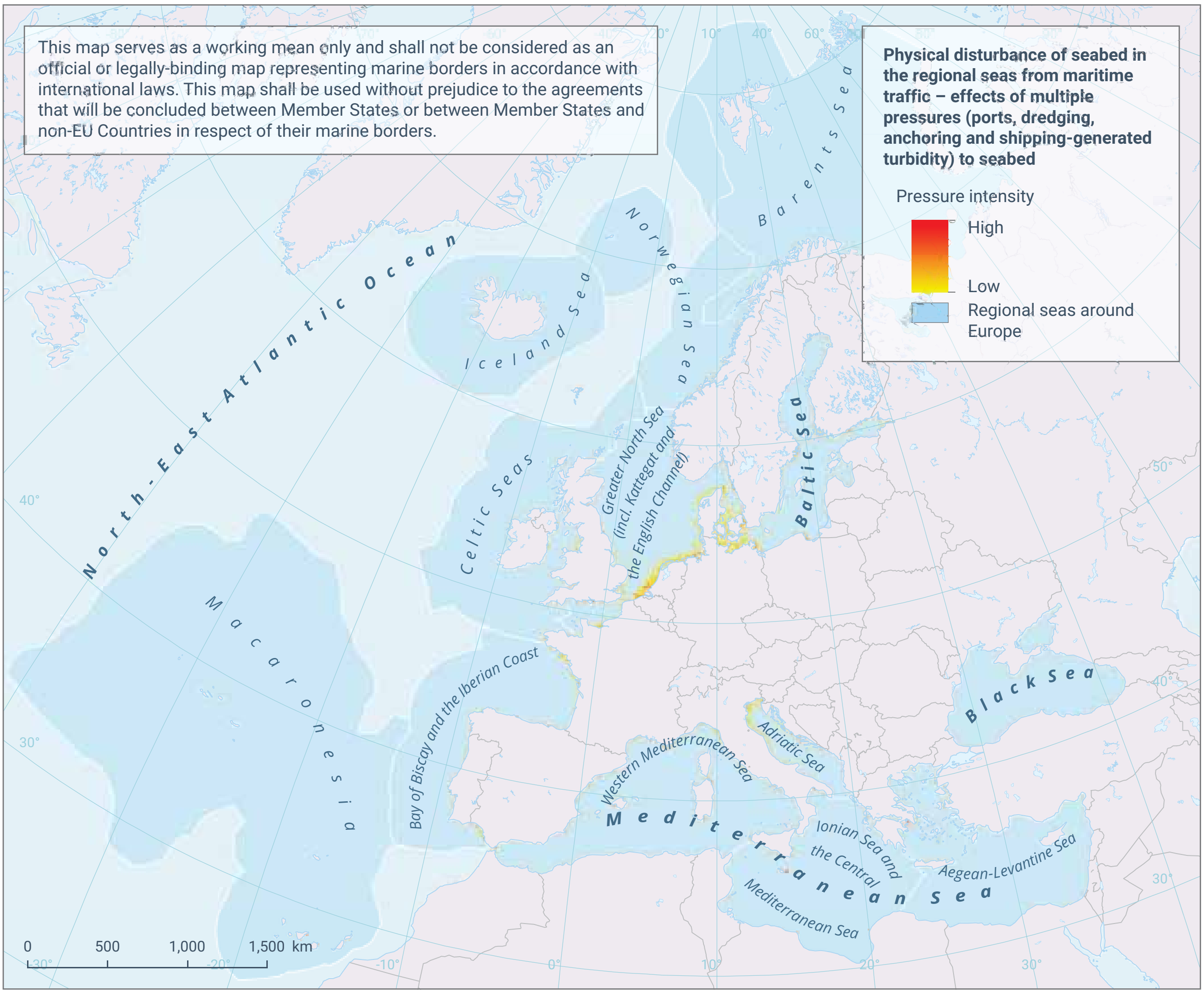
Anchoring

An area of 11,475km² is potentially affected by the pressure of anchoring. This represents less than 0.6% of shallow areas across Europe's regional seas, with depths not exceeding 110m. Nevertheless, since this pressure takes place within shallow near-shore areas where biodiversity is rich, it can still negatively affect benthic habitats. The marine subregions with the largest estimated anchoring areas are the Greater North Sea (3,074km²), the Black Sea (1,492km²) and the Aegean-Levantine Sea (1,400km²).

Combined multiple pressures

Physical disturbance is caused by several human activities that affect the seabed either directly or indirectly. The following indicator shows the combined effects of maritime traffic, including port activities (e.g. expansion of port facilities, harbour dredging), ship lane maintenance by dredging, ship anchoring, as well as shipping related turbidity. Pressure and impacts layers, analysed in the sections above, have been combined into a composite indicator where the intensity of the pressures has been estimated on a scale from 0.1 (low pressure) to 1 (high pressure) (see Map 2.9). The cumulative effect of these pressures is damaging marine ecosystems.

Map 2.9 Physical disturbance of seabed in European regional seas from maritime traffic



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Notes: Pressure intensity layers produced under sections expansion of ports, dredging, shipping-related turbidity and anchor damage have been reclassified to unified intensity scale 0.1 – Vey low to 1– Very high. In the second step the corresponding layers were combined into composite physical disturbance of seabed grid pressure layer where final intensity value of each grid cell equals the maximum intensity value of all assessed layers in the corresponding cell.

Source: EEA, 2024 (using EMODnet bathymetry, Regional Seas Around Europe, EMODnet benthic habitats, MSFD Benthic Broad Habitat Types, EMODnet vessel density, EMODnet dredging, Copernicus Corine Land Cover 2018).

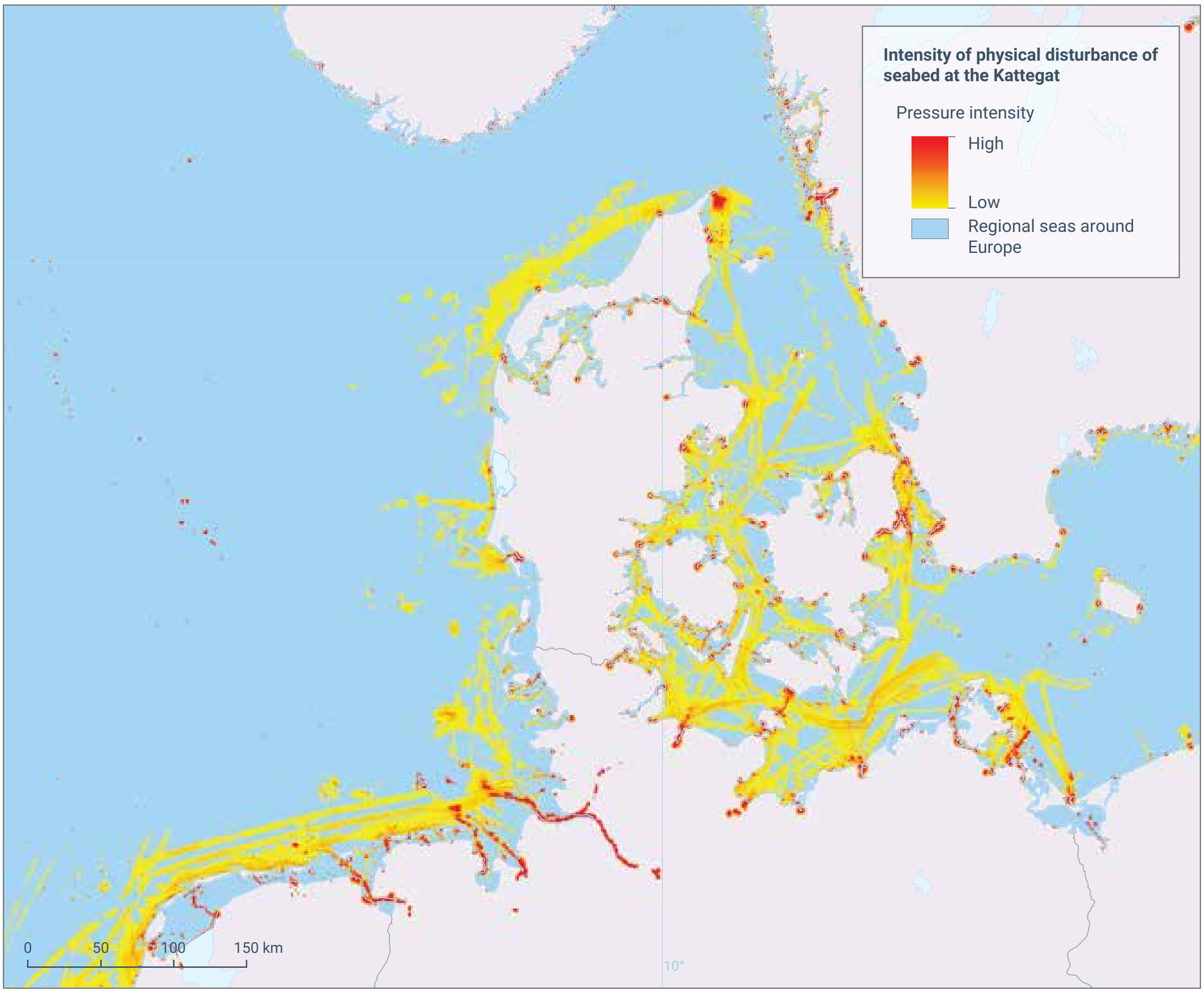
About 170,000km^2 (or 1.2% of Europe's regional seas) are subject to physical disturbance of seabed by maritime transport only, with notable subregional differences. The regions with the highest percentage of impacted area are the Greater North Sea (including the Kattegat and the English Channel) (10.4%), the Adriatic Sea (8.7%) and the Baltic Sea (8.4%). These seas have a significant share of marine area impacted by high shipping traffic in areas shallower than 30m.

The MSFD threshold value for Good Environmental Status (GES) concerning habitat loss is 2% of the benthic marine area and approximately 0.2% of broad benthic habitats spanning over 405 marine reporting units (MRUs) reported by EU Member

States are physically lost due to substantial modification of seabed attributed to maritime transport.

In Map 2.10, the yellow colour shows moderate impact to physical disturbance of seabed in Kattegat, mainly caused by turbidity from vessels. High impact (red colour) mostly occurs at ports and their vicinity, where the seafloor has been deepened to maintain navigable waterways. Marine habitats in such areas are assessed as highly physically disturbed or even completely degraded.

Map 2.10 Intensity of physical disturbance of seabed at the Kattegat



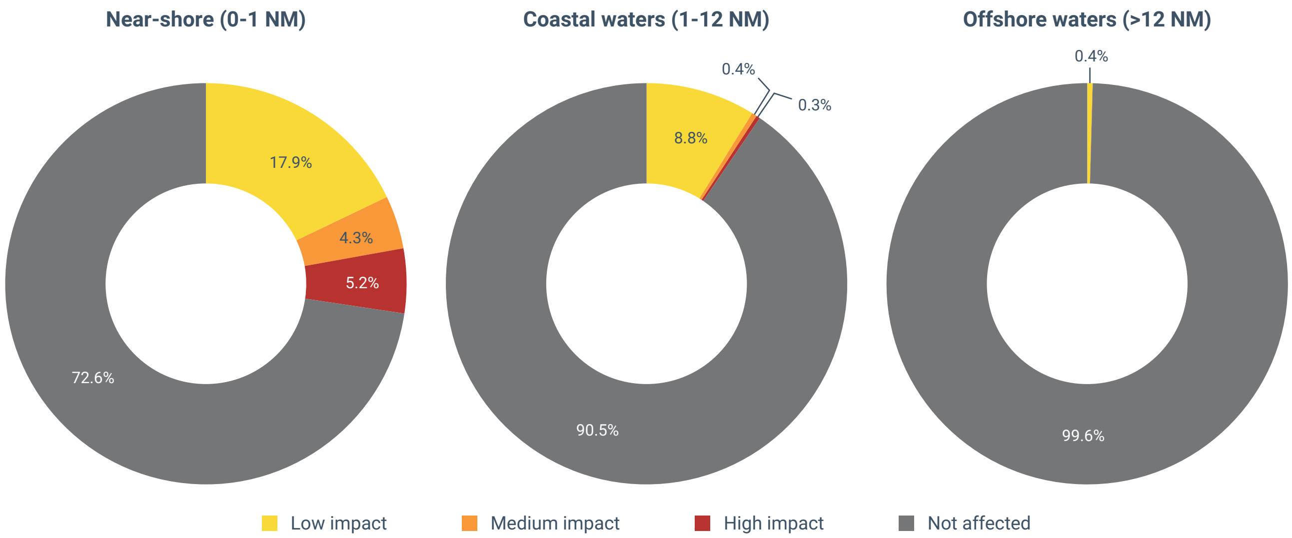
Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Source: EEA, 2024 (using EMODnet bathymetry, Regional Seas Around Europe, EMODnet benthic habitats, MSFD Benthic Broad Habitat Types, EMODnet vessel density, EMODnet dredging, Copernicus Corine Land Cover 2018).

Biodiversity is richest in near-shore waters, where land and sea meet. Near-shore habitats, which may be affected by marine traffic, are also among the most productive and vulnerable ecosystems as they form an interface between freshwater and marine waters.

Analyses indicate that 27% of the seabed in near-shore marine waters, extending up to one nautical mile (NM) from the coastline, experiences physical disturbance from maritime traffic, with 5% of the area subject to high impact. The level of impact diminishes moving away from the coastline. It is estimated that 10% of territorial waters across Europe are affected (1-12NM from the coastline). Marine traffic only affects 0.4% of the seabed in offshore waters beyond 12NM from the coastline.

Figure 2.49 Percentage of physically disturbed seabed in near-shore (0-1NM), coastal (1-12NM) and offshore (>12NM) waters in the regional seas



Notes: Near shore = 0-1NM zone; coastal waters = 1-12NM zone (for Greece, 1-6NM); offshore = 12NM-END, where END = equidistance to neighbouring state or 200NM. The analysis covers only the waters of EU Member States.

NM, nautical miles.

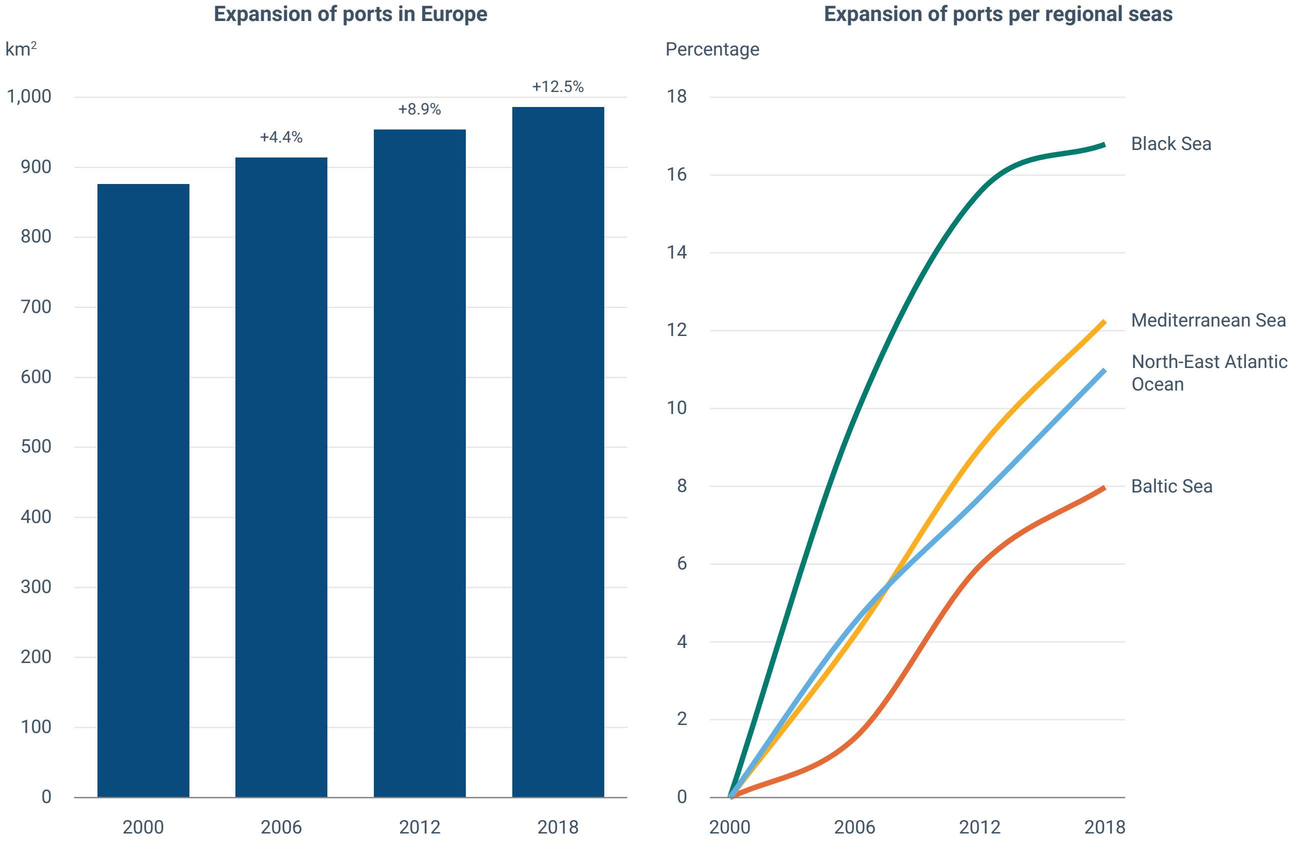
Source: EEA, 2024 (using EMODnet Digital Bathymetry, MSFD Benthic Broad Habitat Types, EMODnet vessel density, EMODnet Human Activities – Dredging, EEA marine assessment areas buffer zones).

This chart overlays MSFD broad habitat types with the composite indicator (including ports, dredging, anchoring and shipping-related turbidity) and MRUs. Maritime transport disturbs approximately 4.2% of broad benthic habitats spanning over 405 MRUs reported by EU Member States. Approximately in 25% of reported MRUs more than 10% of the broad habitat area was disturbed as a result of maritime transport.

2.4.3 Seabed disturbance: A special focus on ports

Ports represent the core of the maritime shipping industry, functioning as the departure, entry and transfer points for a vast spectrum of goods, services and individuals transported via ships. Port expansion experienced a significant surge in Europe between 2000-2018, resulting in a 12.5% increase in port area (see Figure 2.50). The expansion has been most prominent in the Black Sea (17% or 9km^2), followed by the Mediterranean Sea (12% or 35km^2), the North-East Atlantic Ocean (11% or 53km^2) and the Baltic Sea (8% or 14km^2). This surge in port development can be mainly attributed to an increase in international cargo movement (EEA and EMSA, 2021). A rise in tourism and recreational activities has also led to an increased demand for marinas to accommodate private boats and yachts. European countries, in particular those with attractive coastlines and waterfronts, have expanded marina facilities to cater to this growing demand, promoting tourism and supporting local economies.

Figure 2.50 **Port expansion in Europe (left) and per regional sea (right) between 2000-2018 ([33]).**



Source: EEA, 2024 (using Copernicus Corine Land Cover 2018, 2012, 2006 and 2000).

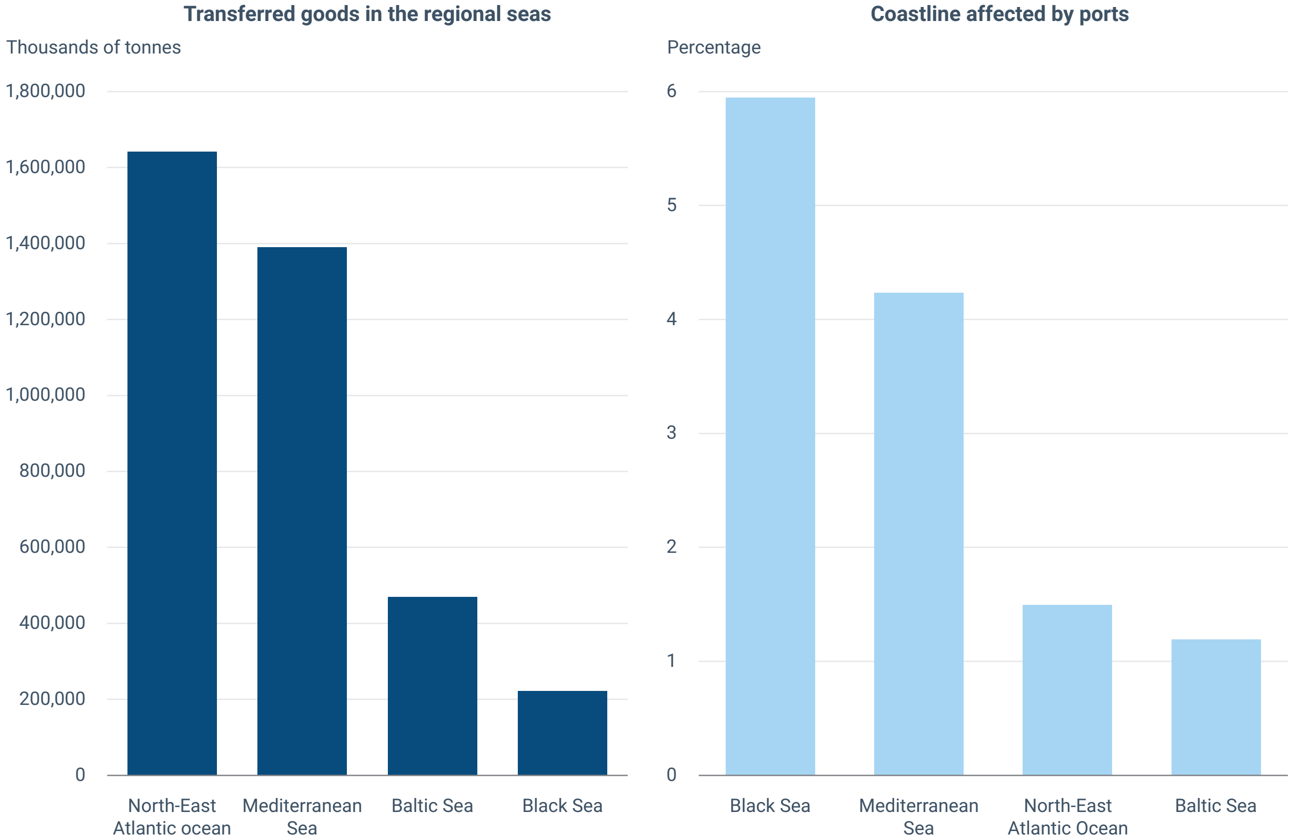
Almost 3% of the coastline is occupied by ports. The port area is the largest in north-east Atlantic Ocean, where the largest ports lead in terms of inward and outward transferred tonnes, including Rotterdam in the Netherlands (400 million tonnes per year), Hamburg in Germany (200 million tonnes per year) and Antwerp in Belgium (100 million tonnes per year).

Even though the total area of ports in the Black Sea is relatively small, accounting for only 51km² or 5% of the total, it is the region with the highest percentage (5.9% or 249km) of coastline affected by ports ([34]) (Figure 2.51). The lowest percentage of coastline affected by ports is the Baltic Sea (1.2% or 757km) and this is caused by the very long and rugged coastline composed of numerous islands and archipelagos.

([33]) Analysis as visualised on the left figure has been on the areal information on ports as provided in Copernicus Corine Land Cover spatial datasets. The information on the port area for the reference year 2018 has been estimated using the CORINE Land Cover 2018 dataset. Conversely, the areas for previous years (2012, 2006 and 2000) have been estimated using CORINE Land Cover Change layers which provide land cover change information between the analysed periods. As Copernicus data does not distinguish between coastal and riverine ports, only those ports were analysed which are situated up to 10km from the coastline as defined in regional seas around Europe dataset. The dataset for the Black Sea includes only port areas located in Bulgaria, Romania and Türkiye as these are only three countries along the Black Sea coast that are covered in the Copernicus CLC datasets. Non-EEA countries situated along the Mediterranean Sea (e.g. Tunis, Egypt, Israel) are not included in this assessment as they are not part of Copernicus CLC datasets. To calculate the expansion of ports per marine region (right figure), the coastal ports have been overlayed with regional seas around Europe layer. Percentage of expansion has been calculated in accordance with the first year with data (2000). The dataset for the Black Sea includes only port areas located in Bulgaria, Romania and Türkiye as these are only three countries along the Black Sea coast that are covered in the Copernicus CLC datasets. Non-EEA countries situated along the Mediterranean Sea (e.g. Tunis, Egypt and Israel) are not included in this assessment as they are not part of Copernicus CLC datasets.

([34]) Only ports in EU part (Bulgaria and Romania) are considered in these analyses.

