European Maritime Transport Environmental Report 2021

European Maritime Safety Agency

European Environment Agency

European Maritime Transport Environmental Report 2021

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Commissioners' Welcome

We are particularly proud to present you this first *European Maritime Transport Environmental Report* (EMTER), which is the product of fruitful cooperation between the European Maritime Safety Agency and the European Environment Agency.

Maritime transport is an essential vector for European trade and a driver of economic growth across the internal market. It provides a vital lifeline linking the EU's islands and peripheral areas with the mainland and contributes to thriving economic hubs in coastal areas and around our ports.

Yet, at the same time — and despite progress over the years — maritime transport remains an important source of greenhouse gas emissions and other harmful pollutant emissions to water and to air. Continued action to reduce its environmental footprint is needed for the sector to play its part in turning Europe into a climate-neutral continent by 2050, meeting our zero pollution ambition and halting and reversing biodiversity loss.

Only an integrated approach that looks at all facets of the sector and the full range of its externalities, will allow us to ensure its successful transformation into one that is clean, in harmony with the environment and our planetary boundaries and works in the interest of all Europeans. This sustainable transformation will also be the very licence for maritime transport to continue growing and a guarantee of its long-term resilience as global competition intensifies.

This all-encompassing, 'whole-of-government' approach is also the philosophy behind recent flagship EU policy initiatives such as the Sustainable and Smart Mobility Strategy, the Zero Pollution Action Plan, and the new Blue Economy Strategy. But delivering on these policies will only be possible if we are able to base our actions on reliable, high-quality, up-to-date data and scientific evidence. That is why this report matters so much.

It is the first time such a broad range of data sources and information on the maritime transport and the environment have been brought together in one document. The report provides a comprehensive analysis of the maritime transport sector, its environmental impact, progress made so far, and the challenges it still faces going forward in terms of decarbonisation, pollution reduction, protection of biodiversity, circularity and climate adaptation. It further provides a clear overview of environmental standards and EU and international rules for shipping and the effects of those measures to date. In short, it is a reference document that will not only inform our own policy efforts to foster maritime transport's sustainable transition in the EU and at global level — but also inform our citizens of these efforts.

This important new evidence base is already providing us with a strong rationale for two important EU proposals aimed at supporting maritime transport to confront its challenges: FuelEU Maritime, which will kickstart the use of sustainable alternative fuels in the sector and the integration of shipping into the EU's Emissions Trading System. We are convinced that these initiatives will allow us to lead the way towards zero-emission, zero-pollution shipping, and chart our course towards a more competitive, modern, sustainable and resilient maritime sector that is fit for the future.

Virginijus Sinkevičius — European Commissioner for the Environment, Oceans and Fisheries
Adina Vălean — European Commissioner for Transport

Foreword

It is our pleasure to present the first *European Maritime Transport Environmental Report* (EMTER).

This report, the result of the joint effort of the European Environment Agency and the European Maritime Safety Agency in close cooperation with the European Commission, is yet more proof of the extraordinary potential and added value of cooperation between EU institutions.

The work on this report started at the end of 2019, in circumstances completely different to those we are all living under today. The COVID pandemic has had major implications for all of us, but we are proud that it did not influence the work on this report, neither in terms of quality nor timing.

This is the first edition of the European Maritime Transport Environmental Report, and we would like to stress that our focus and motivation has been to provide a factual analysis of the environmental dimension of the maritime transport sector, highlighting, when relevant, challenges and opportunities. As you will read, this report presents up-to-date information on the relevant EU and international environmental standards and describes current and future actions which may contribute positively to the reduction of the impact of maritime transport on our environment.

We are all aware that the maritime transport sector is essential when it comes to global trade and the economy, with a strong international dimension and with substantial economic and social benefits to the EU. At the same time, just like other economic activities, we also recognise that it has an impact on the environment, health and wellbeing of EU citizens.

Safeguarding the health and wellbeing of citizens and the environment alike is a key prerogative and objective of the EU. This is highlighted by the European Green Deal and its objectives, aims and targets as translated into the existing and future legislative frameworks, such as the EU Sustainable and Smart Mobility Strategy, the Zero Pollution Action Plan, FuelEU Maritime and Integrated Maritime Policy initiatives. Environmentally friendly, low carbon, digital and smart maritime transport should be seen as an opportunity rather than a challenge; an opportunity to build a leading position for European industries in new economic and technological fields benefiting European citizens, and to develop and transition to a more sustainable Europe, protecting and conserving nature and our ecosystems, developing knowledge and employing new technologies. For an international sector such as the maritime sector, building global partnerships in this process is essential.

It is important to highlight the trends and acknowledge the coordinated efforts and results already achieved in terms of decreasing the environmental footprint of the maritime transport sector. That is why this report also contains information on monitoring and reporting, existing and new mitigation technologies, research and development projects, as well as future trends and scenarios.

The transition to a more sustainable maritime sector is a political, social and economic prerogative. It is only by working together, as we did during the process that led to this report, that we will reach the common goal of providing high-quality maritime services, while reducing pollution and negative effects on our climate and on marine biodiversity and transition to sustainability.

Maja Markovčić Kostelac — EMSA Executive Director
Hans Bruyninckx — EEA Executive Director

Acknowledgements

The *European Maritime Transport Environmental Report* (EMTER) was prepared by the European Maritime Safety Agency (EMSA) and the European Environment Agency (EEA). Its development was coordinated by a Steering Group made up of representatives of these two organisations and the European Commission.

The Steering Group gratefully acknowledges the following organisations for the provision of data and analysis used in the report: Finnish Meteorological Institute (FMI), Ecologic Institute EU, AZTI (Technological Center for Marine and Food Research), Fundación Valenciaport and Finnish Environment Institute (SYKE).

The following European Commission Directorates-General provided helpful comments on the various versions of the report: Mobility and Transport, Environment, Climate Action, Joint Research Centre, Maritime Affairs and Fisheries, and Research and Innovation. In addition, the Innovation and Networks Executive Agency (INEA) supported the report with information on EU projects in the area of sustainable maritime transport.

Member States, industry associations and civil society representatives were invited to provide comments on the report as well as additional information in the context of the EMTER Stakeholder Consultation. Substantial inputs were received from several stakeholders, which helped in improving the text and formed essential inputs to the report. EMSA and EEA would like to thank all experts involved in this process for their fruitful contributions, provided during the EMTER Stakeholder Consultation workshop (which took place on 2 December 2020) and the written consultation exercise.

The experts who provided written comments include (in alphabetical order) Anita Künitzer (German Environment Agency, Germany), Antidia Citores (Surfrider Foundation), Bernard Vanheule (Costa Crociere), Commander Vernardaki Foteini Nikoletta (Hellenic Coast Guard, Greece), David Loosley (Baltic and International Maritime Council), Don Gregory (Exhaust Gas Cleaning Systems Association), Dorte Kubel (MAN Energy Solutions), Dragos Rauta (International Association of Independent Tanker Owners), Faig Abbasov (Transport and Environment), Florent Le Courtois (Naval Hydrographic and Oceanographic Service, France), Helén Johansson (Swedish Transport Agency, Sweden), Henk Prins (MARIN), Ida-Maja Hassellöv (Chalmers