Figure 2.51 Transferred goods in thousands of tonnes in the regional seas in 2021 (left) and percentage of coastline affected by ports (right) ([35])

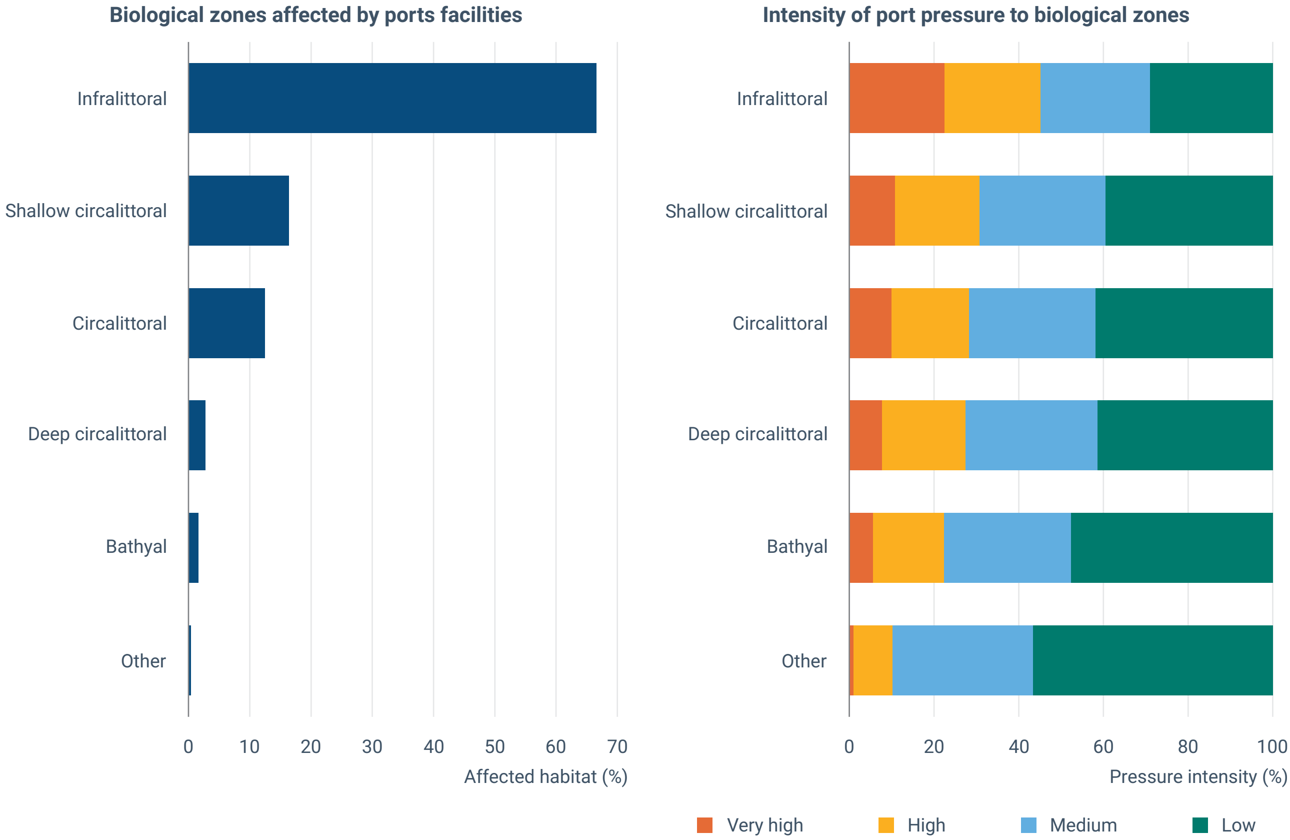


Source: EEA, 2024 (using EMODNET main ports (goods traffic 2021), Regional seas around Europe, EEA marine assessment areas buffer zones).

The process of constructing port infrastructure involves activities like land conversion, reclamation, breakwater construction, pile driving and extensive earthworks, all of which contribute to degradation of marine habitats.In addition, operational port activities such as ship manoeuvres and seabed modifications also impact the area. The infralittoral biological zone (the shallow water closest to the shore) is subject to the most intense and widespread degradation, whereas other biological zones (e.g., the shallow circalittoral and circalittoral) are significantly less impacted (Figure 2.52).

([35]) Sum of tonnage (left figure) graph has been calculated by summing the inward and outward weight of transferred goods in 2021 per port. As the EMODNET port layer includes also riverine ports, only those ports were selected which are lay less than 50km from the 10km from the coastline as defined in regional seas around Europe. To aggregate the port information to marine regions the derived dataset has been overlayed with regional seas around Europe layer. The percentage of near-shore marine area affected by ports (right figure) has been calculated by first applying 1NM buffer belts to CLC ports. To calculate the estimation of coastline affected by ports per marine region, the marine area affected by ports layer has been overlayed with 1NM marine buffer belt as provided in EEA marine assessment area dataset. The result of this intersection presents a proxy of percentage of coastline affected by ports. The dataset includes only port areas located in EU Member States because the 1NM buffer belt layer includes only marine buffer belt areas calculated from the EU coastline.

Figure 2.52 Percentage of biological zones affected by ports facilities and intensity of port pressure to biological zones in regional seas (36)

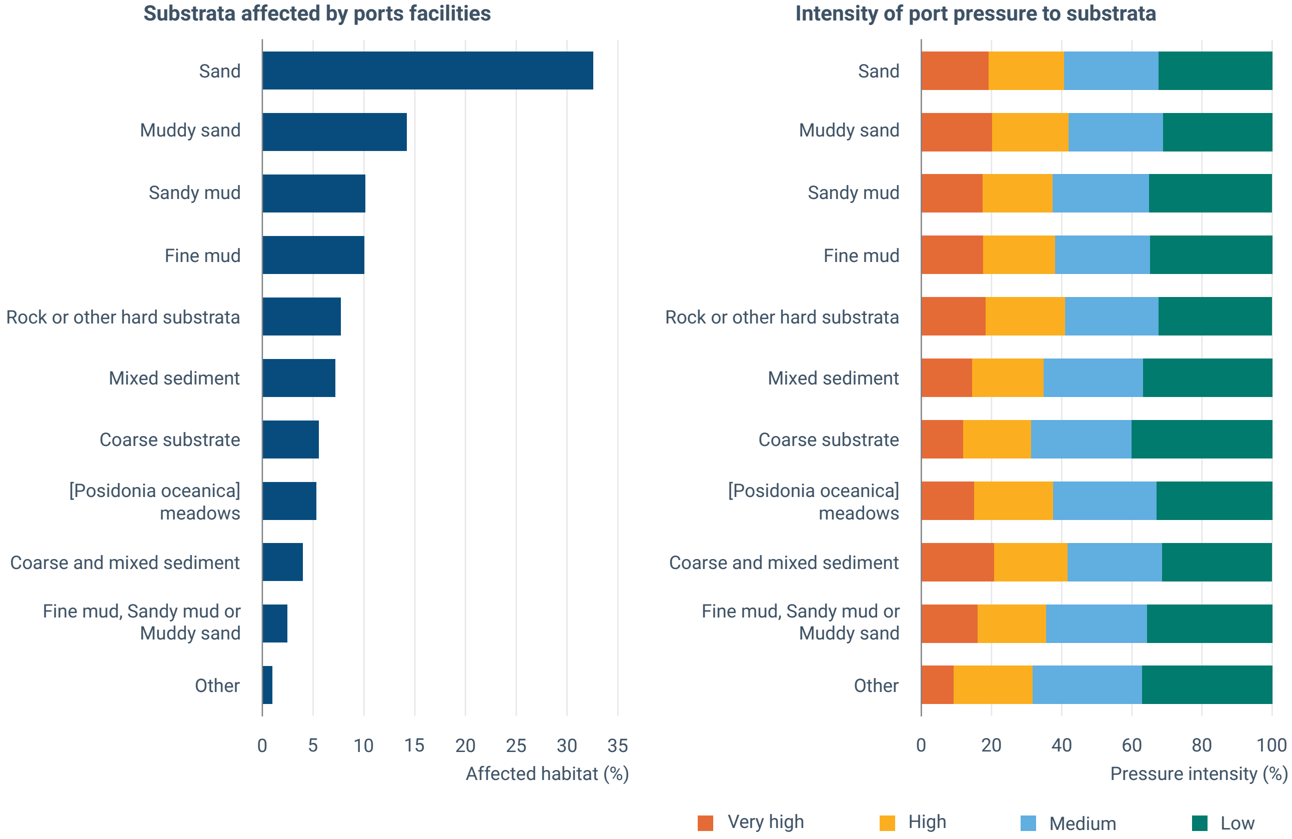


Source: EEA, 2024 (using MSFD Benthic Broad Habitat Types and Copernicus Corine Land Cover 2018).

The damage caused by ports creates a range of issues, such as diminished water quality, alterations in coastal morphology and hydrology and the deterioration of sand and mud substrates (Figure 2.53). The most impacted substrate is sand (33% of affected habitats) followed by muddy sand (14%) and sandy mud (10%). The sand and mud substrata present important habitats for seagrass, microalgae, mangroves, saltmarsh, prawns, bivalves, mud crabs and fish — all of these can be severely degraded due to ports and port-related activities (e.g. dredging).

(36) The percentage of biological zones affected by port facilities (depicted in the left figure) was determined through an analysis of the distribution of benthic broad habitats within a 1NM buffer zone surrounding the ports. In the right figure, the pressure intensity was computed, considering that the intensity of pressure exerted by ports diminishes with increasing distance from the port itself. The pressure intensity is notably high in close proximity to the port facility and gradually decreases with distance, categorised as follows: 0-0.25NM (Very high), 0.25-0.5NM (High), 0.5-0.75NM (Medium) and 0.75-1NM (Low).

Figure 2.53 Percentage of substrata affected by ports facilities and intensity of port pressure to biological zones in the regional seas ([37])



Source: EEA, 2024 (using MSFD Benthic Broad Habitat Types and Copernicus Corine Land Cover 2018).

([37]) The percentage of substrate type affected by port facilities (depicted in the left figure) was determined through an analysis of the distribution of benthic broad habitats within a 1NM buffer zone surrounding the ports. In the right figure, the pressure intensity was computed, considering that the intensity of pressure exerted by ports diminishes with increasing distance from the port itself. The pressure intensity is notably high in close proximity to the port facility and gradually decreases with distance, categorised as follows: 0-0.25NM (Very high), 0.25-0.5NM (High), 0.5-0.75NM (Medium) and0.75-1NM (Low).

3 Achieving decarbonisation targets

Key messages

- The recently adopted EU 'Fit for 55' package extended the EU Emission Trading System (ETS) to maritime transport. Shipping companies will surrender allowances for a portion of their greenhouse gas emissions: 40% of their verified emissions as of 2024, 70% as of 2025, and 100% as of 2026.
- In 2023, the EU adopted the FuelEU Maritime Regulation, Alternative Fuel Infrastructure Regulation (AFIR) and the Renewable Energy Directive (RED). In addition, changes to the Energy Taxation Directive (ETD) and the Ship Source Pollution Directive were proposed.
- The FuelEU Maritime Regulation stipulates that the yearly average GHG intensity of the energy used on board ships will have to be reduced from the 2020 baseline by a minimum of 2% by 2025 and 6% by 2030, and afterwards in 5-year steps up to 80% by 2050. To achieve the emission reductions and energy intensity expected by 2030, fossil fuel consumption should be significantly limited.
- The FuelEU Maritime Regulation measures enforcing the use of onshore power supply by 2030 are supporting the transition to low-carbon and renewable energy sources.
- In 2023, the EU maritime sector had 1083 battery-powered ships in operation, with 160 more on order for 2024. Methanol use is rising, with 33 ships in operation and 29 on order in 2024. The number of wind propulsion uses is increasing, with installations on over 30 ships and ongoing retrofits on 26 more.
- Hydrogen-powered ships include three in operation and five on order. The projected electrolyser capacity by 2030 could supply hydrogen fuels for 13-19% of the global fleet if sufficient renewable electricity and capacity increases are realised. Green ammonia production needs a 3-4-fold increase to support the foreseen demand. Addressing safety and emissions is crucial for scaling up these technologies.

Spurred by the ambition of the European Green Deal, this chapter reviews the 'EU basket of measures' reflecting the EU's goal to cut GHG emissions, analyses the CO_2 emission outlook scenarios of the maritime sector and describes the major alternative energy carrier solutions to reach the required CO_2 targets. It has a particular focus on the Fit-for-55 proposals related to the decarbonisation of the maritime transport sector, which explore the introduction of market-based measures and the uptake of new renewable energy sources, as well as the global targets as agreed in the new IMO GHG strategy. In addition, it brings together previous sections and provides an energy transition foresight analysis, firstly to 2030 and then onwards to 2050. This will support assessments of the challenges and opportunities the sector is facing in the implementation of new targets for decarbonisation.

3.1 An EU basket of measures

In 2021, all EU Member States committed to turn Europe into the first climate neutral continent by 2050. To meet this ambition, the European Commission proposed a basket of measures to increase the contribution of maritime transport to EU climate efforts. These measures form part of the Fit for 55 package of legislation designed to reduce EU GHG emissions by at least 55% by 2030 compared to 1990 levels (EC, 2021d). They were adopted in 2023 and include the EU ETS extension to maritime transport (EU, 2023b), the revised FuelEU Maritime Regulation (EU, 2023d), the revised Alternative Fuel Infrastructure Regulation (AFIR) (EU, 2023c), the Renewable Energy Directive (RED) (EU, 2023a) and the Energy Taxation Directive (ETD) (EP, 2021). The EU measures under the Fit for 55 package sit along those to be agreed at global level within the IMO (see new IMO GHG strategy (IMO, 2023a)).

3.1.1 EU Emission Trading System

In 2023, the European Union Emission Trading System (EU ETS) was extended and adopted to cover, as of January 2024, GHG emissions from all large ships (of 5,000 gross tonnage and above) entering European Economic Area ports, regardless of the flag they fly (EU, 2023b). Shipping companies will have to purchase and surrender EU ETS emission allowances for each tonne of reported GHG emissions in the scope of the EU ETS system, which will cover carbon dioxide (CO_2) as of 2024 and additionally methane (CH_4) and nitrous oxide (N_2O) as of 2026.

Shipping companies will have to surrender allowances for a portion of their emissions only during an initial phase-in period: for 40% of their verified emissions as of 2024, for 70% as of 2025 and for 100% as of 2026. It should be noted that the EU ETS extension to maritime covers Tank to Wake (TTW) emissions. Special considerations are also made for sustainable biofuels.

Emissions from maritime transport are included in the overall ETS cap, which defines the maximum amount of GHGs that can be emitted under the system. The cap is reduced over time to achieve an overall emission reduction of 61% by 2030 compared to 2005, so that all ETS sectors contribute to the EU's climate objectives. This will incentivise energy efficiency, low-carbon solutions and reductions of the price difference between alternative and traditional maritime fuels, therefore allowing the sector to actively contribute to the EU's decarbonisation goals. The EU ETS has been a crucial tool in the EU's efforts to combat climate change.

3.1.2 FuelEU Maritime Regulation

The FuelEU Maritime Regulation (EU, 2023d) on the use of renewable and low-carbon fuels in maritime transport entered into force on 1 January 2025. The Regulation aims to increase the use of low and zero carbon fuels in maritime transport, by requiring a progressive reduction of GHG intensity of the energy used on board ships above 5,000GT calling at EU ports. The yearly average GHG intensity of the energy used on board ships (measured in gCO_2eq/MJ) will have to reduce by a minimum of 2% in 2025 and 6% in 2030, following in five-year steps up to 80% by 2050. Reductions are required to be measured from a reference value calculated on the basis of data reported under MRV for 2020 ($91.16gCO_2eq/MJ$).

In addition, the Regulation includes specific incentives for the introduction of renewable energy in shipping, through the uptake of renewable fuels of non-biological origin (RFNBO). A sub target of 2% for RFNBOs will be applied from 2034, if the uptake of these fuels by 2031 is below 1% of the total used.

The Regulation rewards ships using RFNBOs by doubling the use of such fuels when calculating the GHG intensity of the energy used onboard for compliance with FuelEU until the end of 2033. It is based on a life cycle, Well-to-Wake methodology accounting for emissions in production, distribution and use of these fuels onboard ships. In addition to CO_2 emissions, methane (CH_4) and nitrous oxide (N_2O) emissions are accounted for in the total CO_2-equivalent calculation.

Setting the eligibility criteria for fuels contributing to GHG intensity reduction is key to the proper implementation of the regulation. The Renewable Energy Directive (RED) is the main reference for certification. The Regulation will also mandate the use of onshore power supply (OPS) for passenger ships and container ships above 5,000 gross tonnes in main EU ports from 1 January 2030 (and in all ports that develop such capacity from 1 January 2035). Zero-emission technologies as alternatives to OPS will also be allowed.

3.1.3 Alternative Fuel Infrastructure Regulation

The new Alternative Fuels Infrastructure Regulation (AFIR) (Regulation (EU) 2023/1804) has three main objectives: (1) to ensure that there is sufficient infrastructure network for the (re)charging and (re)fuelling with alternative fuels, (2) to provide alternatives to fossil fuel-powered engines for vessels at berth, and (3) to ensure that the infrastructure is operational and user friendly.

It requires Trans-European Network (TEN-T) maritime ports to install electricity supply to serve the demand of at least 90% of containerships and passenger ships above 5,000GT calling at that port, by 1 January 2030. This requirement applies specifically to ports with port call thresholds of 100, 40 and 25 port calls/year, for containerships, passenger ferries and cruise ships respectively. In addition, AFIR requires designated ports to provide an appropriate number of refuelling points for liquified methane since January 2025, as well as to develop and submit plans for the deployment of hydrogen, methanol and ammonia refuelling points (EU, 2023c).

3.1.4 Renewable Energy Directive

A new Renewable Energy Directive (RED III) was adopted to allow Member States to choose one of two binding targets applicable to the overall transport sector (EU, 2023a). The first target aims to reduce by 14.5% the GHG intensity of transport fuels from the use of renewables by 2030, while the second target aims to achieve an absolute rate of 29% of renewable energy in final energy consumption across all transport sectors by 2030. The revised Directive also includes a renewable energy target of 42.5% by 2030 to which maritime transport can contribute, representing an increase of 28.5% from the previous binding target of 14%.

Other binding targets include a combined sub-target of 5.5% of advanced biofuels and renewable fuels of non-biological origin (RFNBOs), with a minimum level of 1% for RFNBOs. Furthermore, RED III includes a first-ever indicative target of 1.2% of renewables in the maritime transport fuels sector. It also limits the amount of energy supplied to maritime transport to 13% of the Member State's gross final energy consumption. This applies to both GHG intensity reduction and the renewable energy share in transport.

3.1.5 Energy Taxation Directive

The revision of the Energy Taxation Directive, which was first published in 2003, aims to align the taxation of energy products with EU energy and climate policies. It promotes clean technologies and removes outdated exemptions and reduced rates that currently encourage the use of fossil fuels. Under the proposal for the revised Directive launched in 2021, which is still to be finalised, marine fuels used by maritime transport will no longer be fully exempted from energy taxation for intra-EU voyages in the EU. Other revisions include measures to avoid the double taxation of stored electricity or the recognition of hydrogen as an energy product (EP, 2021).

3.2 Climate neutral energy solutions

3.2.1 Biofuels

The drop-in characteristics of biofuels offer an attractive solution for quick adoption by the existing fleet, however most of them are not CO_2-neutral on a well-to-wake basis. Their ease of use without substantial modifications to engines, fuel tanks, fuel pumps or fuel supply systems, along with the possibility to blend them with fossil fuels makes them relevant in the context of meeting initial gradual decarbonisation targets.

The shipping sector will have to compete with other sectors in terms of future demand, similarly to other alternatives. The competition for biomass is expected to grow after 2030. This will result in price rises, which could make biofuels an unattractive option for shipping. In addition, projections of the amount of sustainable biomass are uncertain. There are also concerns regarding availability and the capacity to scale up the necessary biofuel production to reduce shipping GHG emissions.

With a view to mitigating the risk of excessive pressure in terms of indirect land use and deforestation, FuelEU includes a safeguard against the use of food and feed crop biofuels. This instead promotes advanced biofuels and waste or advanced RED Annex-IX feedstocks. Estimates suggest the available feedstock biomass for 2030 is between 7.3 and 18 EJ. For 2050, the estimation is between 7.0 and 19 EJ (EMSA, 2023d). It should be highlighted that the global energy demand from shipping in 2018 was approximately 14 EJ (IMO, 2020a). This is expected to rise in line with increased demand for maritime transport volumes.

Biofuels with greater promise for use in shipping can be ranked on sustainability, availability, technology readiness level (TRL) for production, suitability and projected costs. The most promising are bio-methanol, Fischer-Tropsch (FT) diesel, biomethane from digestion of waste and residues and dimethyl ester (DME).Fatty acid methyl esters (FAME) from fat, oil or grease feedstocks (FOG) and biomethane from gasification could also be suitable options. FAME from vegetable oils, hydrotreated vegetable oils (HVO) from FOGs or from vegetable oils are perhaps less promising.

3.2.2 Methanol

Methanol is well suited to internal combustion engines, gas turbines and fuel cells and it is easier to store compared to the other alternative fuels. The Internal Combustion Engine (ICE) technology currently available and under development makes it an attractive alternative for retrofits as well as new builds. Several retrofitting solutions are being developed to adapt existing engines to dual-fuel engine for operation on methanol. These include: the MAN project, which is developing four-stroke engine retrofits; the FASTWATER project, developing and demonstrating retrofit kits for dual fuel ICE engines (FASTWATER, 2020); and the Horizon Europe (HE) project SYNERGETICS – set to end in 2026 – which will compare two different methanol retrofits in a test environment with respect to a range of performance parameters (SYNERGETICS, 2023). The outcome from first phase of the Green Maritime Methanol (GMM) project has already been presented, which is a feasibility study on the application of methanol as a marine fuel which showed it to be viable from technical and operational perspectives. The second stage of the project, GMM 2.0, aims to bring the technology to higher technology readiness levels (TRL 5/6 to TRL 7/8) (Green Maritime Methanol, 2024). The MENENS project, a Joint Industry Project (JIP), is also working on the adoption of methanol as an alternative energy carrier to reduce emissions from the Dutch shipping industry (MENENS, 2024).

Methanol is widely available and there is a well-developed supply chain in place as it is used extensively in the chemical industry. It is available in over 100 ports worldwide as a commodity. Although ethanol has physical properties that are like methanol, the latter is simpler to produce and is therefore expected to be significantly cheaper (currently there is no vessel burning ethanol). While methanol prices are influenced by factors distinct from other maritime fuels, it can be a competitive alternative to conventional fossil fuels, offering shorter payback periods compared to other alternatives.

A wide set of ship types are exploring methanol, such as tugboats. For example, the Zero Emission Waterborne Transport (ZEWT) partnership has set the objective to demonstrate by 2030 the integration of safe storage and maintenance guidelines as well as state-of-the-art power conversion technologies, both on newbuilds and retrofits (WATERBORNE, 2021).

3.2.3 Hydrogen

Hydrogen (H_2) fuel is a new feedstock for production of other types of fuels and chemicals. It can be used directly as a fuel or clean-energy source. While shipping has limited experience using hydrogen as a fuel and some of the key technologies (such as engines) remain under development, there is sufficient land-based experience with its production and use that would serve as a sound basis for its transition to a marine fuel. However, there are some barriers, such as hydrogen's low energy density (around four times less than marine diesel) which would increase the storage needs onboard a ship or the frequency of bunkering, the cost of the equipment and significant need to expand the global capacity to distribute and produce green hydrogen.

Currently, hydrogen is produced using fossil energy carriers, mostly natural gas in steam reformers. In the future, hydrogen can be expected to be produced on larger scale using renewable energy. There are different production pathways for green hydrogen: electrolysis (using renewable electricity), direct solar hydrogen production, biomass fermentation and thermochemical biomass conversion. Currently, the global production of green hydrogen is less than 0.1 million tonnes per year. Comparatively, the current global energy demand of international shipping is estimated to be about the equivalent of 95 million tonnes hydrogen per year.

Well-to-Tank GHG emissions of green hydrogen produced by means of water electrolysis are expected to be close to zero except for leaks from the supply chain. Additionally, the combustion of green hydrogen does not directly generate GHG emissions but only as a result from the combustion of pilot fuels required to start the combustion of hydrogen if used in an internal combustion engine ([38]). H_2 has a Global Warming Potential (GWP) estimated to be between 6.4-15.3 at 100 years and

([38]) However, in case a net zero carbon fuel is used as a pilot fuel, GHG emissions can be eliminated on well-to-wake basis.

between 19.7-44.1 at 20 years. This is mainly due to its reaction with radicals in the upper atmosphere, resulting in a prolonged atmospheric lifetime of other GHGs such as CH_4 as well as to the perturbation of tropospheric ozone and stratospheric water vapour (Frazer-Nash Consultancy, 2022; Warwick et al., 2022).

Using hydrogen in an internal combustion engine only emits a limited amount of Particulate Matter (PM), and does not emit sulphur dioxide, carbon monoxide, heavy metals, hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs). Hydrogen combustion can lead to the thermal formation of nitrogen oxides (NOx). NOx emissions can be controlled through primary measures such as the optimisation of the combustion process. Aftertreatment systems like Selective Catalytic Reduction (SCR) devices can also reduce NOx emissions, yet may lead to the production of other GHGs such as N_2O.

Storing hydrogen can be technically challenging too, largely depending on the specific ship general arrangement. Compressed gas storage suffers from low storage densities even at high pressures, while liquid hydrogen must be stored in specialised, highly insulated or vacuum-insulated tanks (EMSA, 2023b). Another issue is the energy consumption from pressurization and cooling of the stored hydrogen, reducing the energy efficiency of this fuel pathway. The storage capacity of hydrogen, in either liquid or compressed state, will be a challenge for certain ship types. Vessels plying short-sea routes – primarily coastal vessels – have the potential to adopt hydrogen as a fuel because of their frequency of port calls. Bunkering would also support lower bunker capacities once hydrogen-bunkering infrastructure becomes available.

Other major concerns related to hydrogen as marine fuel are its wide flammability range, leakage potential, ability to permeate through a large range of metals, flame speed and detonation/deflagration issues. In addition to the use of hydrogen bunkered and stored in its hydrogen form, to avoid the foresaid challenges posed by hydrogen at those stages, other hydrogen-based compounds like ammonia, methanol and other liquid organic hydrogen carriers are being explored as hydrogen carriers for maritime uses.

3.2.4 Synthetic fuels

Synthetic fuels are a group of compounds and an interesting option for the replacement of traditional fuels. Novel technologies have created two main classes of synthetic fuels: renewable fuels of non-biological origins (RFNBOs) and electro-fuels (e-fuels). They mimic the chemical-physical characteristics of typical fossil fuels, but are produced with no biomass, renewable or non-fossil feedstocks. This new type of energy source has been studied to potentially offer medium- and long-term marine fuel alternatives. Even more so than other alternatives, these types of fuel can reduce carbon output to zero (or very close to it) and are only paralleled in this regard by waste biofuels and blue synthetic fuels with carbon capture, utilisation and storage (CCUS).

Fuels produced using renewable sources other than biomass include diesel, methanol, ammonia (NH_3), hydrogen (H_2), liquified petroleum gas (LPG), dimethyl ether (DME), compressed natural gas (CNG), ethane, and ethanol (IMO, 2023c). Similarly, the FuelEU Maritime Initiative (EU, 2023b) mentions e-diesel, e-methanol, e-LNG, e-H_2, e-NH_3, e-LPG, and e-DME. The majority of these fuels are commonly composed from a mixture of synthetically assembled/synthesised hydrocarbon (Hydrogen and Carbon) molecules. Possible production pathways for renewable hydrogen are (from most to least promising): electrolysis, artificial photosynthesis, solar power and microbial electrolysis. Renewable CO_2 is obtained through the capture of CO_2 from the processes of direct air capture (DAC) and oceanwater capture.

Synthetic fuels offer the potential for high decarbonisation and have been estimated to have a GHG emission reduction of 94% including manufacturing emissions (Concawe, 2022). Nevertheless, both RFNBOs and e-fuels pose several risks, such as methane evaporation and hydrogen leakage, which could account for possible increases in GHG emissions (EMSA, 2024b). Other concerns refer to the various pathways used for the generation of renewable electricity, including the energy conversion process, land and sea surface area used and potentially polluting waste. In fact, large-scale operations would need considerable growth in renewable electricity plants, electrolyser, DAC plants and e-fuel synthesis plants.

While the scale of production of renewable electricity is predicted to follow the growth of this large-scale production, the bottleneck is expected to be the capacity to perform DAC. Global renewable electricity production worldwide could be large enough to enable the global fleet to use e-fuels by 2030. DAC capacity is not expected to be able to realise the same growth. In addition, the shipping sector will not be the only sector needing and using renewable electricity, green hydrogen and renewable carbon dioxide; it will have to compete with other sectors, with direct uses such as electric road vehicles and electric boilers and furnaces.

There seem to be enough suitable locations at which renewable electricity can be produced and meet global energy consumption standards, however there is still a limit on the capacity of countries and economies to build solar and wind parks, conversion systems and transport and distribution infrastructure.

Overall, the challenge with DAC seems to be a lack of technology and knowledge. For example, DAC technology is currently considered 'non-mature' and almost none of the e-fuel production pathways are therefore considered technologically advanced enough to enter the market (e-methanol and its point source carbon capture is a notable exception). There is also lack of information on the potential effects of e-fuel spills on the environment, which adds to the uncertainty regarding their usage.

3.2.5 Ammonia

Anhydrous ammonia (NH_3) has been identified as a potential alternative fuel, particularly for deep sea cargo vessels. It faces substantial safety concerns due to its toxicity, however, as well as knowledge gaps. In particular, NOx emissions are expected to be high, requiring the widespread adoption of more advanced aftertreatment technologies such as SCR systems. Moreover, nitrous oxide (N_2O) emissions arising from combustion are significant, questioning the overall benefit from a climate perspective. The issue is further complicated as aftertreatment systems to control NOx also emit N_2O through secondary reactions on the catalytic units. Unlike NOx emissions for which commercial aftertreatment systems such as SCR units are already widely available, N_2O is more difficult to convert. No widespread solution is currently available to control its release in the atmosphere.

Additionally, the detrimental effects of ammonia slip resulting from incomplete combustion in the engine and the catalytic process on SCR units must be taken into account (Boretti, 2017; Chiong et al., 2021; Pedersen et al., 2023; Reiter and Kong, 2011; Zhou et al., 2024). Presently, no limits for such slip exist in the maritime sector. This concern needs to be addressed throughout the whole supply chain, as any slip, leakage or spill could lead to issues such as eutrophication, acidification and emissions of potent GHGs (Kanchiralla et al., 2023), which also contribute to stratospheric ozone depletion (Bertagni et al., 2023). Even releases of 0.4% of the nitrogen in ammonia as N_2O into the environment would nullify the climate benefits gained from the fuel uptake/switch (Wolfram et al., 2022).

Although concerns are still high and further research is needed in this area, on a Tank-to-Wake basis ammonia is essentially zero-carbon. Whereas e-ammonia offers a potential climate neutral solution on a Well-to-Wake basis, grey ammonia (produced from fossil methane or coal) is a worse climate solution than conventional fuel oils.

The ammonia production industry has announced a total of 112 projects aimed at producing green and blue ammonia (predominantly green), with a total production of 182Mt/year globally. These projects have a completion duration between two and 24 years. Most of the projects (96%) aim to be completed within 10 years from the announcement to build the plant. If all plants were to be completed on time, their production capacity would be 146Mt/year in 2030. The projects are distributed globally. About 33% of the production is planned in Oceania, 28% in Asia, 20% in Africa, 9% in North America, 7% in South America and 3% in Europe.

Green ammonia for shipping fuel is targeted by 16 projects in 6 countries with combined output of 16.6Mt/year. AREH in Australia is the largest project with 9.9Mt/year (~60% share), while the remaining fifteen projects have yearly output 0.1-1.5Mt/year. In Europe, there are projects in Norway, with four projects amounting to 0.8Mt/year and Germany, with one project of 0.1 Mt/year. In the most realistic scenario, out of the 182Mt/year projected, 33Mt/year is estimated to be available in the most realistic scenario, of which 11Mt/year would be blue.

The estimated final energy demand of global maritime shipping is projected to be between 12.1 to 14.2 EJ in 2030 and between 10.2 to 23.2 EJ in 2050 (EMSA, 2023d; IMO, 2020). This projected energy demand is much higher than current green development plans for green ammonia, which are a mere 5Mt/year. Assuming that the current production of grey ammonia (around 235Mt/year) is converted into green ammonia, production still it would need to increase by a factor of 3-4 to support the demand. Against this, it is possible to try and assume the required production capacity of renewable electricity. With an electrolyser efficiency of 65% and an electricity use from the ammonia synthesis process of 640 kWh per tonne of ammonia, 5,800 to 9,800 terawatt hours (TWh) of renewable electricity would be needed in 2040 to enable the complete switch of global maritime shipping to green ammonia. This level of demand is in the same range as current global renewable electricity production. The worldwide renewable electricity production in 2018 was about 6,600TWh, 63% of which was from hydropower, 19% from wind, 8% from bioenergy, 9% from solar, and 1% from geothermal (IRENA, 2020). Global renewable electricity production is projected to be 15,000-30,000 TWh in 2040, indicating that production is expected to increase by a factor of 2 to 5 between 2018 and 2040 (EMSA, 2023b). These volumes would be sufficient to produce 600 to ,1,000Mt/year of green ammonia for the maritime sector. A large share of the renewable electricity produced will also feed into the power grids to supply worldwide demand for electricity.

3.2.6 Wind propulsion

Wind propulsion systems (WPSs) have been identified as a technology that offers a reduction (and in some cases alternative) to fuel consumption and consequently reduces GHG emissions from shipping. Wind propulsion systems are designed to transform wind energy into ship propulsion power. WPS can be used to replace partly (or depending on the system to a large extent) the main engine power by wind power. If adequately used and suitably designed for the operating profile of the ship, this can contribute to a reduction of a ship's GHG emissions, air pollution and underwater noise emissions. Replacing main engine power translates to less fuel consumption and corresponding energy used or emissions for the same transportation work. The FuelEU Maritime Regulation rewards ships using wind-assisted propulsion systems, which are effectively considered a zero-emissions energy source through rewarding factors in the calculation of the energy GHG intensity.

The actual reduction of the fuel consumption that can be achieved by means of WPSs depends on a variety of factors, ranging from technological to environmental factors but also on how a ship is operated. This creates some uncertainty when it comes to assessing the effectiveness of the systems in general. As an example, the speed of the vessel has an impact on the potential savings. In general, a higher vessel speed leads to lower per voyage savings. Container ships, passenger ships, Ro-Ro cargo and refrigerated cargo ships sail relatively fast. This does not mean that the use of WPSs cannot be profitable for those ships, but the payback time of the investment into a WPS may be expected to be comparatively longer. Also, the higher the percentage of main engine power compared to auxiliary power, the higher the potential for savings. Looking at the WPS from a different perspective, the wind power can be used to add to the main engine power instead. Then the ship would be able to sail at a higher speed without increasing its fuel consumption. In this case, the use of the WPS would not contribute to a reduction of the fuel consumption but will also not increase it or its GHG emissions.

Most WPSs require deck space to be installed, though this is mostly the case for retrofitting and is less of an issue for newbuilds. The availability of deck space depends on the ship type and size. As an example, container ships and passenger ships have limited deck space available compared to for example bulk carriers or tankers. For ships with relatively little deck space, a kite or other innovative solutions could be an alternative option. For container ships, containerised WPSs have also been developed. Interference with cargo handling and on land infrastructure is another issue. This is tackled by foldable or tiltable solutions, which are very common. Such solutions also limit the undesired effects at high wind speeds. Additionally, there are some other placement criteria which must be fulfilled to allow for a safe and comfortable use of WPSs ([39]) (e.g. to avoid the creation of blind spots or placing WPSs next to a cabin on a passenger ship).

The weight of the devices varies significantly between the different types of WPSs, however the effect on the cargo capacity of the vessels will not be considered crucial. From a design viewpoint, the ship structure should allow for the safe transmittance of forces generated by the WPS onto the ship. This may require reinforcement of the ship in that area but this is not considered to be a technical barrier. The availability of wind will have an impact on the efficiency of WPS. This depends on the specific route, the route direction, the seasonal variations and the openness and closeness to land. To gain maximal efficiency from WPS, routes should be adjusted via route optimisation to find a balance between wind availability and route length. In addition, proper integration of WPS on board will also increase efficiency. WPS solutions have so far already delivered yearly fuel savings of between 5% and 9% for certain ships. The most promising technologies have reported higher potential energy savings: the CHEK project (CHEK, 2020) and the European Institute of Innovation & Technology's Bound4blue project (up to 30%) (Bound4blue, 2015). The Orcelle project is expected to demonstrate more than 50% energy gains in a Ro-Ro vessel by 2027 (Wallenius Wilhelmsen, 2022).

Other direct renewable solutions like solar or wave energy are being explored, either individually or combined, like wind-solar power systems (WSHPS) (e.g. Project WHISPER) (WHISPER, 2023).

([39]) These criteria are covered by Class guidelines, as described in EMSA (2023).

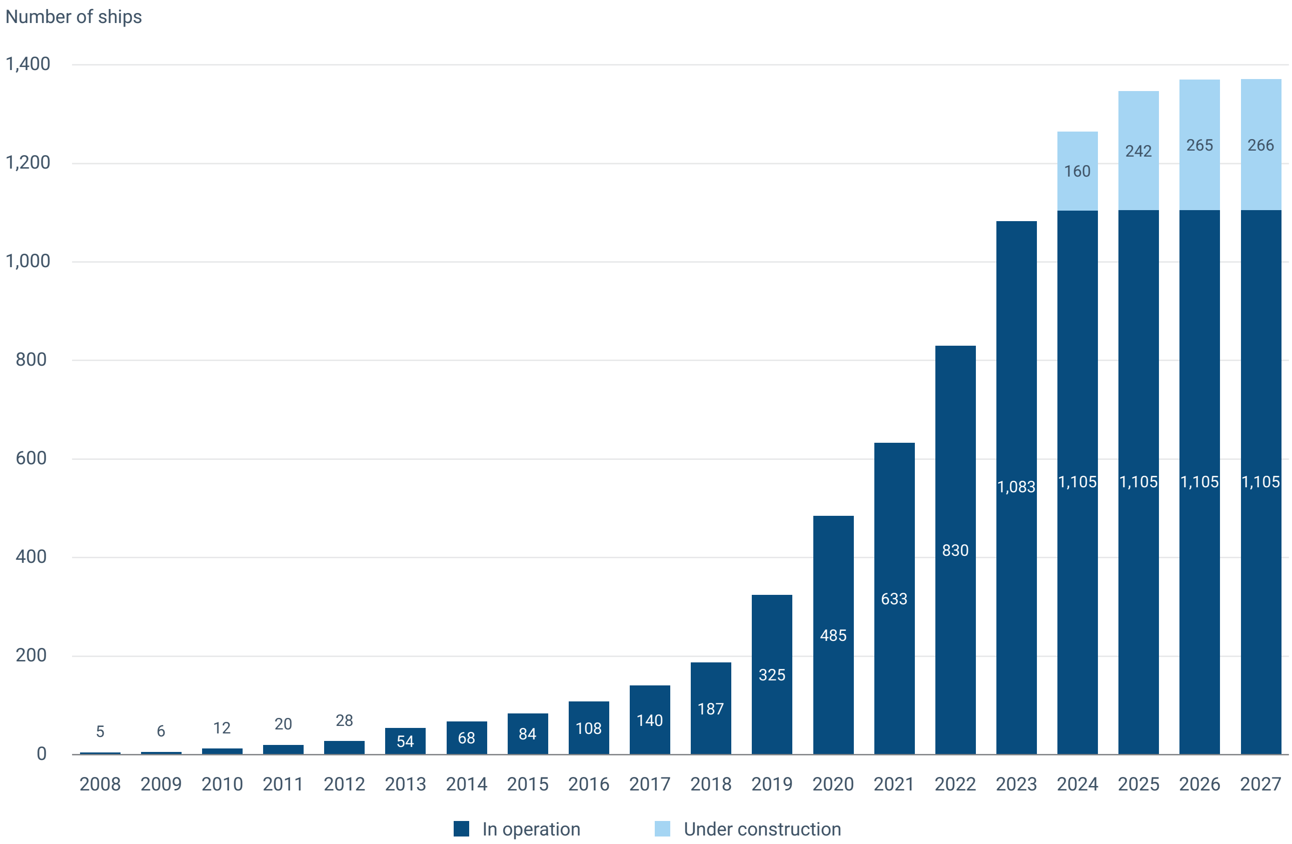
3.2.7 Batteries

Although batteries are commonly used on board ships, heavy-duty batteries of the kind needed for propulsion and energy can only be provided by traction batteries. Batteries can be used on all-electric ships, as part of hybrid electric solutions or even as a zero-emission technology for FuelEU Maritime Regulation compliance at berth. Current traction batteries are to a large extent based on lithium-ion (Li-ion) chemistry, however their low energy density remains one of the main challenges. The most promising technology on the horizon appears to be solid state electrolyte, which may have particular advantages for the maritime environment with regard to safety and energy density.

Currently, the entire maritime market to date comprises less than 1% of the total amount of lithium-ion batteries produced yearly and to some extent this explains the greater costs associated with introducing a marine battery system. In 2023 there were 1,083 ships with batteries in operation, with 160 already on order for 2024 (see Figure 3.1). Data from the European Alternative Fuels Observatory (EAFO) received in 2024 reveals a total of 257 ships in operation using batteries in the EU (plus a further 82 on order in 2023), the majority of which (110) are car and passenger ferries (EAFO, 2024).

The leading ship types using batteries are ferry ships, offshore supply and fishing vessels. Currently, most ships with batteries use hybrid systems.

Figure 3.1 Total number of ships with batteries and known construction projects for 2024-2027



Source: The ship register — Maritime Battery Forum, 2024.

The predictability and limited operational profile of ferry ships has made them the most suitable ship type for full electrification through the incorporation of battery energy storage systems. Examples include Ellen from the H2020 project E-FERRY (E-FERRY, 2020), currently operating at 22 nm or the 'MS Medstraum' from the H2020 project TrAM, the first fast ferry, operating at a typical cruising speed of 23 knots (TrAM, 2020). However, it is expected that more powerful and energy storage capacity will enable a wider set of ship types to fully or partially use batteries in the near future. This will require the implementation of currently unavailable fast, standardised, modular and scalable charging solutions. In parallel, swappable batteries are being explored (e.g. in the H2020 project CURRENT DIRECT or HE project SYNERGETICS (CURRENT DIRECT, 2020; SYNERGETICS, 2023)). Innovative grid architecture is also required to enable operational flexibility through the hybridisation of storage units.

3.2.8 Fuel cells

A fuel cell power pack consists of a fuel and gas processing system and a stack of fuel cells that convert the chemical energy of the fuel to electric power through electrochemical reactions. Different fuel cell types are available which can be characterised by the materials used in the membrane. The most common fuel cell types are the polymer electrolyte membrane fuel cell (PEMFC) and the solid oxide fuel cell (SOFC). In fact, planar SOFC systems seem to be the most energy efficient, as they allow for high fuel utilisation paired with high cell voltages (Blum et al., 2011). Furthermore, all fuel cells need a battery support to take up the peak loads. There are dynamic response differences between these two cell types. SOFCs have much lower response times than PEMFCs. Another differentiation between fuel cells is low versus high temperature fuel cells. The former only require pure hydrogen as a fuel, which produces CO- and sulphur-free waste. Alcohol fuels may also be used for on-site or on-board reforming at lower temperatures, giving the advantage of being ultra-clean and sulphur-free. Alternatively, high temperature fuel cells may use both H_2 and CO as fuels, which implies that: (1) fuel processing can be achieved in less steps, (2) there is the advantage of the availability of existing infrastructure of production, and (3) hydrocarbon fuels have higher energy density (Song, 2002).

Fuel cells may have useful applications also in connection to the FuelEU Maritime Regulation. An important element is that no air pollutants such as SOx or NOx are generated (or at least in negligible amounts), together with CO or particulate matter. In addition, no methane slippage is produced due to the almost immediate conversion of the molecule into hydrogen and CO_2. Finally, fuel cells can make use of advanced biofuels, RFNBO and recycled carbon fuels (RCF) which favours compliance with the RED targets while at berth.

The total shipment of fuel cells in 2015 amounts to 335MW, with the transport sector accounting for 178MW and the stationary sector for 157MW. The largest manufacturers are in South Korea and the United States, followed by Japan.

3.2.9 Nuclear propulsion

Nuclear propulsion has been identified as an alternative power system to help the shipping industry achieve net zero emissions. However, concerns over the inclusion of nuclear power in the merchant fleet are centred on the lack of sector-related policies and regulations, as well as safety risk concerns (both at sea and at port), high costs, stigma, lack of civil acceptance and potentially significant environmental impacts in case of accidents. In addition, there are also concerns around the management and final disposal of resulting radioactive waste. So far, few commercial ships beyond icebreakers have made use of nuclear propulsion systems (Raymond et al., 2022).

Various options using nuclear power have been identified: zero-emission ships using electrification methods, the direct use of micro or small modular nuclear reactors or the storage and transfer of energy to the vessels from onshore nuclear power plants located near ports. Moreover, one hypothesis suggests nuclear energy could be used as a cogeneration element to produce green fuels such as nuclear-based pathways for hydrogen, ammonia or methanol.

It may not be possible to convert or retrofit existing merchant ships into nuclear-powered ships. However, it seems that in the long run, nuclear power could become a financially viable option when compared to other proposed alternative fuels such as ammonia or hydrogen due to its high energy efficiency and overall low resource use (Bhattacharyya et al., 2023). This is provided safety and environmental risks associated with nuclear technology application to commercial maritime transport are duly assessed and mitigated.

There are three main types of nuclear reactor designs to be used onboard ships: the Pressurised Water Reactor (PWR), the Heat pipe and the Molten Salt Reactor (MSR) (Lloyds Register, 2023). Notably, the MSR stands out as the most likely to be implemented. It is a type of reactor developed in the 1950s that is starting to be tested onboard ships due to its small size and modular characteristic when compared with conventional reactors. Furthermore, other characteristics all improve operational safety, such as its high efficiency, low waste generation and more importantly low operation pressures. Operation temperatures are higher than in other reactors however, which may create further operational concerns (ANSTO, 2023; Bhattacharyya et al., 2023).

Challenges may include high corrosiveness of the molten salts used, elevated operating temperatures and possible damage to materials from high-energy particles created by the fission processes. The major concern of the MSR is the corrosivity of the molten salts as well as its impurities (the selection of materials is very important). Due to the chemical nature of the circulating salts, oxidation of the inner metal surfaces may not occur as in other types of reactor designs, leaving them less protected (Calderoni and Cabet, 2012; Roper et al., 2022). Training and regulation are other main topics of discussion in the sphere of nuclear power onboard ships.

3.2.10 Onboard carbon capture and storage

Carbon capture and storage (CCS) technology onboard vessels is currently being developed as an alternative or current solution, in the absence of mature applications for clean fuels as well as the uncertainty over whether demand could be met. CCS technology refers to the capture and separation of CO_2 from various sources and its conversion into other substances for further use or transport. CO_2 is collected, purified and used as a raw material in other industries or permanently stored under the land or ocean bottom (Wang et al., 2022).

Current research on carbon capture and storage mainly seems to focus on thermal power generation, coal chemical industry and cement production (Hua et al., 2023). The uniqueness of onboard CCS for the shipping industry results from the fact that there is limited space to utilise on board the ship. Furthermore, the design and placing of the CO_2 storage tank on board the vessel must be taken into consideration in parallel to the ship's characteristics (power limitations, operational patterns, etc.). Space availability should also be compared with the need for that space, especially when comparing this technology to other alternative fuel options. Stability needs to be checked as issues may also arise due to the nature of ships constantly sailing offshore.

The capture and storage of CO_2 onboard ships may require a specialised fleet, as the substance is liquefied and stored in tanks before being loaded onto ships for transport. Moreover, waste generated from CCS will require specific handling and disposal. Ships transporting CO_2 can adopt a semi-refrigerated type, in which the optimal pressure of the storage tank should reach 1.5MPa and the temperature should be about -27°C (Seo et al., 2016). Currently, the fleet of ships transporting CO_2 globally is not numerous, mainly serving the food processing and beverage industries.

However, seeing that the technology is mature and has been practised for more than 30 years, several large CO_2 carriers are being built, including orders from Solvang (Maritime Executive, 2024), Northern Lights (Riviera, 2023b) and Capital Maritime (Riviera, 2023a). These will increase the scale of CO_2 transportation onboard ships, as capacity will go up to 22,000m^3. Considering that CO_2 would have similar characteristics to LNG and LPG, it is safe to say that LPG and LNG carriers could be considered suitable for CO_2 transportation through the retrofitting of existing infrastructure onboard ships. Estimates suggest the capacity of CO_2 transportation by a single ship can reach 10,000–100,000 tonnes (Brownsort, 2015).

Regarding safety issues, the storage of CO_2, both gaseous and liquid, poses certain risks. If liquid CO_2 leaks, the cryogenic gases could cause damage to the ship structure or crew. Besides, if the liquid CO_2 tank encounters high temperature, the gasification will increase the pressure in the tank and there is a risk of explosion. This puts forward higher requirements for CO_2 purity, CO_2 storage tanks and sealing systems.

3.2.11 Onshore Power Supply

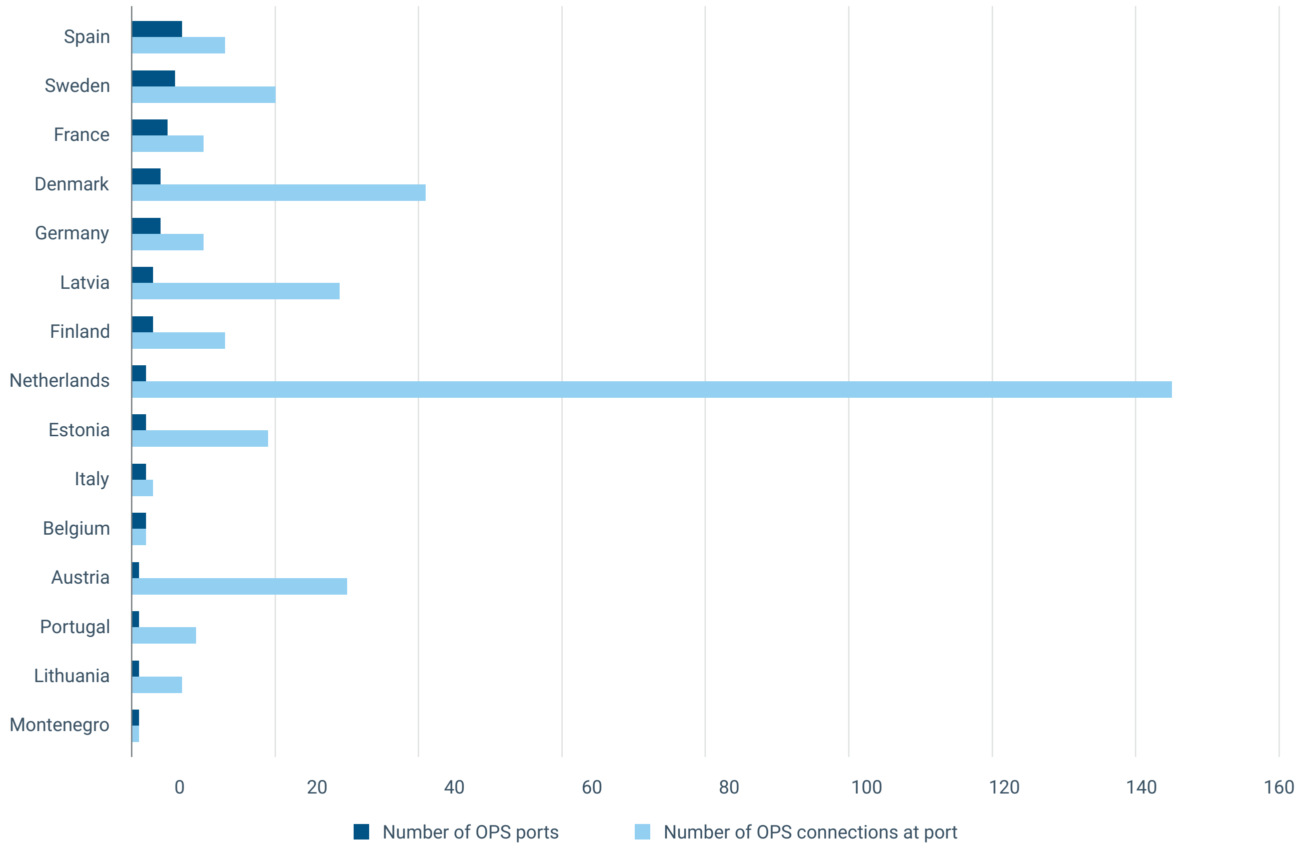
A limited number of ships in the world are equipped with the necessary elements for high-voltage (Onshore Power Supply) OPS, with the European Alternative Fuels Observatory (EAFO) reporting this number to be 33 ships (EAFO, 2024). In the EU, there are three container ships, nine cruise ships and 15 Ro-Pax ships calling at ports equipped with high-voltage OPS.

In addition, there are ships designed and built as 'OPS ready', preparing them for a simplified conversion once the decision to retrofit OPS equipment is made. The elements provided in OPS-ready ships are typically space-related, allowing room for growth not only in the ship's general arrangement and the specific structural spaces for cable routing but also in the main switchboards.

According to the EAFO, at least 44 ports from 15 EU Member States have already implemented onshore power connections. This means that at present, there are 352 berths with available shore-to-ship power supply facilities in the EU (see Figure 3.2).

For the cruise sector, in Europe as per April 2023 there were 6 ports with at least one berth with OPS, four already funded and 14 planed. Furthermore, according to the CLIA *State of the cruise industry* report, 30% of ships which represent 40% of capacity are plug-ready and 30% are to be retrofitted (CLIA, 2023).

Figure 3.2 European ports and number of berths with OPS connection



Note: OPS, Onshore Power Supply

Source: EAFO, 2024.

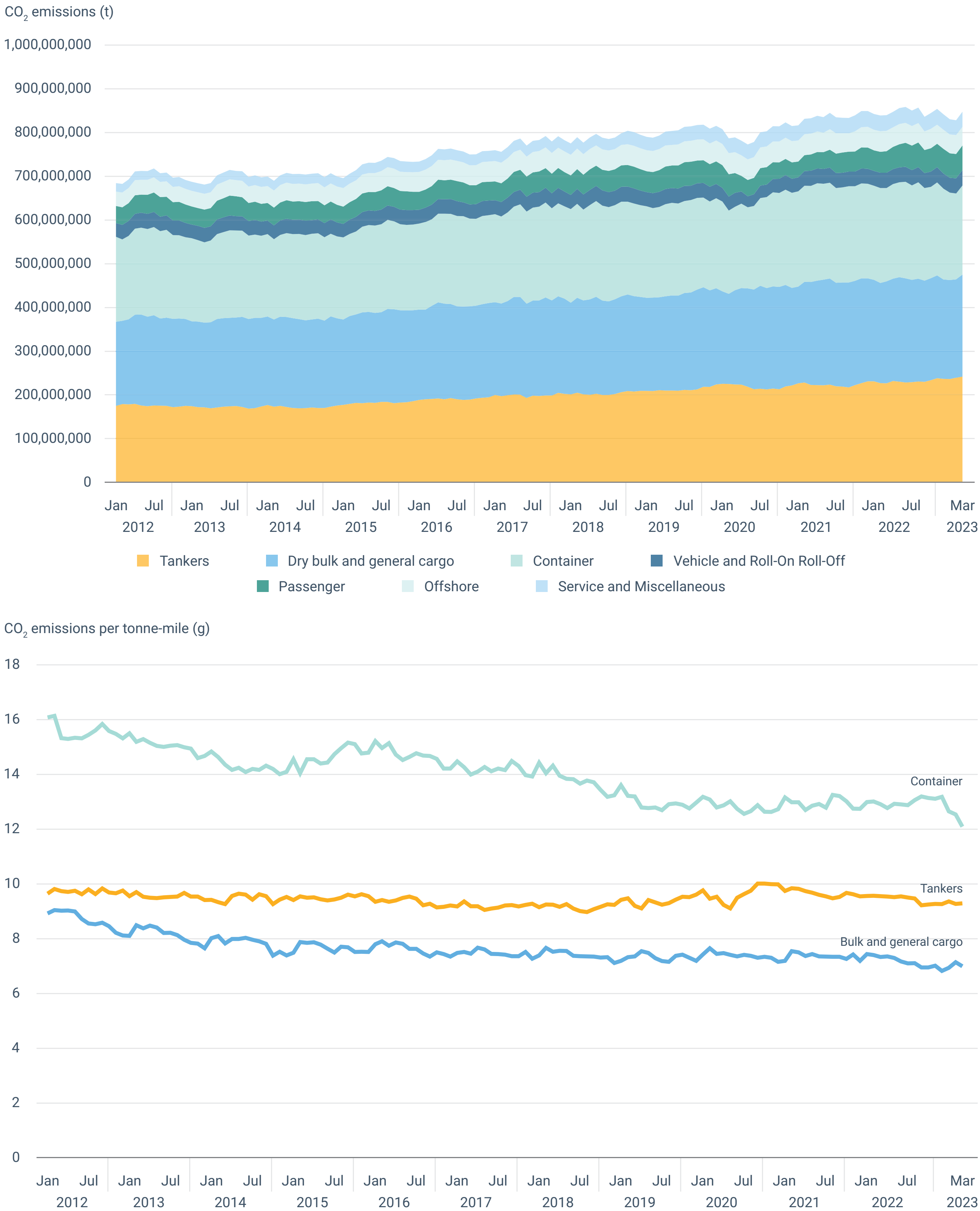
3.3 Energy transition foresight

3.3.1 CO_2 emissions outlook

While shipping is considered one of the least carbon intensive modes of transport, it emits 3-4% of all EU CO_2 emissions. These are projected to grow quickly if mitigation measures are not swiftly introduced (EC, 2023c). CO_2 emissions from fuel sold in the EU for international navigation have increased by around 36% since 1990, contrary to domestic navigation emissions that have decreased by 26% over the same period. Today, CO_2 emissions from international navigation represent close to 90% of all EU seaborne navigation emissions and according to projections, these could grow by around 14% between 2015 and 2030 and 34% between 2015 and 2050 in a business-as-usual scenario (EU, 2023f).

Despite the marked increase in ambitions, CO_2 emissions have increased every year since the Paris Conference of Parties (COP) in 2015 (except for the 2020 pandemic year) (IEA, 2021). A report published by the Getting to Zero Coalition and commissioned by the World Economic Forum (WEF, 2021) examines multiple ways to reduce GHG emissions from shipping. This includes reducing demand for shipping, increasing the energy efficiency of the sector to reduce use of fossil fuels and reducing the GHG intensity of shipping's fuels. A more recent report by the United Nations Convention on Trade and Development (UNCTAD) shows that while the total emitted CO_2 from the sector is still growing at the global level, the emissions per ton-mile for the three top emitting ship types are decreasing (see Figure 3.3) (UNCTAD, 2023). Although achieving further reductions in energy demand (and therefore in CO_2 emissions) is possible through increased energy efficiencies, sustainable fuels are also necessary.

Figure 3.3 **Total CO_2 emissions per ship type, 2012-2023 (above); CO_2 emissions per tonne-mile for world fleet monthly three main ship types, 2012-2023 (below)**

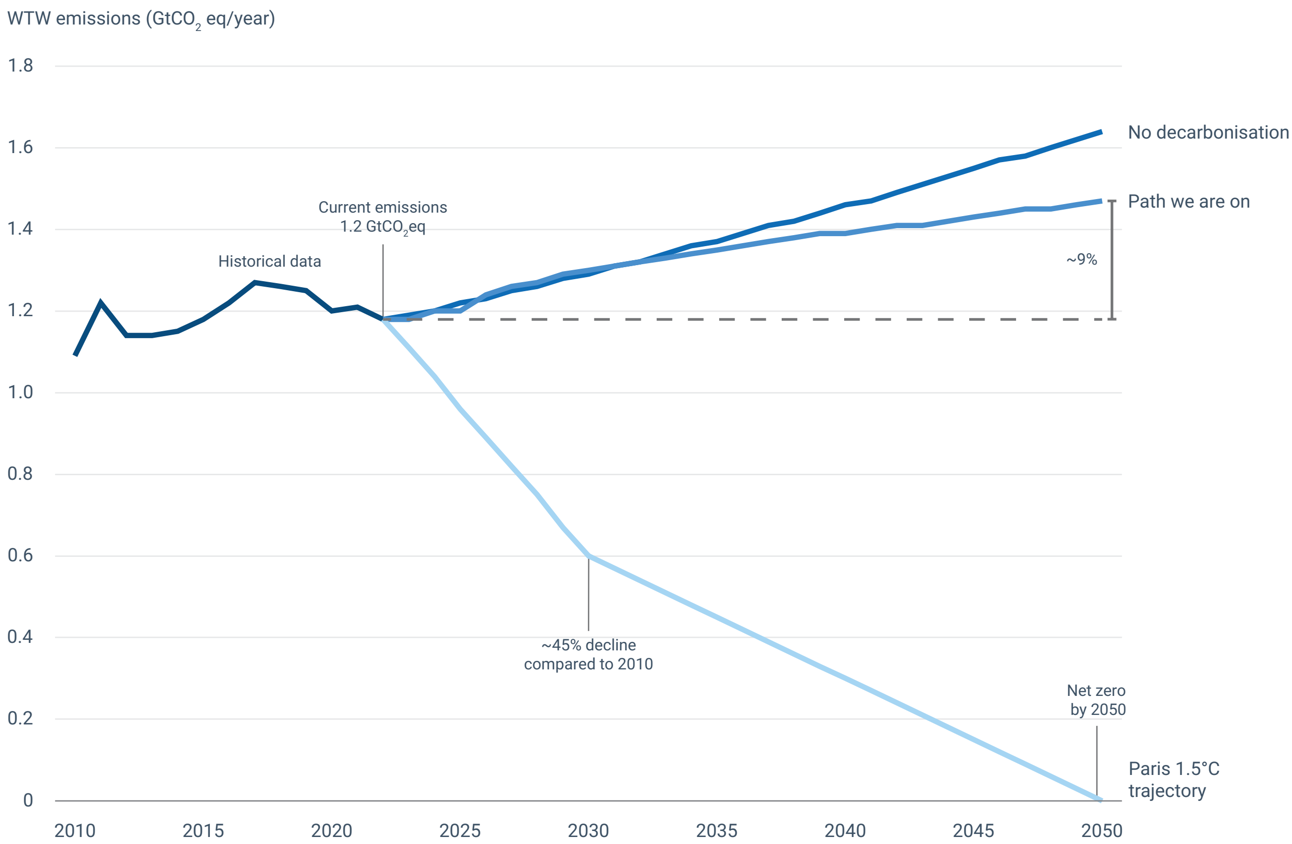


Source: UNCTAD, 2023.

The Maritime decarbonisation strategy published by Maersk Mc-Kinney Moller Centre for Zero Carbon Shipping (MMMCZCS) in 2022 (prior to the agreement on the revised IMO GHG strategy), analysed Well-to-Wake (WTW) emissions under different scenarios (MMMCZCS, 2022). The report estimated the hypothetical scenario of reducing emissions by 45% in 2030 (compared with 2010). That scenario would require limiting the fossil fuel consumption to approximately 6EJ of the total energy demand from the global fleet (the estimated energy demand by the global fleet is projected to be 12.1 to 14.2EJ in 2030) (see Figure 3.4).

Aside from reducing activity in the sector, this can be achieved by implementing energy efficiency measures and replacing fossil fuels with low-emission alternative fuels. In other words, limiting the sector emissions requires using both less and greener fuels.

Figure 3.4 **Emissions based on IPCC global trajectory, and showing scenarios for: no decarbonisation, business as usual and Paris 1.5 trajectory**



Notes: WtW $GtCO_2$ eq/year, Well-to-Wake Gigatonnes of CO_2 equivalent per year.

Historical data is based on the Third IMO GHG Study and Fourth IMO GHG Study. 'Path we are on' is based on MMMCZCS data and analysis as described in the ITS 2021

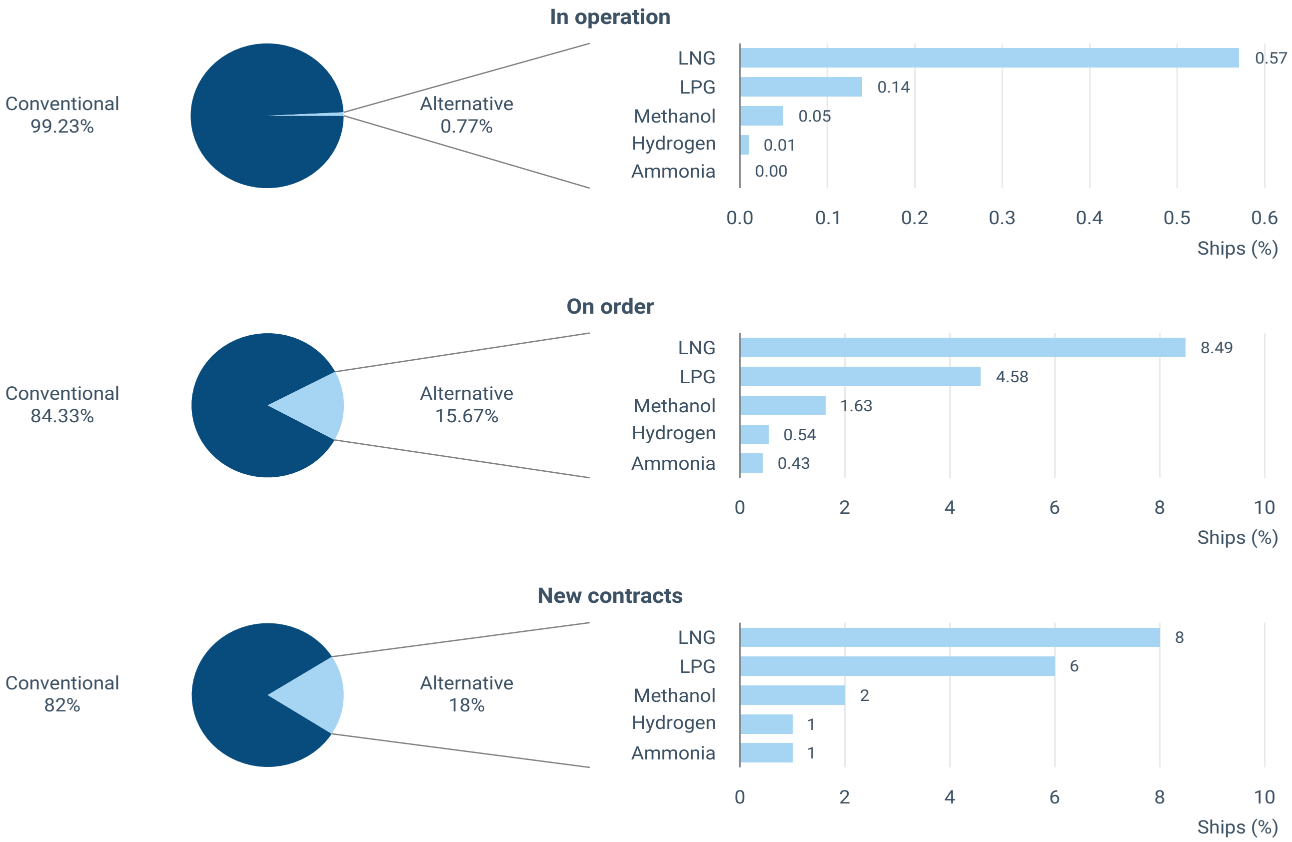
Source: MMMCZCS, 2022.

3.3.2 Roadmap to energy transition in 2030 and 2050

The 2023 IMO GHG strategy (IMO, 2023) stipulates that international shipping should reduce the total annual GHG emissions by at least 20% by 2030 (striving for 30%), as well as reducing its carbon intensity by at least 40% compared to 2008. In addition, EU targets, included in the FuelEU Maritime Regulation and the new Renewable Energy Directive (RED III), set the maximum GHG intensity of the energy used on board ships to be 85.69 CO_2eq/MJ (from a baseline of 91.16 CO_2eq/MJ in 2020) by 2030. They also require 1% of the energy used on ships to be renewable fuels of non-biological origin (RFNBO) (i.e. synthetic fuels) by 2031.

The above targets already provide some important indications of the necessary adaptations the maritime industry must make in the coming decades. Global energy consumption of the shipping industry is approximately 14EJ/year (IMO, 2020a), equivalent to 3.2% of the global primary energy consumption of 442EJ/year (in 2022; IEA, 2023). To achieve the expected emission reductions and energy intensity expected from the IMO and EU provisions by 2030, fossil fuel consumption should be limited to approximately 11.28EJ of the total energy demand.

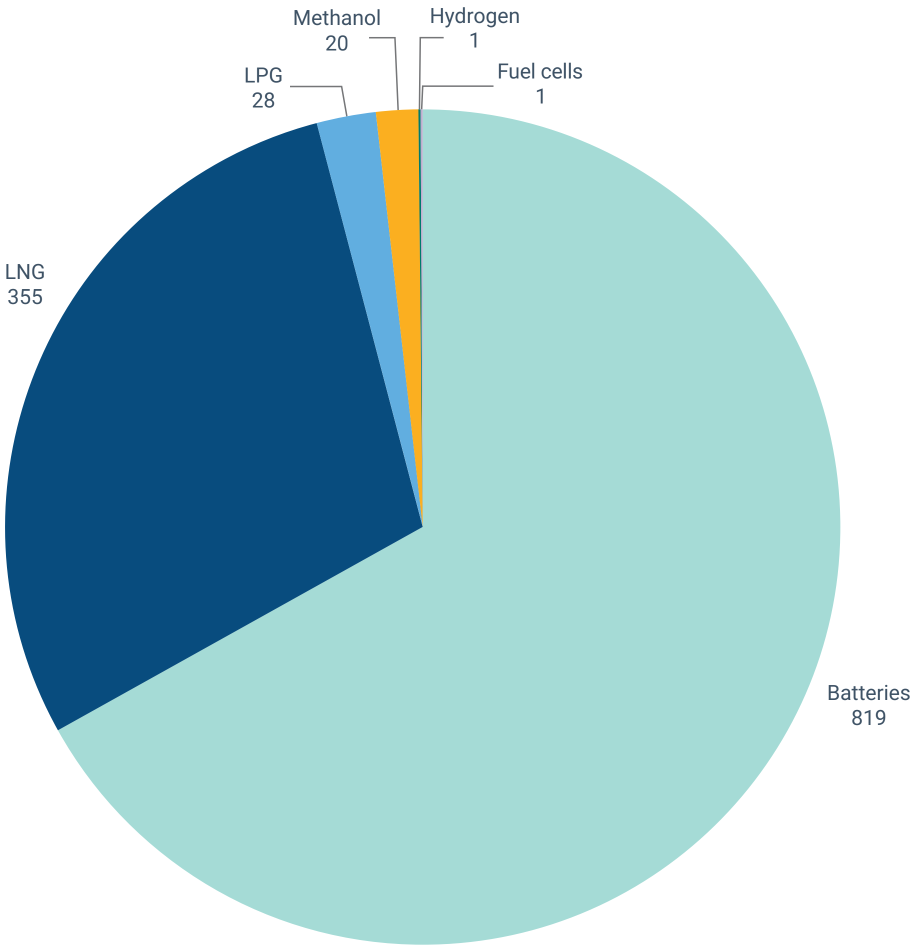
Figure 3.5 Percentage of global fleet using or capable of using conventional vs alternative fuels (in operation, or on order and regarding the new contracts) in 2023



Notes: LNG, Liquefied natural gas; LPG, Liquefied petroleum gas.

Source: DNV, 2023.

Figure 3.6 **Global number of vessels using or capable of using alternative fuels (in operation or on order)**



Source: EAFO, 2024.

RED certified sustainable biofuels with at least 65% less well-to-wake GHG emissions compared with fossil fuels can use reduced CO_2-emission factors. This, together with their drop-in characteristics, means that biofuels should become an immediate, attractive and cost-effective solution for the existing fleet.

The projections for the availability of sustainable biomass volumes vary considerably. Projections for 2030 forecast between 6.3 to 8.0 exajoules (EJ) of available biomass volume in the EU and increasing to 6.7 to 14.7 EJ by 2050. In 2030, maritime shipping is projected to consume 1 to 2.4% of the EU's potential biomass. Among the different biofuels, looking into their potential based on their sustainability, availability, technology readiness level (TRL) for production, suitability and projected cost, the most promising are bio-methanol, synthetic Fischer-Tropsch (FT) diesel, biomethane from digestion of waste and residues and Dimethyl ether (DME). In 2030, the total cost of ownership (TCO) of some biofuels (i.e. hydrotreated vegetable oil and FT) is at a similar level as the estimated TCO for a conventional marine fossil fuel oil. For the other biofuels, the TCO would still remain higher compared to marine fossil fuels, though clearly the difference would be lower than in 2022 (see Table 3.1).

Table 3.1 Comparison of biofuel cost developments

Fuel	Feedstocks	Cost 2030	Cost trend 2030-2050
FAME	FOGs (fats, oils and grease)	- €	Falling
FAME	Vegetable oils	- €	Falling
HVO	FOGs	V	Stable
HVO	Vegetable oils	V	Stable
FT diesel	Lignocellulosic biomass	V	Falling
DME	Lignocellulosic biomass	V	Falling
Methanol	Lignocellulosic biomass	- €	Falling
Ethanol	Sugar & starch crops	- €	Falling
Ethanol	Lignocellulosic biomass	V	Falling
SVO	Vegetable oils	- €	Stable
Pyrolysis bio-oil	Lignocellulosic biomass	-	Stable
HTL biocrude	Lignocellulosic biomass	V	-
Liquefield Bio Methane (LBM)	Waste and residues (digestion)	€€	Increasing
Liquefield Bio Methane (LBM)	Lignocellulosic biomass	V	Stable

Notes: * - €: lower than 2020 prices; V: similar to 2020 prices; €€: higher than 2020 prices.

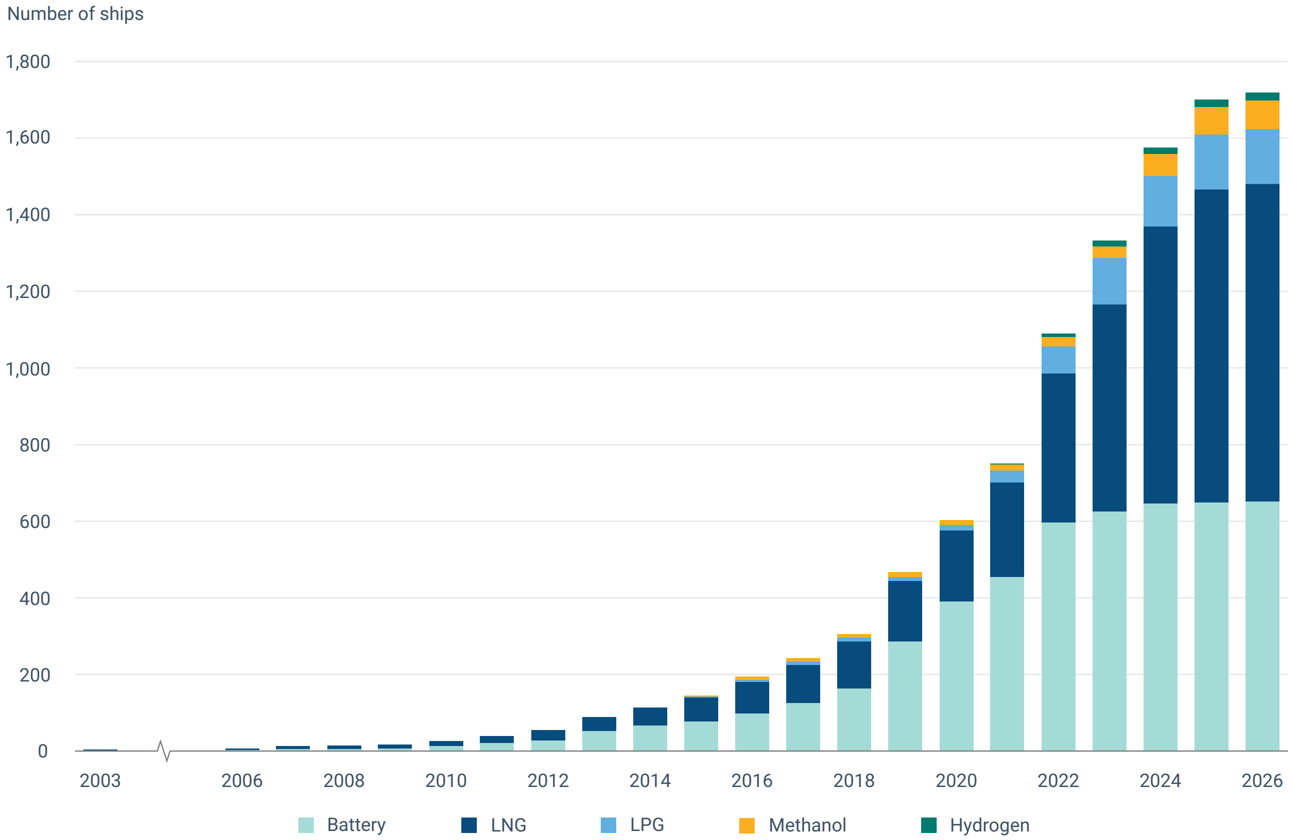
Source: EMSA, 2023d.

The LNG fleet has been growing on a yearly basis. The fleet grew by 32.2% from 2021 to 2022. In total there are 79 bunkering facilities worldwide, of which 33 are in Europe. The total capacity from the 33 bunkering facilities in Europe is 163,796m^3. LNG is still the main fuel alternative out of technological options available to shipowners for car carriers and container ships; it is also becoming significant for tankers and bulk carriers (EAFO, 2024).

LNG is a hydrocarbon-based source of energy and the liquid form of natural gas composed mostly of methane. While LNG combustion produces lower GHG emissions compared to marine diesel, it also entails emissions from non-combusted methane (i.e. slipped emissions). Furthermore, methane emissions from leakage during extraction, processing and transport phases as well as from unburned methane raise doubts about LNG's contribution to achieving the GHG emission targets in shipping.

Nevertheless, according to EAFO forecasts, LNG will remain in the short-term one of the main alternatives to conventional marine fuel oil onboard ships, followed by batteries, both currently and in the coming years (Figure 3.7).

Figure 3.7 **Alternative power solutions by number of ships in the EU (2003-2023) and forecast (2024-2026)**

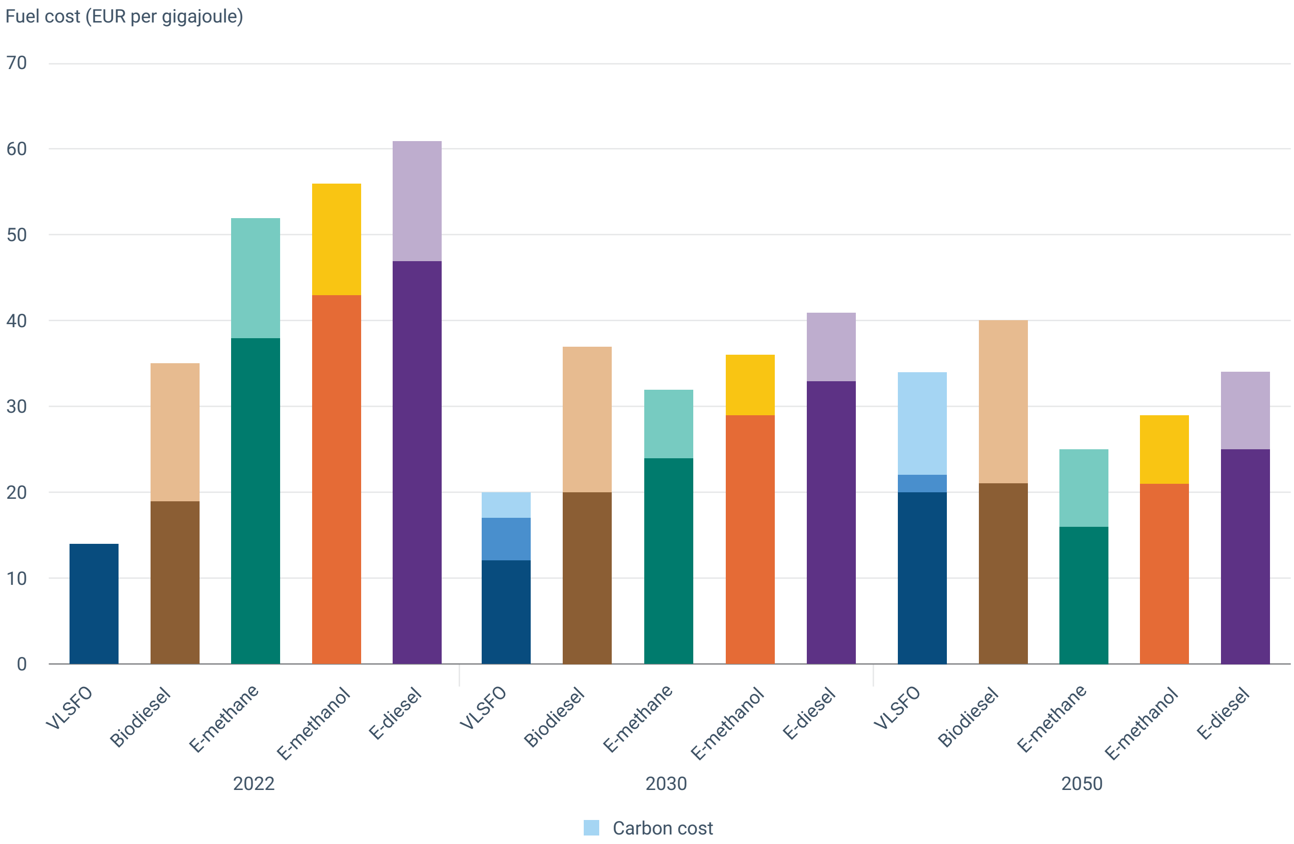


Source: EAFO, 2024.

While the number of ships using methanol is still very low, it is growing, and demand is expected to increase. According to the EAFO (2024), the global count for ships able to use methanol as a fuel as of 2024 is currently 33, with another 29 already on order for this year. Within Europe, six ships are currently in operation and 17 on order. Together with biofuels replacing fully or partially the existing power solutions for maritime, synthetic fuels, including e-fuels, can be considered advantageous as 'drop-in' fuels and are also expected to replace fossil fuels in the future. Existing standards and regulations are expected to facilitate to some extent their adoption as marine fuels. Ongoing regulatory development, industry guidance and best-practice publications should support this further.

However, there is still a need for further development for a wide adoption of these fuels. Renewable e-fuels (i.e. fuels made from renewable hydrogen (produced using renewable electricity and water electrolysis) and renewable CO_2, if required) can include notably e-diesel, e-methane, e-methanol or, in the longer term, e-ammonia. The most practical way to introduce e-fuels in shipping is either by fully replacing fuel oils or by blending e-fuels with compatible fossil-based marine fuels in quantities verified by equipment suppliers and engine designers. The introduction of drop-in e-fuels such as e-diesel and e-methane allows for the continued use of current fuel infrastructure and ship engines. Early estimations indicate that the cost of these e-fuels (in EUR/GJ) would still be significantly higher compared to that of marine fossil fuels (Figure 3.8).

Figure 3.8 Projected fuel cost of e-fuels and VLSFO (including carbon cost)



Notes: VLSFO, Very Low Sulphur Fuel Oil.

Opaque colours indicate maximum possible cost.

Source: EMSA, 2024b.

Electrification will play an important role in short-range waterborne applications and hybrid power solutions. This is a pattern for the wider transport sector; the AFIR and FuelEU Maritime Regulation's requirements on OPS by 2030 will encourage the adoption of electric solutions for maritime applications. The ZEWT partnership aims to demonstrate the technologies that will enable vessels to navigate up to 150-200 nm, integrating high-capacity batteries solutions as single energy source, by 2030 (WATERBORNE, 2021). To achieve that goal, further developments can be expected on the integration of low weight and high-power capacity battery systems in high voltage AC and DC distribution systems. Longer distance applications using fuel cells will require the electrification of the distribution system. The application of DC grids on-board is expected to increase due to a reduction of complexity, increased modularity and improved integration.

In the roadmap towards 2030, retrofits will support the fleet to achieve the goals set by then. The main solutions revolve around improving the ship efficiency (e.g. air lubrication systems, smart energy management, holistic hydrodynamic and operational optimisation or engine retrofits), exploiting renewables or zero emission energy sources (such as wind assisted propulsion, solar energy or hybridisation of the propulsion system) and emission reductions not linked to energy sources (e.g. better on-board treatment of solid or liquid waste from ship exploitation).

When looking at the investment required for new vessels that can operate using zero-emission fuels, it is critical to highlight that vessels have a lifetime of 20-35 years. This means that investments in new vessels today will have a huge impact on the ability of the sector to achieve the decarbonisation targets in 20 to 30 years from now (i.e. around 2050). In 2022, the first ammonia-ready vessel was delivered and there has been substantial progress in the development of zero-emission fuel technologies globally. The International Energy Agency identified that, to avoid sunk costs on fossil-fuelled vessels, new ships should be designed to be able to convert to zero-emission fuels in the future (IEA, 2022).

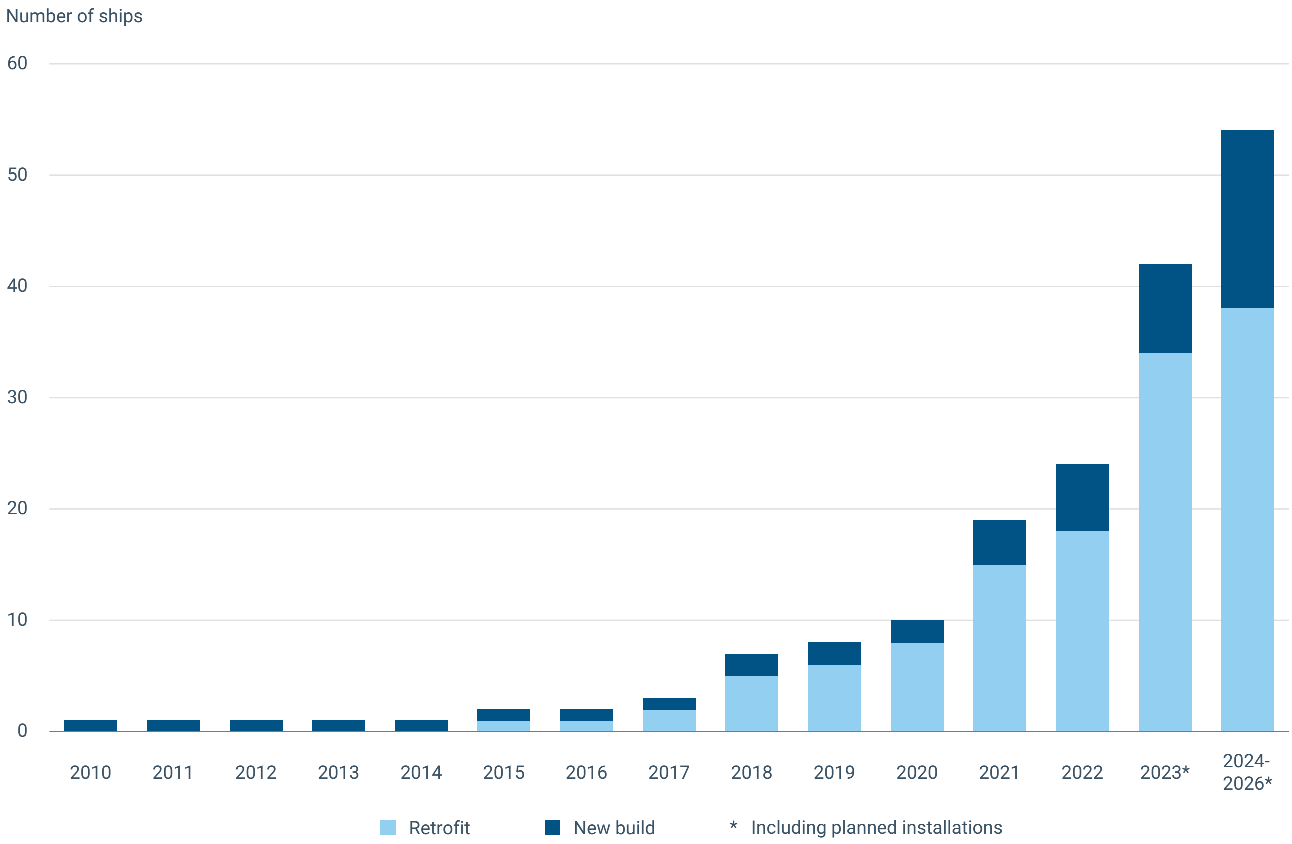
Ammonia is expected to be produced on a larger scale in the future. It is widely considered a hydrogen energy carrier: renewable hydrogen could be efficiently shipped after its conversion to ammonia. Although ammonia is not currently used as a fuel by ocean-going ships, recent analysis of the required land storage and distribution, onboard storage and conversion to energy – in either an internal combustion engine or a fuel cell – has revealed no insurmountable barriers to the use of ammonia as a marine fuel. Several research and development projects are in progress, while standards are being developed for the use of ammonia as a fuel. Marine engine makers generally agree that the diesel cycle is initially found to be best suited for combustion of ammonia, but research is ongoing for both combustion concepts with no engine yet available in the market. Availability of these options is expected during the second half of this decade.

To produce the renewable hydrogen required for the production of ammonia or e- fuels, the process of water electrolysis is used. Although different electrolyser technologies exist, newer technologies are still under development. The renewable electricity available for the renewable hydrogen production, along with the global electrolyser capacity, are still low. According to EAFO, in Europe there are already three ships in operation using hydrogen (two ships classified as 'other activities' and one tug) plus another ten (ships classified as 'other activities') are on order (DNV, 2023). By 2030 the renewable electricity production capacity could be high enough to meet the global maritime hydrogen-based fuel demand. In practice, a large share of the produced renewable electricity will feed into the power grids to supply worldwide demand for this energy source in other industries.

It is estimated that between 1,300 to 1,900GW of electrolyser capacity would be needed to produce enough hydrogen-based fuels to supply the entire maritime sector in 2030. However, the announced electrolyser projects worldwide would lead to an installed electrolyser capacity of 170 to 365GW by 2030. The projects announced to date are an important step compared to the worldwide capacity in 2020 (0.3GW) and to the sum of electrolyser projects planned for the 2021-2026 period (16.7GW). Assuming that the projected electrolyser capacity volumes are realised, the global capacity could produce hydrogen-based fuels for 13% to 19% of the global maritime fleet by 2030.

Currently, wind propulsion systems have been installed on more than 30 ships (plus another 11 are wind ready) and installation is ongoing on another 26. Of these ships, 16 are newbuilds and 38 are being retrofitted, (two kite installations are also ongoing on either newbuilds or existing ships) (see Figure 3.9). More than one third of the WPS ships are equipped with rotor sails. These were the first to market and the first to reach critical mass in a couple of sectors and are thus the most popular current form of WPS. Estimating the associated fuel consumption reductions from the wind technologies depends on several factors, including characteristics of the technology (e.g. type, number and dimension of units) and the ship, together with the operation and environmental factors. Although a big variation in the savings has been observed, savings can be significant. For example, rotor sails account for up to 30% savings (EMSA, 2023c). It is certain that wind assisted technologies can contribute to achieving the GHG reduction targets, making this technology vital in the shipping sector's low-carbon transition up to 2050.

Figure 3.9 **Number of ships equipped with wind propulsion systems**



Source: EMSA, 2023c.

Projections on the number ships planned to be equipped with WPS vary. A recent report published by EMSA (EMSA, 2023c) puts this number at 50+ (see Figure 3.9), while information from the International WindShip Association (IWSA) refers to over 100 ships (private communication).

Other energy efficiency solutions based on propulsion and reconfiguration of ship architecture and operation will add to the mix of applications contributing towards zero-emission shipping, particularly for long distance shipping. The physical improvements of vessels will be paired with digital solutions that will enhance their application as well as provide operational and maintenance decision-making improvements. Energy efficiency retrofit solutions will support the current fleet efforts in lowering emissions by 2030, while newbuilds should already incorporate energy efficient applications by design in order to maximise their performance and sustainability by 2050. Some of the technologies being developed range from monitoring and forecasting the full spectrum of ships' energy needs and operating profiles (feeding into digital twins models of the vessel), optimisation of port call and bunkering, both from the ship and port side, waste heat recovery solutions, improved hull performance solutions or novel propulsion systems promising up to 20% efficiency gains.

Fuel cells can also provide a suitable alternative in combination with zero carbon fuels. Although more expensive than combustion engines, they offer higher efficiencies and different emission footprints from the conversion of molecules. Among them, solid oxide fuel cells are highly efficient, moderately sized fuel cells. High operating temperatures mean that with heat recovery, total fuel efficiency can reach about 85% and possibly increase more with further development. Data from EAFO reveals four ships on order with fuel cells (two containerships and two ships classified as 'other activities') (EAFO, 2023).

Several research efforts are developing technological solutions to the upcoming challenges of the maritime energy transition (MARIN, 2024a). One example is the Joint Industry Project (JIP) ZERO, which focuses on the capabilities, functioning, performance, reliability and safety of integrated systems to prototype 'engine rooms of the future' to ensure reliable future operations in realistic conditions (MARIN, 2024b).

3.3.3 Green corridors

As stated in previous sections, reducing emissions from shipping requires major investments in infrastructure for the production and supply of alternative fuels. Considering the sector's international nature, these investments must be developed at a global level. The Clydebank Declaration for Green Shipping Corridors, announced at COP 26, supports the establishment of at least six green corridors: zero-emission maritime routes with further development in the next decades (UNFCCC, 2022). In the meantime, in their 2023 *Annual progress report on green shipping corridors,* the Global Maritime Forum reported 44 Green Corridors to be under development.

Green corridors are routes from port to port on which the decarbonisation of the shipping sector and its fuel supply is accelerated by private and public action with a participation from ports, ship operators and others along the value chain. Green corridors will contribute to the development of alternative fuel supply chains, speed up the scaling process by offering real life demonstration of solutions and technologies, and unite individual first mover actions across the value chain. Since shipping will be competing with other industrial sectors for the same fuels, it is paramount that this industry uses such fuels efficiently and promotes energy-efficiency technologies in this context. Green corridors can act as a key enabler of investments, which will create hubs for new energy production and use that can scale up rapidly and attract further investment.

GHG emission abatement is the obvious goal in any green corridor, with availability of zero-emission fuels that can be stored and re-fuel in accordance with the same standards and safety requirements. Since those can look very different based on the regions, the initial phase is critical. In some regions the availability of a specific zero-GHG energy carriers might make certain vessel segments more relevant, while in others it could be secondary attributes, such as availability of the local workforce, infrastructural development opportunities or the opportunity to increase technical insights. At port level, planning for infrastructure investments is based on estimations of the future demand of alternative fuels, which considering the uncertainty and complexity of the future fuel mix poses a great challenge for ports. As such, close cooperation between all relevant parties is required in order to ensure an efficient deployment of the necessary infrastructure.

Along a green corridor, policy makers can put in place mechanisms that will enable the transition of the industry such as regulatory measures, financial incentives or safety regulations, while engaging all stakeholders (fuel producers and suppliers, port operators, ship owners, ship operators, cargo owners, specialists and experts, shipyards, financial institutions, etc.) (EC, 2023d).

3.3.4 Human element and seafarer training outlook

The increased use of any alternative fuels and new ship technology necessary for the sustainable transition of the maritime sector comes with several skill and training challenges. For example, experience so far highlights the need for additional specialised seafarer training in order to ensure a safe operation on board vessels. This includes areas such as fuel storage, personal protection, emergencies and transport of fuels.

Furthermore, the uptake of new low- and zero-carbon fuels onboard ships will require the reskilling and upskilling of both seafarers and port employees due to novel and different technical characteristics compared to current marine fuels that have various safety implications. This need is apparent also for highly automated systems which may not require heavy crew interaction, but nevertheless require awareness, maintenance and emergency procedure trainings.

According to the scenario by Lloyds Register and University Maritime Advisory Services (UMAS) where alternative fuel-use ramps up in the 2020s, while envisioning the achievement of net-zero GHG emissions from international shipping by 2050, 450,000 seafarers will need additional training by 2030 and 800,000 by the mid-2030s (Raymond et al., 2022).

At an international level, the shipping industry is developing and calling for the adoption of interim guidelines on the training of seafarers on ships that use alternative energy sources. This will guarantee harmonised training processes and a coherent approach prior to the establishment of specific guidance and requirements of minimum training in the STCW Convention and Code (IMO, 1978).

Due to there being several different strategies regarding decarbonisation, the disparity in knowledge and experience makes this a complex task. In addition, the current slow uptake of alternative energy sources as compared to conventional fuels may create a bottleneck for seafarer training. Technology can facilitate those aspects through tools such as simulators. Some already exist, including engine-room training, bridge training and LNG cargo-handling simulators (IMO, 2023b).

4 Knowledge gaps

Key messages

- The absence of mandatory monitoring and reporting requirements for some domains contributes to incomplete information about the environmental impact of maritime activities.
- Rapid advancements in maritime technologies, such as alternative fuels and propulsion systems, create new challenges for assessing emissions as well as safety risks.
- The Innovation Fund, financed by EU ETS revenues, is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies.
- Priorities for the EU strategic research agenda include Alternative Fuels and Green Technologies; Decarbonisation, Emission Monitoring, and Reduction; Digitalisation and Smart Shipping; Port Automation; Zero Pollution and Circular Economy; Human Element, and Climate Resilience and Adaptation.

This EMTER report highlighted the environmental challenges and the opportunities faced by the maritime transport sector. New and ambitious targets have been set to reach the goals of the European Green Deal and shipping is now integral to this endeavour. While we strive to analyse the trends and prospects of how the sector is performing in terms of environmental sustainability, it is important to identify information gaps that still exist and recognise the role research and innovation can play in closing these gaps and accelerating this transition. Most attention is currently focused on decarbonisation efforts, but there are still domains where additional data, information and knowledge is needed to overcome the other environmental challenges that lie ahead.

4.1 Gaps

The maritime transport sector faces a number of gaps in knowledge, information and data for environmental monitoring and reporting. Ultimately these gaps can hinder effective regulation of the sector's environmental impact. The report highlights how a lack of standardised methodologies for monitoring, data collection, and reporting across the different domains poses a challenge, while noting that standardised guidelines for measuring emissions, whether to the atmosphere or sea, are essential for accurate and comparable monitoring.

The absence of mandatory reporting requirements for some domains contributes to incomplete information about the environmental impact of maritime activities. For example, the sector is a significant emitter of several pollutants that are currently not regulated despite the availability of suitable technological solutions to both reduce and monitor these emissions, as discussed both in Section 2.1.1 and Annex A1.1. The lack of regulation for some pollutants often coincides with reduced monitoring and limited direct measurements in representative conditions. Indeed, a limited infrastructure for real-time monitoring and a lack of enforceable regulations make it difficult to track and control the environmental impact of vessels operating in high sea areas in real world conditions. Improved international cooperation is essential to address this gap. As already discussed in Section 2.1.2, this may result in disproportionately higher emissions of some pollutants in real operating conditions, leading ultimately to an underestimation of the sector's impacts.

The environmental impact of the maritime sector extends beyond vessel operations to include shipbuilding, maintenance and end-of-life processes. While comprehensive assessments of the entire maritime supply chain has not been a focus of the EMTER report, it is important to highlight that understanding the life cycle emissions of vessels requires data on manufacturing processes, shipbreaking practices and maintenance activities, which are often not readily available, as also discussed in Section 2.3.3 and in Annex A1.1.9. Indeed, monitoring and enforcing sustainable practises in these sectors is not easy for many reasons, including the international dimension of the issues. Today the existing regulation is largely circumvented by ship owners re-flagging their ships to non-EU flag countries, in particular to 'open registries', with the view to dismantle the ships in facilities with lower environmental standards.

Rapid advancements in maritime technologies, including the adoption of alternative fuels and propulsion systems, create challenges in accurately tracking and assessing emissions. The sector is in a state of transition, with new technologies being introduced to reduce environmental impact. During this transition, the lack of data or the limited knowledge on the impact that the adoption of some of these technologies may have, is an important element to consider. For example, the large-scale adoption of alternative fuels such as NH_3 or methanol would result in safety challenges and in emissions of currently unmonitored and/or unregulated substances, for example, N_2O or Formaldehyde (HCHO). This would require adequate policy safeguards to be in place, as well as environmental monitoring frameworks and pollution response guidance.

Addressing these gaps requires international collaboration, the development of standardised reporting frameworks and increased regulatory measures to ensure transparency and accountability in environmental monitoring and reporting. This is where the EU and its member states have made an important step forward, as the European Green Deal and the related 'EU basket of measures', e.g., linked to the Fit-for-55 package or the Zero Pollution Action Plan offer a set of regulatory and monitoring frameworks to close these gaps.

4.2 The role of research and innovation

The Innovation Fund, financed by EU Emissions Trading System revenues, is one of the world's largest funding programmes for the demonstration of innovative low-carbon technologies. The fund focuses on highly innovative clean technologies and big flagship projects with European added value that can bring significant pollutants and GHG emissions reductions.

Innovation Fund projects cover a wide range of innovative technologies in areas such as energy- intensive industries, renewables, energy storage, net-zero mobility and buildings, hydrogen and carbon capture, use and storage. The EU funding for research has already supported more than 300 shipping projects with some EUR 400 million and 20 million ETS emission allowances (i.e. about EUR 1.6 billion with a price of EUR 80 per allowance) which should be deployed up to 2030 via the Innovation Fund to support the decarbonisation of the maritime sector.

The EU's strategic research agenda aims to support development and technology readiness in a number of areas, including:

- alternative fuels and green technologies:
  - research into the environmental impact and safety implications of alternative fuels such as hydrogen, ammonia and biofuels to reduce GHG emissions;
  - innovation in energy-efficient propulsion systems, including wind propulsion, electric and hybrid technologies for vessels;
  - development of sustainable and eco-friendly ship designs to enhance overall energy efficiency.
- decarbonisation, emission monitoring and pollution reduction:
  - advancing technologies to decarbonise maritime transport, including carbon capture and storage (CCS) solutions. Additionally, consider the relationship between energy efficiency and other environmental impacts, such as the potential for quieter and more silent propellers to reduce URN;
  - research on emission abatement technologies to reduce air pollutants such as sulphur oxides (SOx), nitrogen oxides (NOx) and particulate matter;
  - real-time monitoring of air and water emissions at sea and in ports.
- digitalisation and smart shipping:
  - integration of digital technologies, IoT (Internet of Things) and big data analytics for real-time monitoring of vessel performance, route optimisation and predictive maintenance;
  - development of autonomous and semi-autonomous vessels to improve safety, reduce human error and optimise operational efficiency.
- port automation and infrastructure:
  - research on automation and optimization of port operations to enhance efficiency, reduce congestion and minimise environmental impact;
  - innovative solutions for shore power and onshore infrastructure to support clean energy adoption in ports.
- waste management and circular economy:
  - research on sustainable waste management practices onboard and at ports, including waste reduction, waste collection and recycling, and disposal of hazardous materials;
  - implementation of circular economy principles to promote the reuse and recycling of materials in shipbuilding, maintenance and waste management.
- human element and training:
  - research on human factors in maritime transport, including crew well-being, fatigue management and training programmes;

  - development of innovative training methodologies, simulators and virtual reality tools to enhance the skills of maritime professionals.

- climate resilience and adaptation:
  - research on the impact of climate change on maritime infrastructure and operations;
  - development of strategies and technologies to adapt to changing weather patterns, rising sea levels and extreme events.

- cross-sector collaboration:
  - encouraging collaboration between the maritime sector, academia, research institutions and other industries to foster interdisciplinary solutions;
  - partnerships to share data, best practices and technological advancements for sustainable maritime development.

Within this context there are two additional key overarching components to be considered. Firstly, it is critical that both safety and environmental aspects are included in the development and evaluation of the technological and operational solutions. Secondly, solutions must be considered holistically, which is to say exploring possible synergies across all climate and environmental objectives. New hazardous scenarios and response operations must be duly factored into safety considerations, for example. At the same time, solutions addressing energy efficiency/carbon intensity should be developed considering their impact on other type of emissions and pollutions (see for example the ongoing work to determine scenarios to combine energy efficiency measures with underwater radiated noise reduction).

4.3 A new integrated monitoring infrastructure

The EU Copernicus services ([40]) have shown the potential of using satellite, modelling and in-situ data for environmental monitoring purposes. Nevertheless, the maritime transport sector has not benefited enough from the development of such services, for example when it comes to air emissions and water discharges. This is mainly due to technical difficulties associated with the monitoring of moving point sources (vessels) over high resolution temporal and spatial scales, as well as the sensibility of sensors required to capture and characterise emissions of vessels to the water and atmosphere. However, new services and tools are in the process of being developed where the needs and requirements of the maritime transport should not be neglected. For example, the EU Destination Earth ([41]) initiative and the Digital Twin of the Ocean ([42,43]) programme can play crucial roles in monitoring emissions from the maritime transport sector by leveraging advanced technologies and data analytics.

The Destination Earth initiative aims to enhance the use of Earth observation data to create digital replicas of the Earth's environment. By utilising satellite data and remote sensing technologies, it can provide real-time and historical information on various environmental parameters. By employing advanced modelling techniques, it will be able to simulate and predict the impact of maritime activities on the environment, including forecasting emissions to the atmosphere and water pollution discharges based on shipping routes, traffic density and vessel types.

([40]) https://www.copernicus.eu/en
([41]) https://digital-strategy.ec.europa.eu/en/policies/destination-earth
([42]) https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/restore-our-ocean-and-waters/european-digital-twin-ocean-european-dto_en
([43]) https://www.mercator-ocean.eu/en/digital-twin-ocean

The Digital Twin of the Ocean programme involves creating a digital replica of the ocean, integrating information obtained from multiple sources such as real-time data from sensors, including on-board ones, satellites and others. This enables continuous monitoring of maritime activities, including vessel movements and emissions. By employing machine learning algorithms, the digital twin can learn and adapt to patterns in maritime emissions. This can help identify anomalies, track changes over time and enhance the accuracy of emission estimates. The project aims to provide a collaborative platform for sharing data and insights, facilitating cooperation between stakeholders such as shipping companies, regulators and environmental organisations, improving transparency and data accuracy.

Together, these initiatives would contribute to a more technologically advanced approach to monitoring emissions, able to integrate multiple sources of information to provide a comprehensive view on the maritime transport sector. Indeed, by combining Earth observation data, predictive modelling, real-time monitoring and collaborative platforms, the EU Destination Earth initiative and the Digital Twin of the Ocean programme may significantly enhance our understanding and management of the environmental impact of maritime activities. However, for this to happen, the maritime transport sector must be an integral part of the requirements and development process, failing this, the services built will not adequately fulfil the needs of the sector.

Abbreviations

AFID	Alternative Fuels Infrastructure Directive
AFIR	Alternative Fuels Infrastructure Regulation
AIS	Automatic Identification System
AQG	Air quality guidelines
ATS	After treatment system
BC	Black carbon
BWM	International Convention for the Control and Management of Ships' Ballast Water and Sediments
BWMP	Ballast Water Management Plan
BWRB	Ballast Water Record Book
CCS	Carbon Capture and Storage
CEAP	Circular Economy Action Plan
CH_4	Methane
CII	Carbon Intensity Indicator
CO	Carbon monoxide
CO_2	Carbon dioxide
COP	Conference of the Parties
CSN	CleanSeaNet
DAC	Direct Air Capture
DCS	Data Collection System
DME	Dimethyl ether
EAFO	European Alternative Fuels Observatory
EC	European Commission
ECA	Emission Control Areas
ECD	Environmental Crime Directive
ECHO	Enhancing Cetacean Habitat and Observation
EEA	European Environment Agency
EEDI	Energy Efficiency Design Index
EEXI	Energy Efficiency Existing Ships Index
EEZ	Exclusive Economic Zone
EFTA	European Free Trade Association

EGCS	Exhaust gas cleaning system
EGD	European Green Deal
EIA	Environmental Impact Assessment
EIT	European Institute of Innovation & Technology
EIV	Estimated Index Value
EQS	Environmental Quality Standards
EMCIP	European Marine Casualty Information Platform
EMEP	European Monitoring and Evaluation Programme
EMSA	European Maritime Safety Agency
EMODnet	European Marine Observation and Data Network
EMTER	European Maritime Transport Environmental Report
EIAPP	Engine International Air Pollution Prevention
ETD	Energy Taxation Directive
ETS	Emission Trading System
EU	European Union
FSC	Fuel Sulphur Content
GES	Good Environmental Status
GHG	Greenhouse gas
GT	Gross tonnage
HBCDD	Hexabromocyclododecane
HCB	Hexachlorobenzene
HCHO	Formaldehyde
HCFCs	Hydrochlorofluorocarbons
HFO	Heavy fuel oil
HKC	Hong Kong Convention
IAPP	International Air Pollution Prevention Certificate
IAS	Invasive alien species
IEA	International Energy Agency
IHM	Inventory of hazardous materials
IMO	International Maritime Organization
IOPP	International Oil Pollution Prevention (Certificate)
IT	Information Technology
kW	Kilowatt
LCA	Life cycle analysis
LNG	Liquified natural gas
LRTAP	Long-Range Transboundary Air Pollution

MARPOL	International Convention for the Prevention of Pollution from Ships
MDO	Marine diesel oil
MED	Mediterranean Sea
MEPC	Marine Environment Protection Committee
MGO	Marine gas oil
MJ	Megajoule
MMMCZCS	Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping
MRV	Monitoring, Reporting and Verification (Regulation)
MS	Member States
MSR	Molten Salt Reactor
MSFD	Marine Strategy Framework Directive
MSPD	Marine Spatial Planning Directive
N_2O	Nitrous oxide
NEC	National Emission Reduction Commitments (Directive)
NECA	Nitrogen oxides Emission Control Area
NH_3	Ammonia
NIS	Non-indigenous species
NM	Nautical mile
NMVOCs	Non-methane volatile organic compound
NOx	Nitrogen oxides
NSN	North Sea Network of Investigators and Prosecutors
ODS	Ozone depleting substances
OECD	Organisation for Economic Cooperation and Development
OPS	Onshore power supply
PAH	Polycyclic aromatic hydrocarbon
PCBs	Polychlorinated biphenyls
PFOS	Perfluorooctane sulfonic acid
PFW	Passively fished waste
PM	Particulate matter
POP	Persistent organic pollutants
PRF	Port Reception Facilities (Directive)
PSC	Port State Control
PVCs	Polyvinyl chlorides
PWR	Pressurised Water Reactor

RED	Renewable Energy Directive
RFNBO	Renewable fuels of non-biological origin
RFRC	Ready for Recycling Certificates
RPAS	Remotely Piloted Aircraft Systems
SCR	Selective Catalytic Reduction
SECA or SOx ECA	Sulphur oxides Emission Control Area
SO_2	Sulphur dioxide
SOC	Statement of Completion
SOx	Sulphur oxides
SRR	Ship Recycling Facilities
SSN	SafeSeaNet
SSP	Ship-Source Pollution (Directive)
STEAM	Ship Traffic Emission Assessment Model
TEN-T	Trans-European Transport Network
TEU	Twenty-foot equivalent unit
THETIS	The Hybrid European Targeting and Inspection System
TPS	Thermoplastic starch
TtW	Tank-to-Wake
TWh	Terawatt hours
UNCLOS	United Nations Convention on the Law of the Sea
UNCTAD	United Nations Conference on Trade and Development
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
URN	Underwater radiated noise
VOC	Volatile organic compounds
WFD	Water Framework Directive
WHO	World Health Organisation
WPS	Wind Propulsion Systems
WtT	Well-to-Tank
WtW	Well-to-Wake
ZPAP	Zero Pollution Action Plan
% m/m	Mass/mass percentage

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Annex 1 Regulatory and monitoring frameworks

This chapter provides a summary of the environmental EU regulatory frameworks for maritime transport, policy targets and monitoring tools aimed at protecting the atmosphere and marine ecosystems. It highlights the monitoring framework as a necessary condition for the effective implementation of regulatory measures and fundamental to track progress and ensure sustainable transition.

A1.1 Emissions to the atmosphere

Air emissions can be categorised into two main groups: GHG and air pollutants. GHGs produce global warming effects, while air pollutants impact air quality, human health and, through their deposition, ecosystems. It is important to note that some compounds belong to both categories, having at the same time an impact on air quality and a warming effect on the atmosphere. For example, methane (CH_4) and nitrous oxide (N_2O) are usually considered potent GHGs, however, methane is known for its impact on air quality as an ozone precursor (Janssens-Maenhout et al., 2018) and literature studies have demonstrated that nitrous oxide is an important ozone depleting substance (Ravishankara et al., 2009). Other pollutants from maritime transport activities, such as carbon monoxide (CO), nitrogen oxides (NOx), non-methane volatile organic compounds (NMVOCs), particulate matter (PM) and black carbon (BC) are also relevant. Estimates included in the Fourth IMO GHG Study indicate that BC, a potent climate pollutant included under particulate matter, was responsible for 6.85% of the global warming contribution from shipping in 2018 (IMO, 2020a). In fact, the report shows BC to be the second most emitted GHG on a voyage-based comparison after CO_2 (analysed in CO_2e). Therefore, GHGs and air pollutants should be analysed in a complementary way.

Some ship emissions are directly controlled through specific regulations, while others are regulated under wider EU directives and global initiatives, which are not specific to the shipping sector, as detailed below.

A1.1.1 Greenhouse gases

GHGs include among others carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). These compounds, once in the atmosphere, absorb longwave radiation reflected from the Earth's surface, distributing this energy to the surrounding air as thermal radiation, ultimately increasing its temperature. The large and increasing amount of emissions associated to anthropogenic sources and their long life in the atmosphere are causing an increase of GHG concentration, causing global warming. Between 2011 and 2020, the global surface temperature increased by 1.1°C compared to 1850-1900 levels. Widespread changes in the atmosphere, ocean, cryosphere and biosphere have occurred and are ongoing. Human-caused climate change is affecting the weather and causing extreme climate events across the globe. This has led to widespread adverse impacts and related losses and damages to nature and people (IPCC, 2023).

Regulatory framework

International framework

In July 2023, members of the International Maritime Organization (IMO) adopted its revised IMO GHG Strategy on the reduction of GHG emissions from ships (IMO, 2023a), aiming to keep the path of decarbonisation for the shipping sector and paving the way for future work of the organisation. The revised strategy is a non-binding framework which aims to reduce GHG from international maritime shipping and presents an enhanced level of ambition compared to the 2018 strategy. More specifically, the revised strategy provides for candidate measures aiming at: (1) increasing the energy efficiency of ships, (2) reducing the carbon intensity of ships, (3) promoting the uptake of zero or near zero GHG emission technologies, fuels and/or energy sources, and (4) reaching net-zero GHG emissions from international shipping by or around 2050. Moreover, two indicative checkpoints have been introduced aiming at reducing the total annual GHG emissions from international shipping compared to 2008 level: (1) by at least 20%, striving for 30%, by 2030, and (2) by at least 70%, striving for 80% by 2040 (resolution MEPC.377(80)) (IMO, 2023a).

In addition, guidelines on life cycle GHG intensity of marine fuels (LCA guidelines) were adopted in July 2023. The LCA guidelines consider the well-to-wake (WtW) emissions of marine fuels used onboard (i.e., both upstream (Well-to-Tank) and downstream (Tank-to-Wake) emissions). The guidelines also consider wind propulsion systems as one of the fuel pathways. Further work is ongoing on the sustainable use of marine fuels by the maritime sector (resolution MEPC.376(80)) (IMO, 2023d). Furthermore, interim guidance on the use of biofuels is also in place to certify proven GHG reductions and removals in accordance with sustainability criteria on a WtW approach (MEPC.1/Circ.905) pending further development of the LCA guidelines to be used in the context of the carbon intensity indicator (CII) and data collection system (DCS) regulations.

Instruments already in place at the international level include: (1) the ship energy efficiency rating scheme based on the CII and the Energy Efficiency Existing Ship Index (EEXI), which entered into force on the 1 January 2023 under resolution MEPC.328(76), (2) the requirements for collection of fuel oil consumption data through the IMO DCS and the development of a ship-specific Ship Energy Efficiency Management Plan (SEEMP), and (3) the design parameters for ships through the Energy Efficiency Design Index (EEDI). The CII, EEXI and EEDI measures will be further aligned with the revised Strategy to achieve the necessary downward reductions of GHGs.

Moreover, the Kigali Amendment to the Montreal Protocol on Substances that Deplete the Ozone Layer (ODS) will reduce the amount of hydrofluorocarbons that can be produced and consumed in the world. As some of these fluorinated GHGs are often used in air-conditioning and refrigeration systems on board ships, this instrument will therefore also impact on this sector.

European Union framework

The Commission's communication, a non-binding document on the European Green Deal, references the maritime sector in a push to 'accelerating the shift to sustainable and smart mobility'. Overall, CO_2 emissions from waterborne transport represent 3-4% of total EU CO_2 emissions in 2020 (EC, 2021a) and demand for waterborne transport services is expected to grow further in the future (EC, 2021h).

The Fit for 55 package (EC, 2021d) sets out the EU target of reducing net GHG emissions by at least 55% by 2030 and proposes a comprehensive set of policy measures to drive the decarbonisation of the sector. This policy framework covers: (1) the revision of the EU Emission Trading System (EU ETS) and its extension to the maritime sector (EC, 2021c; EU, 2023b), (2) a new FuelEU Maritime Regulation (EU, 2023d) that requires ships to reduce the GHG intensity of fuels used and use onshore power while at berth, (3) the revision of the Alternative Fuel Infrastructure Directive (AFID) (EU, 2023c) into a new regulation with more ambitious targets on the capacity of ports to expand and to offer shore-side electricity requirements and refuelling points, (4) the revision of the Renewable Energy Directive (RED) (EU, 2023a) with strengthened sustainability criteria for the use of bioenergy, and (5) the revision of the Energy Taxation Directive (ETD) proposing taxation of marine fuels (EP, 2021). The above-mentioned measures are strongly interconnected and interact with each other.

These measures are expected to facilitate the uptake of cleaner fuels across the value chain of production, distribution and supply, by creating the necessary demand for low or zero GHG fuels. The revised EU Regulation on Fluorinated Greenhouse Gases, approved in 2024 updating Regulation (EU) No 517/2014 aims to reverse EU emissions from these human-made chemicals with a high GHG potential and implement the EU's binding commitments to the Kigali Amendment of the Montreal Protocol. It also provides for more ambitious requirements on the use and emission control of these gases by phasing out the placing on the market of hydrofluorocarbons by 2050 in the EU, while emissions of fluorinated gases must be prevented to the extent possible. In addition to the above regulatory measures, Horizon Europe and the Innovation Fund will continue supporting research and innovation towards the decarbonisation of the maritime transport sector.

Carbon dioxide, methane, and nitrous oxide

The monitoring, reporting and verification regulation (Regulation (EU) 2015/757, MRV Regulation), introduced as of 1 January 2018, is a common system for the monitoring, reporting and verification of CO_2 emissions from shipping (EU, 2023b). With the revision of the Regulation adopted in May 2023 (Regulation (EU) 2023/957), the scope of the MRV Regulation has been extended to include CH_4 and N_2O starting from emissions occurring as of 1 January 2024 which requires companies to report and monitor these emissions, by having a monitoring plan, approved by the Member State responsible administering authority.

The regulation covers all ships over 5,000 gross tonnes (GT) loading or unloading cargo or passengers at ports in the European Economic Area, in respect of the GHG emissions released during their voyages from or/and to ports in the European Economic Area, for commercial purposes of cargo or passengers. From 2025, the MRV Regulation also covers offshore ships of and above 5,000GT, as well as offshore ships and general cargo ships between 400GT and below 5,000GT. The regulation does not apply to a limited number of categories of ships ([44]). The regulation is flag-neutral, which means that ships have to monitor and report their emissions regardless of their flag (EC, 2020a). It covers exclusively tank-to-wake (TtW) GHG emissions originating from the use of fuels used as energy vectors on board ships.

Monitoring and reporting framework

Greenhouse gas emissions from maritime transport activities are currently monitored and reported in Europe under two main frameworks. The main differences in terms of scope, methodologies and input data between the two are further detailed under Chapter 2 and under Table 2.1, of this report, where resulting datasets are analysed.

GHG inventories

The EU, as a party to the UNFCCC, reports annually on GHG inventories for emissions and removals within the area covered by its Member States (i.e., emissions taking place within its territory). The legal basis for the compilation of the EU inventory is the Regulation (EU) 2018/1999 (EU, 2018). The EU GHG inventory comprises the direct sum of emissions and removals from the national inventories compiled by the EU Member States. Energy data from Eurostat are used for the reference approach for CO_2 emissions from fossil fuels, developed by the Intergovernmental Panel on Climate Change (IPCC). Reported emissions in the inventories are calculated based

([44]) Such as warships, naval auxiliaries, fish-catching or fish-processing ships, ships not propelled by mechanical means and government ships used for non-commercial purposes.

on the type and quantity of the maritime fuel sold in the reporting country, where navigation includes all waterborne transport activities, irrespective of the ship size and type. Navigation is considered domestic if the ship departs and arrives in a port from the same country (note that this can cover trips of significant length). Emissions from fishing fleet are reported under a dedicated entry in the GHG inventories (the 'Agriculture/Forestry/Fishing' category in the energy sector) and are always considered domestic, irrespective of where fishing activities occur.

GHG emissions under the MRV Regulation
The MRV Regulation requires shipping companies to monitor and report GHG emissions from the activities within its scope. Shipping companies may resort to a calculation or a measurement approach, applying from the four different methods to monitor tank-to-wake emissions: (1) bunker fuel delivery note and periodic stocktakes of fuel tanks; (2) bunker fuel tank monitoring on board; (3) fuel flow metres for applicable combustion processes; and (4) direct GHG emissions measurement. At the present time, the most common approach for determining GHG emissions from ships is the calculation approach, which is based on the use of activity-based emission factors combined with vessel-specific data, such as fuel consumption, engine power and operating hours. These emission factors are typically based on the IMO guidelines or other internationally recognised standards (EEA and EMEP, 2023; IPCC, 2006).

The regulation foresees, as a general rule, the monitoring of GHG emissions on a per voyage basis, while the reporting is done on the basis of the relevant parameters monitored at aggregate level throughout the year (EU, 2015b).

The verification of emissions is a fundamental step of the MRV process and follows the monitoring of emissions from actors within the scope of the regulation. Both monitoring and verification steps are facilitated by the THETIS-MRV system, an IT tool operated and maintained by the European Commission and EMSA, through which shipping companies comply with their obligations by submitting the verified emissions reports. Relevant reported information is made available to the public annually by 30 June, in accordance with the regulation provisions on publication of information (EC, 2020a).

Non-CO_2 emissions are not always easy to link to fuel consumption, since they may originate from processes which are not directly related to combustion. An example is the significant increase in N_2O emissions, formed as by product of catalytic reactions, recorded in the road transport sector after the introduction of SCR systems (Selleri et al., 2021).

A1.1.2 Air quality and depletion of the ozone layer

Air pollution remains a key environmental and health risk in Europe and globally, even with declining trends in the past two decades. This has led the World Health Organisation (WHO) to update their air quality guidelines (AQG) in 2021, with stricter limits for air pollutants which is also reflected in current EU legislative work on the Zero Pollution Action Plan adopted by review of the European Commission Ambient Air Quality Directive. Also, the Zero Pollution Action Plan targets an improvement of air quality that aims to reduce by 2030 premature deaths from exposure to fine particulate matter by 55%, compared with 2005 (EC, 2021g). Air pollution emissions are linked to several environmental issues such as tropospheric ozone depletion, acidification, and nitrification, which is why another target of the Zero Pollution Action Plan is to reduce by 25% the EU ecosystems where air pollution threatens biodiversity. Furthermore, air pollution emissions are responsible for several health issues as asthma, heart disease and stroke. In addition, the reduction of pollutants such as the ones from SOx emissions to the atmosphere has also a positive effect on secondary aerosols formation, which contribute to the total PM emissions as well as to soil and sea acidification due to their deposition. Exposure to fine particulate matter in the EU-27 was responsible for approximately 238,000 premature deaths, according to the EEA report Air Quality in 2020 (EEA, 2022a). The exposure to fine particulate matter and nitrogen dioxide (NO_2) above the WHO recommendations are estimated to cause hundreds of thousands of premature deaths globally with impacts being already compared to actions such as smoking (WHO, 2021). The effect of many air pollutants is not only local. This means that air pollution can have long-range effects and even far from inhabited regions or coasts even when pollutants are released. In a recent study conducted to support the impact assessment for the revision of the EU Ambient Air Quality Directive, shipping emerged as the primary source of over the limit NO_2 exposure. It was noted that individuals residing near ports and in port cities face significant health risks due to this exposure, both presently and in the coming years (2030-2050). Moreover, the study highlighted the impact of shipping on air quality concerning SO_2 and PM exposures and associated health issues (EC, 2022).

Regulatory framework

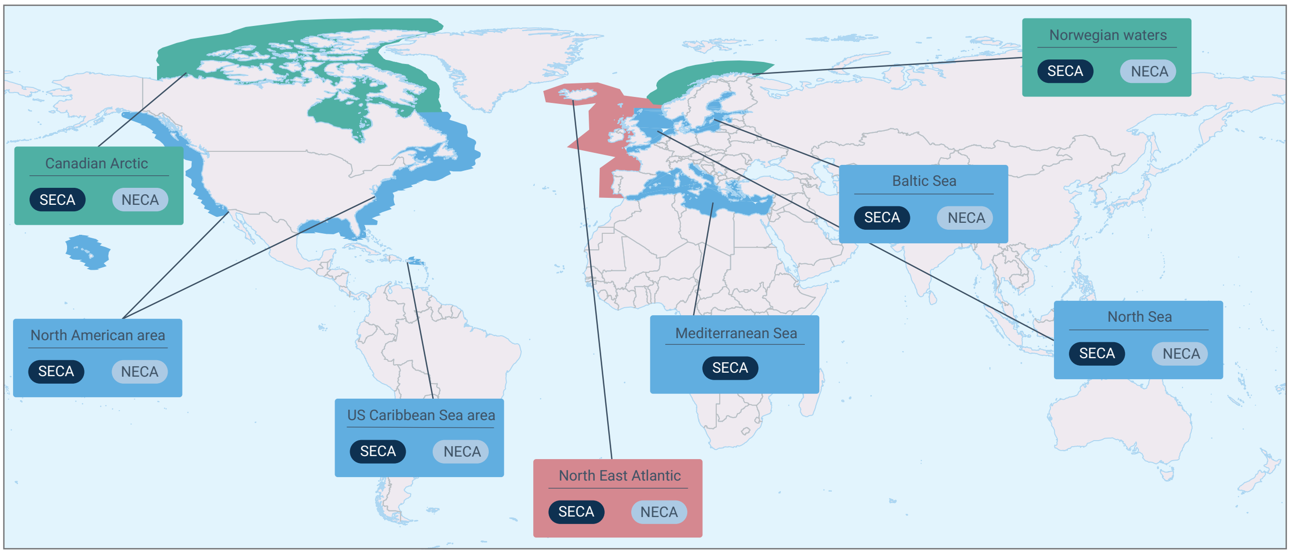
International framework

The main regulatory instrument dealing with air pollution from ships at IMO level is the International Convention for the Prevention of Pollution from Ships, also known as MARPOL and specifically Annex VI (IMO, 2006). This was added to the Convention in 1997 and finally entered into force in 2005. MARPOL's Annex VI limits some of the main air pollutants from ships' exhaust gas, including NOx, SOx and particulate matter (PM). It also prohibits deliberate emissions of ODS and regulates shipboard incineration and emissions of volatile organic compounds (VOCs) from tankers. Another international instrument is the Geneva Convention on Long-Range Transboundary Air Pollution (LRTAP), signed in 1979 that entered into force in 1983, now more commonly referred to as the 'Air Convention' that proposes a system for governments to cooperate and work together for the protection of health and the environment from air pollution that affects different countries (EU, 1981). It includes eight separate protocols covering a range of pollutants such as SOx, NOx, VOCs, heavy metals, persistent organic pollutants (POPs), and NH_3.

Emission Control Areas (ECAs)

Emission Control Areas, as defined under MARPOL Annex VI, further restrict SOx and NOx emissions in specific sea areas. There are currently two such areas in EU seas, the Baltic Sea and the North Sea (including the English Channel). The positive effect of the introduction of the SECA in the Baltic and North Sea regions can be already seen and are presented in Chapter 2.

Map A1.1 **Proposed and existing SOx and NOx emission control areas (ECAs: SECAs and NECAs, respectively)**



Reference data: © EuroGeographics, © FAO (UN), © TurkStat Source: European Commission – Eurostat/GISCO

Proposed and existing SOx and NOx emission control areas (ECAs: SECAs and NECAs, respectively)

Established ECAs   Newly adopted ECAs   Possible future ECAs

0   2,000   4,000   6,000 km

Source: EMSA internal data (2024).

From 1 May 2025, the Mediterranean Sea will also become an ECA for SOx (resolution MEPC.361(79)) (IMO, 2022c) (Map A1.1). Estimates suggest more than 30,000 vessels navigate the Mediterranean Sea each year. It supports 20% of the seaborne trade and statistics estimate that 24% of the global fleet and more than 17% of worldwide cruises regularly passed through this basin in 2019 (GEN, 2021). The implementation of the Mediterranean SECA in this region aims to reduce the impacts of these busy high traffic density routes and mitigate the health and environmental issues related to air pollution. Furthermore, the signatories of the Barcelona Convention (UNEP, 1976) agreed to assess and discuss the possible technical and economic feasibility of an ECA for NOx in the next two years.

Sulphur oxides (SOx)
In 2020 the IMO established the 'global sulphur cap' (Resolution MEPC.305(73)) (IMO, 2018). This resolution limits the content of sulphur in the marine fuel to a maximum of 0.50% m/m for ships sailing in all sea areas (outside SECAs which have as limit 0.10% m/m) and prohibits the onboard carriage of marine fuels for combustion purposes, i.e. propulsion or operation on board a ship, which are non-compliant with the regulation.

Nitrogen oxides (NOx)
NOx emissions in the maritime sector are regulated by IMO under Regulation 13 of MARPOL Annex VI (IMO, 2018). More specifically, the regulation targets emissions from all diesel engines with a power output exceeding 130 kW, installed on a ship either newly built or that underwent a major conversion on or after 1 January 2000. Currently, the IMO approach foresees three different limits, namely tier I, II and III. This three NOx tiers dictate the specific maximum allowable NOx emissions for a marine engine, depending on ship's keel laying date and sailing area (within an ECA or not), with tier III being the most stringent.

Particulate matter (PM)
For the maritime sector, at international level, there is no legislation targeting PM directly. Regulation 14 from MARPOL Annex VI, regarding the sulphur content of marine fuels and its emissions, indirectly targets PM — without limiting it or proposing a monitoring scheme as it is one of the criteria used for the definition of SECAs.

Literature shows that low-sulphur fuels have lower emissions of PM. Also, EGCS can reduce PM emissions. Studies from Lehtoranta et al. (2019) and Zetterdahl et al. (2016), showed that by switching the marine fuel from high sulphur HFO to a low-sulphur distillate fuel there is a reduction of both the PM mass (by up to 67%) and average particle size. Although particulate mass is reduced, the number of particles emitted, their dimension and their effect on human health and in the environment,still need to be addressed. This effect can already be observed in existing SECAs and is analysed in Chapter 2 under discharge waters and contaminants.

Black carbon (BC)
Currently, black carbon emissions are not directly regulated at the international level. However, both the Arctic Council and the IMO are actively considering the impacts of BC in the Arctic (AMAP, 2021). The climate change effects of BC emissions from shipping are increasingly understood (Comer et al., 2015; IMO, 2020a).

The Sub-Committee on Prevention of Air Pollution from Ships has been instructing and guiding the work at IMO, by revising existing data on measurement methods, drafting recommendatory goal-based control measures, identify ways to apply thresholds values for black carbon and research on the marine fuels to further consider direct control measures. From July 2024, the carriage and use of heavy fuel oil by ships in the Arctic was banned since HFO is considered to be the main source of black carbon emissions as well as it is a persistent oil which is extremely difficult to clean in the event of a spill, with the potential to get trapped in and under Arctic Sea ice (IMO, 2021b). Subsequently, the guidelines on recommendatory goal-based control measures to reduce the impact of black carbon in the Arctic are gaining shape with discussions pointing for the adoption of the guidelines in its next session (currently scheduled for February 2024).

Ozone Depleting Substances (ODS)
Global initiatives not specific to the maritime sector firstly set commitments to phase-out of consumption and production of ODS, to prevent emissions such as the 1985 Vienna Convention for the Protection of the Ozone Layer (UNEP, 1985), the 1987 Montreal Protocol (UNEP, 1987) on substances that deplete the ozone layer (noted as one of the most successful examples of international cooperation) and the 2018 Kigali Amendment on the phasing down of hydrofluorocarbons (UNEP, 2018).

In shipping, deliberate emissions of ODS are prohibited under MARPOL Annex VI, regulation 12 (IMO, 2006). These emissions are defined as the ones which occur, for example, during maintenance, servicing, repairing or disposing of cooling systems or equipment (however, they do not include minimal releases associated with the recapturing or recycling of ozone-depleting substances).

Emissions from shipboard incinerators
Incineration on board of ships is normally allowed only in a dedicated incinerator, with the specific requirements defined under MARPOL Annex VI. Examples of the main requirements are the temperature of the exhausts in the 800-1200°C range; the unburned components in ash residues at maximum 10% w/w; and the CO in the exhaust maximum average 200mg/MJ. However, it is possible to incinerate sewage sludge and sludge oil generated during the normal operation of a ship, but not within ports, harbours and estuaries.

Volatile Organic Compounds (VOCs)
According to the provisions of MARPOL Annex VI, VOCs emissions from cargo are to be regulated only for tankers (oil or chemical ones) and only in ports or at terminals. This regulation also applies to gas carriers when the type of loading and containment systems allow safe retention of non-methane VOCs on board or their safe return ashore. Following on from the regional instruments put in place to prohibit the release of gaseous cargo residues (vapours) that are harmful to the environment (i.e. degassing and venting) for inland navigation vessels (CDNI, 2017) attention will now turn to analyse how these might be applied to the maritime transport sector too.

European Union framework
At EU level there are several legislations that target air pollution, however not all of them are specific to the maritime transport sector. Besides the ratification of international conventions such as the Air Convention (LRTAP), EU directives limit the national emission totals of pollutants by Member States, including the transport sector. One example is the National Emission Reduction Commitments directive (NEC Directive), which entered into force in 2016, replacing existing rules on the annual ceilings for national emissions (Directive 2001/81/EC) and set national emission reductions for the Member States including for NOx, NMVOCs, SO_2, NH_3 and $PM_{2.5}$ ([45]). The objective is to achieve levels of air quality that do not give rise to significant negative impacts on and risks to human health and the environment.The Zero Pollution Action Plan further defines these targets for the target year 2030 to improve air quality to reduce the number of premature deaths caused by air pollution by 55% and to reduce by 25% the EU ecosystems where air pollution threatens biodiversity, both targets compared to 2005. Finally, the NEC Directive also requires that the Member States draw up national air pollution control programmes, which should contribute to the successful implementation of air quality plans established under the Ambient Air Quality Directive (AAQD) (EU, 2016c).

Regarding sectoral legislation applicable to shipping, the following EU regulations and directives exist:

Sulphur oxides (SOx)
At the European level, the sulphur content of liquid fuels, including those for ships, has been regulated since 1999 with the Directive 1999/32/EC (the 'Sulphur Directive') (EU, 1999) and since then limits have been continuously reduced by several amendments in 2005 and 2012 respectively. The Directive (EU) 2016/802, (EU, 2016a) codified in 2016, broadly transposes in EU law the IMO limits on the sulphur content of marine fuels to 0.10% m/m inside SECAs as of 2015 and to 0.50% m/m in all other areas as of 2020, while a limit of 0.10% sulphur content also for ships at berth in EU ports was established in 2005.

Member States are responsible for the enforcement of this directive for all vessels of all flags, including vessels whose journey began outside the EU, in their territorial seas and exclusive economic zones, including the domestic one. Furthermore, Member States, 'shall endeavour to ensure availability of marine fuels that comply with the Directive' and inform the European Commission of such availability in its ports and terminals. The specific abatement methods defined by the directive are mixture of marine fuel and boil-off gas, biofuels and EGCS.

Nitrogen oxides (NOx)
While there is no direct EU regulation for NOx, EU legislation broadly addresses NOx reduction from international shipping. EU Member States are required to comply with the international legislation under MARPOL Annex VI and the NECAs. Attention

([45]) In addition, if available, the NEC Directive requires member states to report also on PM_{10}, black carbon and thermoplastic starch (TPS), metals such as cadmium, lead and mercury and POPs, polycyclic aromatic hydrocarbon (PAH), dioxins, furans, polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCBs), as agreed under the Gothenburg Protocol.

is wide and concerns were raised at the IMO because of current non-compliance. Indeed, applicable limits are being checked through emission remote sensing in NECAs at low engine loads. Moreover, NOx engine standards applicable in the EU for inland vessels are among the strictest in the world.

Particulate matter (PM)
At the EU level, particulate matter is broadly regulated. Emissions from engines used in Inland waterway vessels and rail are limited within the Non-road mobile machinery Directive (EU, 2016b), however in a less restrictive way when compared with road transport (DNV, 2016). The revised AAQD (EU, 2024) and the NEC Directive (EU, 2016c) cover PM in their reporting, which are not directly linked with the maritime transport emissions. Regarding road transport, European legislation covers this emissions both on particle mass and particle number (see Euro 6 Regulation – Regulation (EC) No 1151/2017) (EU, 2017b) and Euro VI - Regulation (EC) No 582/2011 (EU, 2011)).

Black carbon (BC)
While at the European level there is no regulation in place for the shipping sector, within the NEC Directive, Member States have a reporting obligation for BC, whenever they monitor this pollutant. Reports are also being developed to support international actions. As an example, the EU-funded action on black carbon occurred from 2018-2020 to develop knowledge on sources and emissions, while supporting international processes. In addition, the recent EU policy for the Arctic also makes a reference to black carbon (EC, 2021e).

Ozone depleting substances (ODS)
International agreements have been transposed into EU policy frameworks since the 1980s, with a high-level of ambition for the fast phase-out of ODS. The Regulation on Substances that Deplete the Ozone Layer aims to fulfil the Montreal Protocol and also adds new, additional requirements to prevent emissions (EU, 2024). In general, ODS production, use and trade are prohibited in the EU with only few exemptions. Moreover, the intentional release of ozone-depleting substances into the atmosphere is prohibited under this Regulation, including when contained in products and equipment. All feasible measures must be taken to avoid unintentional emissions.

Monitoring and reporting framework

Air pollution inventories
The joint EMEP/EEA (European Monitoring and Evaluation Programme /European Environment Agency) air pollution inventories for navigation are annual estimates provided by Member States based on fuel consumption. These inventories are the outcome of the reporting required under the Air Convention (Article 8) and include emissions of CO_2, CH_4, N_2O, carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), SOx, NOx and PM for all water-born transport ranging from recreational craft to large ocean-going cargo vessels. For the purposes of the inventories, the definition of both navigation and fishing activities are consistent with ones defined under the auspices of the IPCC reporting and presented previously in the GHG section.

Sulphur oxides (SOx)
The Sulphur Directive requires EU Member State to ensure frequent and accurate sampling of the marine fuels available on the market or to be used on board ships, as well as regular verifications of the ships' logbooks, bunker delivery notes and sampling of the fuel on board ship.

Furthermore, Member States must deliver an annual report to the European Commission (by 30 June) fulfilling several requirements on the monitoring and sampling carried out in the previous year, such as total annual number of vessels inspected, samples taken, as well as non-compliant vessels, penalties applied, a list of all the name and address of marine fuels suppliers in the relevant Member States, etc.

According to the Directive, ships must keep onboard information regarding the fuel used and in case of inspection produce the evidence. The Sulphur Directive also stipulates that the ship's logbook should be correctly completed including fuel-changeover operations when entering in SECA areas. In 2015, a Commission Decision (EU) 2015/253 laid down the rules for the fuel sampling and reporting aiming for the cost-efficient and coherent implementation and enforcement of the directive (EC, 2015). It defines the fuel sampling methods and information to be included in the annual report and, defines that Member States shall inspect 10% of the ships' logbooks and bunker delivery notes on board from the total number of individual ships calling in EU ports per year.

Nitrogen oxides (NOx)
The control of Diesel engine NOx emissions is achieved through the survey and certification requirements leading to the issue of an Engine International Air Pollution Prevention (EIAPP) Certificate and the subsequent demonstration of in-service compliance in accordance with the requirements of the mandatory regulations, NOx Technical Code 2008 (resolution MEPC.177(58); IMO, 2008). This is performed in an early stage in laboratory on a test bed (pre-certification) or directly on board (combined pre-certification and initial certification). In both cases, this is done according to standard test cycles with predefined speed and load profiles and performed in reference conditions. Ensuring compliance with the limits established in MARPOL Annex VI should translate into low NOx emissions in real applications. Nevertheless, for this to take place, testing conditions must be fully representative of those encountered in real world operation in term of load profiles, ambient temperature, fuel quality, etc.

Particulate matter (PM)
From a monitoring perspective, although there is no specific reporting and monitoring scheme exclusively dedicated to PM emissions, the existing reporting and monitoring mechanisms, along with regulatory measures targeting SOx, NOx, and fuel quality indirectly contribute to the reduction of PM emissions from the maritime sector. There are inventories targeting PM, however, these inventories are estimations based on calculations of local emission factors linked to fuel consumption. The challenge is to accurately determine emission factors which adequately reflect the variety of ship operations, a problem which is further complicated by the fact that available PM measurement tools are not commonly used in the shipping sector (DNV, 2016).

Observations from remote piloted aircraft systems and other remote sensing technology used by Member States

EMSA's remotely piloted aircraft systems (RPAS) services are designed to assist with maritime surveillance activities linked with the implementation of Member States' coast guard functions. These unmanned aerial vehicles (or drones) are equipped with different types of sensors and cameras that can collect and transmit real-time data to users, helping them with tasks such as monitoring ship emissions, detecting oil pollution, and maritime surveillance operations.

RPAS can be used for air pollution monitoring by using gas sensors ('sniffers') to measure the SOx, and CO_2 content in a ship's plume. The fuel sulphur content (FSC) of the ship's fuel can be estimated by considering the ratio between SOx and CO_2, adjusted by an emission factor. In the case of nitrogen, the emission can again be estimated by considering the ratio with CO_2 and additionally factoring in the fuel efficiency of the engine, expressed in g/kWh. Both fuel sulphur content and NOx emission rates are estimated with a certain level of uncertainty, which under specific circumstances may account to up to 30% (FSC) and 50% (NOx emission rate) of the value.

EMSA's RPAS are also equipped with optical cameras and AIS receivers, which can capture images of the monitored vessels and retrieve their information, such as geographical position and heading. Data related to fuel sulphur content is also shared with the EU platform that logs and exchanges information on the results of individual compliance verifications conducted by Member States' competent authorities under the Sulphur Directive (THETIS-EU).

The gas measurements gathered by RPAS complement the emission monitoring activities undertaken by Member State authorities, ensuring all vessels transiting in European waters comply with legal requirements. Specifically, aerial measurements may be collected in open sea areas, where inspections are not feasible and/or when vessels do not expect measurements (for example in high seas SECA areas).

A1.2 Water pollution

Ships can be a source of pollution in sea water which covers all types of releases that can originate from the normal operations of a ship as well as accidental releases. The pollution includes several types of substances such as oil, chemicals carried in bulk, garbage or sewage, other discharge waters and contaminants emitted into the water column, such as anti-foulants, as well as ballast waters, pollutants deposited via the atmosphere and underwater radiated noise. A ship-related pollution problem arises from the dredging and relocation of contaminated sediments in waterways and ports.

A1.2.1 Contaminants and oil spills

Regulatory framework

International framework

From an international perspective, the MARPOL Convention (The International Convention for the Prevention of Pollution from Ships) covers the regulations for the prevention of pollution and details the discharge requirements for ships (IMO, 1983). The introduction of MARPOL in 1983 was the response to the rising number of tanker accidents in that period. The convention introduced several concepts and regulations that paved the way for safer procedures to prevent the occurrence of oil spills. These concepts include separated ballast tanks, double hull regulation, together with other safety-related instruments such as enhanced seafarers training.

Oil

MARPOL Annex I covers the regulations for the control of pollution by oil. For example, it is illegal if a ship discharges oil with concentration above 15ppm (parts per million). This applies to tankers above 400GT while en route outside a special area, for oil, which originates from cargo pump room bilges and has not been processed through oil filtering equipment.

Noxious substances

MARPOL Annex II covers the regulations for the control of pollution by noxious liquid substances in bulk. For example, it is illegal if a ship discharges noxious liquid substances at a rate exceeding the maximum rate for which the underwater discharge outlets were designed. This applies to ships while en route at a speed less than 7 knots discharging residues of noxious liquid substances in Category X, Y or Z (as per the International Bulk Chemical Code) at a distance less than 12NM from the nearest land and in a depth of water less than 25m.

Goods containing harmful substances
MARPOL Annex III covers the regulations for the control of pollution by harmful substances carried by sea in packaged form. For example, it is illegal if a ship jettisons harmful substances in packaged form where it is not necessary for securing the safety of the ship or saving life at sea. This applies to the jettisoning of packaged goods as per the International Maritime Dangerous Goods Code.

Sewage
MARPOL Annex IV covers the regulations for the prevention of pollution by sewage from ships. Ships shall be equipped with a sewage system which can be either a type approved sewage treatment plant, a comminuting and disinfecting system approved by the flag state or a holding tank with capacity to retain on board all sewage. The discharge of sewage into the seawater is prohibited except when ships have in operation an approved sewage treatment plan or are en route at a speed not less than four knots and at a distance of more than 12NM from the nearest land if not comminuted or disinfected. The Baltic Sea has been IMO designated as a special area under MARPOL Annex IV, with special provisions for the discharge of sewage from passenger ships (including cruise ships) in that area, as well as additional standards for both nitrogen and phosphorus.

Garbage
MARPOL Annex V (garbage) regulates the discharge into the marine environment of plastic, domestic wastes, cooking oil, incinerator ashes, operational waste, fishing gear and animal carcasses generated during the normal operation of the ship and liable to be disposed of continuously or periodically. For example, it is illegal if a ship discharges garbage food waste, which cannot pass through a screen with openings less than 25mm. This applies to ships while *en route* within a special area at a distance less than 12NM from the nearest land and for food waste which was not comminuted or grounded.

<u>European Union framework</u>
The Ship-Source Pollution Directive (SSP Directive) (EU, 2005), tackles the issue of illicit discharges from ships and thereafter introduces rules for adequate penalties for infringements (EU, 2005, 2009b).

Geographically, the SSP Directive covers illegal discharges of polluting substances carried by any ship except for warships or other state owned or operated ships used only for government non-commercial service. Ships are covered by this directive irrespective of their flag and the maritime zone in which the illegal discharge was committed. It encompasses all shipping maritime zones in regional seas as set under international maritime law as well as the United Nations Convention on the Law of the Sea (UNCLOS, 1982), from a territorial waters to the high sea (including straits used for international navigation to the extent that an EU Member State exercises jurisdiction over them).

The SSP Directive defines infringements caused by ships and obligations of Member States to follow up such infringements. It implies that the penalties imposed must be effective, proportionate and dissuasive. The SSP Directive works together with the Directive on Port Reception Facilities (PRF Directive) which ensures adequate facilities for ships to discharge their waste in ports.

The SSP implies penalties for the following offences:

- if a discharge of oil is illegal based on international standards set in MARPOL Annex I;

- if a discharge of noxious liquid substances in bulk is illegal based on international standards set in MARPOL Annex II;
- if a discharge of harmful substances carried by sea in packaged form is illegal based on international standards set in MARPOL Annex III;
- if a discharge of sewage is illegal based on international standards set in MARPOL Annex IV;
- if a discharge of garbage is illegal based on international standards set in MARPOL Annex V;
- if a discharge of waters and residues from EGCSs (scrubbers) is illegal based on international standards set in MARPOL Annex VI.

Monitoring and reporting framework

Prior to 2024, the Ship-Source Pollution Directive required Member States authorities to report on its application every three years. However, there were no requirements for the type of information to be reported and as a result there was little information collected. With the 2024 amendment of the SSP Directive, the reporting framework has been improved and more monitoring data will be available to analyse of pollution incidence and penalties imposed. (EC, 2023e).

CleanSeaNet service

The SSP Directive was the impetus behind the creation of the CleanSeaNet service, the European satellite-based oil spill monitoring and vessel detection service, set up and managed by EMSA. The service supports EU Member States and countries of the European Economic Area in detecting and tracing illegal discharges at sea of mineral oil and noxious liquid substances that behave like oil, which in turn enhances Member States' capabilities in addressing illegal discharges from ships to penalise them. Alert reports are generated and sent to the affected Member States in near real time (around 20 minutes after satellite overpass), who then validate the information by their own means for verification on site or inspecting the vessel of the 'potential polluter' at port. Verification feedback from Member States is important in confirming and providing additional information on the pollution type and its source (e.g. offender). Member State can report not only CleanSeaNet service feedback forms on the possible pollution identified but also by pollution incident reports (POLREP) exchanged as part of SafeSeaNet and inspection requests related to suspected MARPOL infringements submitted via THETIS. For example, Member States submit on average only approximately 200 SafeSeaNet pollution incident reports and 120 inspection requests via THETIS annually ([46]). Feedback to CleanSeaNet alerts is higher, with Member States submitting on average 1400 feedback forms annually ([47]).

Voluntary reporting procedures regarding ship-source pollution exist at regional level under the Regional Sea Conventions in Europe. Reporting by relevant parties to Regional Sea Conventions is more advanced in some regions e.g. Baltic and North Seas (where reports on aerial surveillance activities are published annually) and less advanced in others like the Black Sea. In 2022 contracting parties reported to HELCOM ([48]) and 10 contracting parties to the Bonn Agreement ([49]) on oil spills. The regional reporting commitments are however limited to a regional sea which means a narrow geographical scope.

([46]) Compilation of data for period 2012-2021.
([47]) Compilation of data for period 2012-2020.
([48]) HELCOM is an intergovernmental organisation for the environment of the Baltic Sea. HELCOM consists of ten members – the nine Baltic Sea countries Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden, plus the European Union.
([49]) Bonn Agreement is an intergovernmental environmental agreement for the greater North Sea and its wider approaches. The contracting parties of the Bonn Agreement are Belgium, Denmark, the European Community, France, Germany, Ireland, the Netherlands, Norway, Spain, Sweden and the United Kingdom.

International IMO reporting procedures regarding observed ship source pollution and relevant MARPOL enforcement cases also exist. Article 11 of the MARPOL Convention requires parties to the convention to communicate to the IMO certain types of information, including 'an annual statistical report, in a form standardised by the Organisation, of penalties actually imposed for infringement of the present Convention' (IMO, 1983). Reporting to the IMO on marine incidents, including marine safety investigations, has been low and with significant gaps for European parties of IMO. There is no representative information on the number of incidents nor penalties imposed. Contracting Parties of MARPOL should submit their reports using the Global Integrated Shipping Information System ([50]).

A1.2.2 Discharge waters

In addition to MARPOL Annex I and II, several other types of ship source pollution and water discharges from ships are regulated. These include sewage, oily discharges, ballast waters and discharge waters from EGCS in Annex VI. EGCS are also known as scrubbers, which are an abatement technology that aims to reduce SOx emissions from high sulphur fuels by using a fine alkaline water spray through the gas that will produce the SOx, (and to certain extent NOx and other contaminants such as black carbon, PAH and metals) to be dissolved and washed out during the scrubbing process. The development of this type of technology is driven by the introduction of Sulphur Emission Control Areas (SECAs) and by the global sulphur cap mentioned in section A1.1.2 Air Quality and depletion of the ozone layer.

The scrubber process avoids pollution from SOx emissions from high sulphur fuels to the atmosphere and produces acidic wash water as a by-product. Discharges from the scrubbing process to the marine environment may therefore be harmful if the discharge water is not treated in an appropriate way (Ji et al., 2023; et al., 2023). A set of potentially toxic contaminants such as nitrates, metals and other organic compounds may, in fact, be transferred to the marine environment (scrubber water discharges) as a result of the offset of air pollution (reduced SOx emissions to the atmosphere) (García-Gómez et al., 2023; Jönander et al., 2023; Hermansson, et al., 2023a; 2023b; Marin-Enriquez et al., 2023; OSPAR Commission, 2022; Petrović et al., 2022).

Regulatory framework

International framework

In the case of EGCS, at IMO, the discussion on the importance of not transferring such pollution from air to sea has started and attention has been brought to this issue with the adoption of different documents, such as MEPC.340(77) and MEPC.1/Circ.899 on scrubber discharge waters (IMO, 2021c, 2022a) and MEPC.1/Circ.900 on scrubbers' residues delivery to port reception facilities (IMO, 2022b). The transfer of pollution, is covered under the United Nations Convention on the Law of the Sea (UNCLOS), among others, under Article 195, where it is stated that there is a 'duty not to transfer damage or hazards or transform one type of pollution into another' (UNCLOS, 1982). Potential conflicts between the regulations in place and UNCLOS are currently being discussed at the IMO (see for example document IMO MEPC 81/9 (IMO, 2024).

European Union framework

The key EU legislation for scrubber discharge waters is the Sulphur Directive. While there is not a specific EU policy framework regulating the use of EGCS, the MARPOL regulations have been transposed into EU law as an alternative method of compliance with the international standards on SOx emissions by the Sulphur

([50]) International Maritime Organization GISIS database: https://gisis.imo.org/Public/Default.aspx.

Directive. Furthermore, EGCS residues, including wash wasters that do not conform with the IMO discharge criteria into sea are covered by Directive (EU) 2019/883 on Port reception facilities for the delivery of waste from ships and the revised ship-source pollution Directive (EU, 2019a). Lastly, EGCS water pollution can be connected with other European level legislations regulating the marine environment and ship waste, that regulate pollutants that among others, are present in the wash water discharges of EGCS, such as (metals and contaminants) through Directive 2008/105/EC Environmental Quality Standards (EQS) (EU, 2008b), Directive 2008/56/EC Marine Strategy Framework (EU, 2008a) and Directive 2000/60/EC Water Framework (WFD) (EU, 2000).

Monitoring and reporting framework

From a monitoring perspective, the current international framework provides tools under two international non-binding instruments: (1) the 2021 IMO EGCS guidelines (resolution MEPC.340(77)), which provides a set of criteria and schemes to be followed on the testing, survey, certification and verification of the EGCS (IMO, 2021c); and (2) The 2022 IMO Guidelines for risk and impact assessment of the discharge water from ECGS (MEPC.1/Circ.899), which provides a harmonised and unified approach to be used by Member States when considering local or regional regulations to protect sensitive waters/environment from the discharge water from EGCS (IMO, 2022a).

The IMO 2021 EGCS Guidelines establishes a methodology with two schemes for approval of an EGCS by the administration that aims to ensure that scrubbers are effectively meeting the sulphur emission reductions and comply with the emission ratio limits and the environmental criteria for the system's water discharges, leaving the door open to future binding regulations. The discharge of water according to the guidelines is predicted to comply with water quality criteria, pH, PAH, turbidity, suspended particulate matter, nitrates, wash water and discharge water additives and other substance and discharge water from temporary storage.

The EU aims to revise the guidelines. It is expected that the work triggered in 2019 is finalised by 2025 with a possible regulatory development, through the output on Evaluation and harmonisation of rules and guidance on the discharge water from EGCS into at the aquatic environment, including conditions and areas. The European Commission has been very important for developments at IMO, with several submissions on the health and environmental impacts and toxicity of EGCS discharges, asking for the revision of MARPOL to add a clear definition of what are discharge waters (IMO, 2019a, 2019c, 2021a, 2023b).

The IMO Guidelines for risk and impact assessment of the discharge water from EGCS (MEPC.1/Circ.899) and the application of such recommendatory guidelines should be used by Member States when undertaking national, local or regional level risk and impact assessments regarding EGCS discharge water in their territorial waters. Considering various metals as cadmium, lead, nickel and vanadium and also various PAH such as acenaphthene, benzo(a)anthracene and pyrene. Also including in the analysis data concerning and available on a database in the IMO, are physico-chemical data, ecotoxicological data and toxicological data.

However, due to the lack of binding regulations to further control the use of ECGS and resulting wash, a growing number of Member States have restricted or banned the use of scrubbers in high-traffic areas like ports and canals due to their environmental impacts, by introducing, either under national legislation or through Port Authorities, additional conditions for the operation of scrubbers. These measures vary from not allowing discharges of wash waters from open-loop (OL) scrubbers in specific port areas to the prohibition of wash water discharges within 3NM from the coast. To date, restrictions (or bans) are in force in 16 EU and EFTA countries including Belgium, Croatia, Cyprus, Estonia, Finland, France, Germany, Ireland, Latvia, Lithuania, Norway, Portugal, Romania, Slovenia, Spain and Sweden at different levels (EGCS Association, 2023). Information on Bulgaria, Denmark, Greece, Malta, The Netherlands and Poland is not available. In addition, work is progressing towards potentially adopting binding regulations in MARPOL Annex VI to regulate the discharge waters from EGCSs.

With the ambition of further reducing the emission of SOx and the Europe's collective objective to expand SECA regions, we can expect the use of EGCS to increase in the future. According to a recent study by DNV, the global fleet equipped with scrubbers is bound to continue to increase in the following years, with numbers exceeding the 5,000 scrubber-equipped vessels currently registered in 2023 (DNV, 2023a).

A1.2.3 Ballast water and non-indigenous species

Non-indigenous species (NIS) also referred as non-native, alien, invasive or exotic organisms, refer to species that have been introduced to environments outside of their natural range through human activities, including shipping. NIS are called invasive alien species (IAS) when they create serious negative consequences for their new environment.

Currently, around 800 NIS exist in the regional seas (EC and JRC, 2021) and approximately 87 NIS are recognised as invasive in European marine environments (EEA, 2023a). The largest proportion of NIS introductions into regional seas are associated with shipping, via ballast waters and ship hauling (46.6%). Ballast water is used to maintain ship stability during voyages and it is often taken up in one location and discharged in another, so in addition to the introduction of non-native species, the movement of contaminants such heavy metals, poisons or pharmaceutical ingredients can also be a worry (Lv et al., 2022).

Regulatory framework

International framework

At global level the regulatory framework is based on the International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention), which entered into force globally in September 2017 (IMO, 2004). The BWM Convention applies to all ships carrying ballast waters during international voyages. From September 2024, the requirements to carry an International Ballast Water Management Certificate, an approved Ballast Water Management Plan, a Ballast Water Record Book and to meet the D-2 performance standards will apply to all internationally trading ships of 400GT and above. This standard specifies the maximum number of viable organisms in the ballast water discharge (IMO, 2004).

European Union framework

One of the key commitments of the Biodiversity Strategy is to manage established invasive alien species and decrease the number of Red List species – the species that face the risk of extinction – that IAS threaten by 50%. To tackle Invasive Alien Species (IAS) Regulation (EU) No 1143/2014 sets out guidelines to prevent, minimise and mitigate the negative impact of IAS on biodiversity. (EU, 2014b).

The MSFD (EU, 2008a) definition of 'good environmental status' includes a descriptor for preventing adverse alterations to ecosystems caused by NIS.

Monitoring and reporting framework

From a BWM Convention perspective, the number and share of the ships that meet D-2 standard might allow to assess the progress on preventing the spread of NIS and IAS. In addition, an indicator monitoring the decrease of the number of Red List species threatened by the IAS by 50% is currently under development and will be used to monitor the Biodiversity Strategy 2030 (EC, 2023f). MSFD follows an adaptive management approach and thus it must be kept up-to-date and reviewed every six years.

A1.2.4 Underwater radiated noise

Shipping is known to be one of the primary contributors to anthropogenic noise in seas and oceans. Given the characteristics of sound propagation in water and anatomical adaptations, sound serves as the primary mechanism for fauna to interact with the surrounding environment. This includes various functions such as social interactions, reproduction, navigation and the detection of obstacles and prey, especially in environments where light penetration is limited at greater depths. Available evidence shows that shipping contributes to the impacts generated by URN (Cruz et al., 2021; Duarte et al., 2021; Erbe et al., 2019). Several policies are being implemented under the auspices of international multilateral agreements, Regional Sea Conventions and at the EU level.

Regulatory framework

International framework

At international level, in 2023 the IMO successfully reviewed the Guidelines on the reduction of Underwater Radiated Noise (IMO, 2023e). These guidelines, originally proposed in 2014, are intended to assist all relevant stakeholders in establishing mechanisms through which URN reduction efforts can be achieved and recommend shipowners and designers to undertake noise management planning at the earliest design stages. Similarly, URN management planning may be conducted for existing ships. The guidelines provide for the development of a noise management plan that allows a customized approach suitable to an individual ship's design and operation, as well as the establishment of the (predicted or actual) baseline URN level, setting quantitative targets where possible and selecting the URN reduction approaches and related actions.

The revised guidelines also include a dedicated section about the relationship between the Energy Efficiency Compliance Measures and URN. Many of the energy efficiency improvement options to meet energy efficiency regulations (EEDI, EEXI and CII) can result in an improvement in URN performance and could therefore provide positive synergies with climate policies ([51]). The Guidelines also provide a role for Member States administrations and other stakeholders to take supportive actions in defining noise sensitive areas and species, possibly setting future overall URN targets, establishing incentives programmes and on evaluation and monitoring.

European Union framework

Underwater radiated noise is addressed in the EU through the Marine Strategy Framework Directive, which introduces threshold levels and requires the monitoring of underwater noise levels and its adverse effects in EU waters.

One flagship action of the Zero Pollution Action Plan is reducing URN through the EU threshold values to be set under the Marine Strategy Framework Directive (EC, 2021g). The Commission (through the work of the Technical Group on Noise – TG NOISE) established the threshold values in 2022 (TG NOISE, 2022) for underwater radiated noise stemming from activities such as shipping, offshore construction and marine exploration. More specifically, Descriptor 11 of the MSFD covers the introduction of energy, including for continuous URN (to which shipping contributes) and requires that it must be at levels that do not adversely affect the marine environment ([52]).

([51]) See IMO Workshop on the Relationship between Energy Efficiency and Underwater Radiated Noise from Ships, 18-19 September 2023: https://www.imo.org/en/About/Events/Pages/URN-Workshop-2023.aspx.

([52]) Requirement is for Member States to establish threshold values on URN exposure, i.e. on Level for Onset of Biologically significant adverse effects (LOBE) and thereafter monitor and report on this indicator in their seas.

Monitoring and reporting framework

According to the 2017 Commission decision (EU, 2017a), GES for underwater radiated noise must be assessed based on two criteria, one of them being 'Anthropogenic continuous low-frequency sound', where shipping noise is included. The second criteria is that the spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sounds do not exceed levels that adversely affect populations of marine animals, which requires Member States establishing threshold values for these levels through cooperation at Union level, considering regional or sub-regional specificities.

A1.3 Marine litter and waste delivery at ports

A1.3.1 Marine litter, passively fished waste and container loss

Marine litter is defined as all human-made solid items that end up in the coastal or marine environment. The major cause is poor waste management and littering on land, however seaborne activities such as shipping and fishing also contribute to the problem (EEA, 2023b).

Up to a third of the litter generated by merchant shipping is not correctly delivered, disposed of and processed in port (EC, 2018).

Ship paints have also been identified as one of the largest and significant sources of microplastic pollution in the oceans (Gondikas et al., 2023). In macro and micro forms, sea-based sources account for around 20% of marine litter (UNEP, 2005; SEI, 2016).

The loss of containers is also considered as sea-based source of marine litter. Containers transport a great variety of goods, in which toxic products and hazardous substances exist. The loss of containers can lead to containers sinking without any further information about their origin or location. This may cause habitat destruction, especially if they open at sea and liberate the cargo or wash up on the shore.

Regulatory Framework

International framework

Marine litter is a transboundary problem. There is an ongoing process for an international binding agreement on plastics. In February 2022, during the fifth session of the United Nations Environment Assembly (UNEA-5.2), a significant resolution (UNEP/EA.5/Res.14) was adopted to establish an international legally binding agreement on plastic pollution and marine litter (Plastics Accord).The goal is to complete the negotiations by the end of 2024.

The IMO is taking action to address the issue of marine (plastic) litter from ships through a Strategy, adopted in 2021, aiming to achieve zero plastic waste discharges to sea from ships by 2025 (IMO, 2023c). Within this context, several initiatives to address marine plastic litter from ships and strengthen international legislation are ongoing at the IMO. One initiative includes the evaluation of regulatory measures to reduce the environmental risk associated with the transport of plastic pellets. The aim is to improve packaging, stowage on board, labeling, and disaster response and pollution preparedness (Faber, J. et al., 2023). To this extent, an IMO Circular for the carriage of plastic pellets by sea has been drafted and approved by the Marine Environmental Protection Committee (MEPC) at its 81st meeting as an initial measure to reduce the environmental risks associated with the carriage of plastic pellets in packaged form by sea (IMO, 2023c). This represents a first step in a “two-stage approach” that will determine the development of future mandatory measures. Additionally, there is an amendment to MARPOL Annex V to establish reporting mechanisms, modalities, and information requirements to be reported to Administrations and the IMO. This amendment aims to facilitate and enhance the reporting of the loss or discharge of fishing gear.

Recognising the serious hazard to navigation, safety at sea and marine environment from lost containers, the IMO has agreed to amend chapter V of the SOLAS Convention and protocol I of the MARPOL Convention with a view to make mandatory the reporting of lost containers through a standardised procedure from 2026 (IMO, 2022d).

European Union framework

The EU's Zero Pollution Action Plan (EC, 2021g) sets ambitious quantitative targets for reducing plastic litter at sea by 50% (in terms of number of items) and the quantity of microplastics released into the environment by 30% by 2030, taking 2016 as the reference year (EC, 2021g). These targets are supported by the Circular Economy Action Plan, which identifies plastics as one of its five priority areas. The EU Plastics Strategy (COM (2018) 028) specifically addresses the leakage of plastics and microplastics and includes the Single Use Plastics Directive (2019/904/EU) (EU, 2019) which focuses on targeting the ten most found single-use plastic items on Europe's beaches and seas as well as fishing gear containing plastics and the Port Reception Facilities (PRF) Directive 2019/883/EU which includes a requirement to dispose (at port) and report the amounts of passively fished waste (waste collected by fishers in during their fishing operations) including derelict fishing gear delivered by vessels to ports (EU, 2019a).

The MSFD creates a legally binding framework for assessing and monitoring litter quantities, spatial distribution and impacts in the marine and coastal environment and thereby plays a significant role in reducing marine litter and addressing the issue of marine plastic pollution from all sources in Europe.

The new fisheries Control Regulation (EU) No 2023/2842 (just entered into force on 9 January 2024), includes provisions making the reporting of lost fishing gear easier, with obligations to report the loss through electronic logbook, including for small scale vessels and on the retrieval of lost gears as well as requiring Member States to collect and record the information concerning lost gear and provide it to the Commission on request (EU, 2023e). In the updated Fisheries Control Regulation, the failure to fulfil obligations relating to marking of fishing gear and illegal disposal of fishing gear at sea are included in the list of serious infringements, for which MSs have to take additional enforcement measures.

At EU level, the issue of reporting/notification of lost containers is addressed in EU legislation through Directive 2002/59/EC on the establishment of a Community vessel traffic monitoring and information system (EU, 2002) and Directive 2009/18/EC governing the investigation of accidents in the maritime transport sector (EU, 2009a). Directive 2002/59/EC requires that ships report to the coastal Member States containers or packages seen drifting at sea.

Monitoring and Reporting Framework

The Port Reception Facilities (PRF) Directive (EU, 2019) imposes obligations on Member States to collect and report monitoring data on passively fished waste from fishing vessels. Some countries utilise existing schemes such as the Fishing for Litter initiative (KIMO, 2023) to collect passively fished waste data as part of their marine litter monitoring. Passively fished waste can be considered as an indicator correlated to the quantities of litter in the sea. The first data were reported in 2021 (see Chapter 3 for the results).

The Single-Use Plastics (SUP) Directive requires Member States to report on the amounts of fishing gear placed on the market and waste fishing gear collected in ports. The first reporting period is calendar year 2022 with the data submission deadline to the EEA by the 30 June 2024. Waste fishing gear being also part of the passively fished waste, reported data will have to be analysed in relation to both reporting obligations.

Marine litter is also one of the GES descriptors (D10) of the MSFD. There is an ongoing effort at the Technical Group on Marine Litter to define GES threshold, which has already been achieved for the coastline, where the threshold has been set at 20 litter items per 100m of coastline. To achieve GES, Member States must establish and implement a programme of measures, including for the shipping sector, if necessary. Most countries reported on GES (MSFD Art.8).

As previously mentioned, plastic pellets could also be classified in the future as a 'harmful substance' under international maritime law, which would bring about more stringent obligations regarding their handling, as well as mandatory reporting should containers be lost at sea. Discussions regarding are ongoing at the IMO, supported by the EU. Monitoring efforts should also focus on the impacts of these pellet losses on the environment, fauna and human health (including disruption of ecosystems, destruction of habitats, ingestion by wildlife, contamination, etc.).

Finally, although reporting lost containers is mandatory at the EU level and will become mandatory internationally as of 2026, there is currently no prescribed procedure for what to do next. Under the Nairobi International Convention on the Removal of Wrecks, cargo lost at sea from ships are defined as wrecks and both shipowners and maritime administrations are required to, inter-alia, report, locate, mark and remove hazardous wrecks. Its practical recovery is extremely challenging, however, due to untraceability (IMO, 2007; Jo, 2020). Future mechanisms for liability and compensation could also be considered to avoid, clean-up activities being paid for by the coastal municipalities instead of the polluters, for example. To report containers lost at sea within the EU, a reporting model has been developed through SafeSeaNet and has been systematically used since 2012 (EU, 2002). In addition, data reported to the European Marine Casualty Information Platform (EMCIP), as part of the Directive 2009/18/EC governing the investigation of accidents in the maritime transport sector, provides the most comprehensive overview of lost containers within EU waters (EMSA, 2011).

A1.3.2 Waste delivery at ports

Regulatory Framework

International framework

The MARPOL Convention and its Annexes contain general discharge prohibitions for a number of pollutants as described above and sets out the norms and conditions under which certain types of waste can be legally discharged into the marine environment. At the same time, MARPOL requires its contracting parties to provide for facilities in ports and terminals for the reception of the waste and residues from ships. These port reception facilities must be adequate, i.e. capable of receiving the types and quantities of waste from ships normally visiting the port where those facilities are located, without causing undue delay.

European Union framework

The PRF Directive was developed with the aim to protect the marine environment against the negative effects from discharges of waste from ships by improving the availability and use of adequate port reception facilities in the EU and the delivery of waste to those facilities.

In 2021, four implementing regulations were adopted to include specific definitions on the method to check if a ship has sufficient storage capacity for waste; the union risk-based targeting mechanism to select which ships to inspect; the criteria for determining that a ship produces reduced quantities of waste and manages its waste in a sustainable and environmentally sound manner; and the monitoring data methodologies and the format for reporting passively fished waste.

The PRF Directive also encourages lower waste generation and sustainable handling by ships. Ships must fulfil at least one of the mandatory criteria (either on-board waste segregation or adopting environmentally sustainable purchasing policies) to reduce the waste fee in EU ports. The directive also stipulates a minimum annual inspection requirement for vessels, allowing PRF inspectors to record waste disposal operations, which can contribute to the analysis of waste management at sea.

Monitoring and Reporting Framework

The PRF Directive mandates the electronic reporting of waste receipts from ships through the SafeSeaNet system in the EU. The waste receipts provide a valuable source of information on different waste types generated by ships and delivered at EU ports. The electronic reporting of waste receipts started in September 2022.

A1.3.3 Ship Recycling

Regulatory Framework

International framework

The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009 (the Hong Kong Convention or HKC), adopted in May 2009, aims to ensure that ships do not pose any unnecessary risks to human health, safety and to the environment, when being recycled after reaching the end of their operational lives. This also addresses issues such as ships going for recycling which may contain environmentally hazardous substances such as asbestos, heavy metals, hydrocarbons, ozone-depleting substances and others. It also addresses concerns raised about the working and environmental conditions at many of the world's ship recycling locations. The HKC applies to:

- ships entitled to fly the flag of a party to or operating under its authority;
- ships of 500GT and above or to ships operating throughout their life only in waters subject to the sovereignty or jurisdiction of the state whose flag the ship is entitled to fly;
- ship recycling facilities operating under the jurisdiction of a party.

The Hong Kong Convention (ratified by 11 EU Member States by the beginning of 2024) will officially enter into force on June 26 2025 and will cover:

- the design, construction, operation and preparation of ships so as to facilitate safe and environmentally sound recycling without compromising the safety and operational efficiency of ships;
- the operation of ship recycling facilities in a safe and environmentally sound manner;
- the establishment of an appropriate enforcement mechanism for ship recycling, incorporating certification and reporting requirements.

The convention requires that ships sent for recycling will need a ship specific inventory of hazardous materials (IHM), based on a list of hazardous materials included that are contained in an appendix to in the convention.

European Union framework

Regulation (EU) No 1257/2013 (EU, 2013b) on ship recycling (SRR) aims to prevent, reduce and minimise accidents, injuries and other negative effects on human health and the environment when ships are recycled and the hazardous waste they contain is removed. It sets out the following responsibilities for ship owners and for recycling facilities both in the EU and in other third countries:

- Every new and existing ship flagged to an EU Member State has to have an inventory of the hazardous materials on board ([53]).
- Before a ship flagged to an EU Member State is recycled, its owner must provide the facility carrying out the work with specific information about the vessel and that facility should prepare a ship recycling plan. This, for instance, identifies the type and amount of hazardous materials and waste that will be generated from the obsolete vessel.
- A ship flagged to an EU Member State may only be recycled at facilities listed on the EU List of facilities, which was established by Commission Implementing Decision (EU) 2016/2323. The facilities may be located in the EU or in non-EU countries. They must comply with a series of requirements related to workers' safety and environmental protection.
- These requirements are designed to prevent health risks to the workers involved and the neighbouring population and to minimise any adverse effects on the environment. They also provide for specific training and protective equipment for employees dismantling the vessels and require a record to be kept of any incidents or accidents.
- The legislation contains an authorisation process for ship recycling yards within the EU. Those in other countries must submit an application to the European Commission and demonstrate that they fulfil all the criteria in the regulation.

Article 12 of the SRR extends the requirement to have an Inventory of Hazardous Materials (IHM) onboard to all vessels entering an EU port, regardless of the flag. This must be certified through a Statement of Compliance from the flag state administration. Many flag states have met this requirement through using the IHM Certificate in the HKC text and adding a reference to the EU legislation to prove compliance.

One of the main differences between the HKC and the SRR is the requirement for EU flagged ships to be recycled in an EU approved ship recycling facility ([54]). The EU's Waste Shipment Regulation of 14 June 2006 applies within the EU the requirements of the Basel Convention on the Control of Trans Boundary Movements of Hazardous Wastes and their Disposal and also applies an amendment to the Convention adopted in 1995 (EU, 2006). The 'Basel ban' entered into force in 2019 and prohibits the export of hazardous waste from Member States to countries that are not members of the Organisation for Economic Cooperation and Development (OECD).

([53]) The SRR does not apply to: warships, naval auxiliaries or other ships owned or operated by a state and used for the time being only for non-commercial governmental services; ships of less than 500GT; and ships which throughout their life cycle are operated only in waters under the sovereignty or jurisdiction of the Member State whose flag they fly.

([54]) As of January 2024 there are 45 approved facilities — 35 in Europe and the UK, nine in Turkey and one in the United States.

Under the Waste Shipment Regulation, ships flying the flag of an EU Member State sent for dismantling are classified as hazardous waste because dangerous substances are present therein. The regulation covers only vessels that do not fall within the scope of Regulation (EU) No 1257/2013. However, with the future Regulation (EC) No 1013/2006, the ban to export end-of-life vessels for recycling in shipyards located in non-OECD countries will also apply to ships that become waste in the EU under Regulation (EU) No 1257/2013.

Monitoring and reporting framework

In accordance with Article 21 of the SSR, EU Member States must submit reports on ship recycling every three years, including information such as lists of ships to which a ready for recycling certificate has been issued and information on illegal ship recycling. Further to this, Article 30 of the SRR calls for a review of the Regulation 18 months before entry into force of the HKC. An evaluation is presently being undertaken to assess how well the regulation contributes to the general policy objectives of the European Green Deal and the circular economy action plan as well as how it has been applied and its impact to date and to identify shortcomings with its implementation and enforcement.

Issues being considered in the review include a financial measure to improve the number of ships being recycled in the EU listed facilities and improvements in implementation and enforcement. Today the regulation is largely circumvented by ship owners re-flagging their ships to non-EU flag, in particular flag of convenience, with the view to dismantle the ships in non-EU listed facilities, mainly in South Asia.

A1.4 Hazards and physical disturbance of the seabed

A1.4.1 Collisions with animals

Fast-growing maritime traffic, coupled with increased vessel speed and engine power, has heightened the risk of collisions between vessels and marine species (Schoeman et al., 2020). Collisions occur when vessels, ranging from large cargo ships to smaller recreational boats, unintentionally strike marine mammals and fish (Minton et al., 2021). The impact of collisions can be severe, leading to injuries, fatalities and resulting in population declines. Along the Atlantic and Mediterranean coasts, collisions are the main human-caused large cetacean deaths (Peltier et al., 2019).

Regulatory Framework

International framework

At the global scale, voluntary efforts are underway to minimise ship strikes. In 2009 the International Maritime Organization (IMO) developed guidelines to minimise the risk of ship strikes with cetaceans (IMO, 2016).

European Union framework

As part of the EU's Biodiversity Strategy for 2030, one of the targets is to legally protect at least 30% of Europe's seas by 2030, with 10% of the sea area designated as strictly protected (EC, 2020b). The Birds and Habitats Directives, along with the Natura 2000 sites designated under these directives, make a significant contribution towards achieving the strategic targets of the Biodiversity Strategy (EEA, 2023b). Natura 2000 sites preserve rare, threatened or vulnerable marine species and unique marine environments (EEA, 2018). The primary objectives of these protected sites are to reduce anthropogenic pressures that significantly disturb species or damage habitats and to implement positive measures, including mitigating ship collisions with marine mammals. One of the MSFD criteria of good environmental status for species requires that 'population abundance of the species is not adversely affected due to anthropogenic pressures, such that its long-term viability is ensured.' This implies that pressures impacting species' abundance, including collisions with ships, must be managed and reduced where necessary. The Marine Spatial Planning Directive 2014/89/EU (MSPD) mandates the establishment of marine spatial plans and allows Member States to implement spatial zoning, routing measures, speed restrictions or the establishment of traffic separation schemes to minimise the risk of ship strikes and disturbance to marine animals.

Monitoring and reporting framework

Country or regional level monitoring and assessments are currently being conducted as part of MSFD programme of measures. However, at the EU level, there is a lack of comprehensive monitoring schemes and indicators.

A1.4.2 Physical disturbance of the seabed

To safeguard marine biodiversity and living resources, it is essential to ensure the integrity of the seafloor in the face of pressures that could impact its functions and services. The physical disturbance of the seabed from maritime transport and port activities is linked to several human activities such as the expansion of port facilities, wake-induced habitat disturbance, dredging and anchoring. The main disturbance caused by anthropogenic activities is the re-suspension of sediments within the water column and the benthos, as well as abrasion from dredges and anchors. This has both short- and long-term negative repercussions on marine ecosystems, habitats and species diversity (Nylund et al., 2021).

Regulatory framework

International framework

International Maritime Law as well as relevant international conventions, including the United Nations Convention on the Law of the Sea (UNCLOS), sets obligations for the Coastal States to adopt laws and regulations to prevent, reduce and control pollution of the marine environment arising from or in connection with seabed activities subject to their jurisdiction (UNCLOS, 1982).

Furthermore, the Convention pays particular attention for the protection from harmful effects of activities such as dredging and also defines dumping as any deliberate disposal at sea of wastes or other matter from vessels (or other artificial structures at sea). The London Convention (London Convention, 1972) and Protocol (London Protocol, 2006) have very similar definitions, which translate into a list of waste or other material that can be considered for dumping including dredged material.

European Union framework

The MSFD GES descriptor six is related to seafloor integrity. It requires that 'seafloor integrity is at a level that ensures that the structure and functions of the ecosystems are safeguarded and benthic ecosystems, in particular, are not adversely affected' (EU, 2017a).

In 2024, an EC Communication set two thresholds for the good environmental status of seabed integrity (EC, 2024b). These include the maximum threshold of the benthic habitat that can be adversely affected (25%), including a maximum that can be lost (2%). In the case of maritime transport, the seabed areas likely to be under adverse effects or lost include port areas, anchoring areas and dredged shipping lanes.

Monitoring and reporting framework

There is no international framework for the monitoring of seabed disturbance in a systematic way. At the EU level, the MSFD requires that systematic monitoring is carried out of the extent and condition of seabed habitats and the impacts of human activities on seafloor integrity, including where relevant maritime transport. Member States must report to the Commission progress towards the achievement of the threshold values for good environmental status every six years.

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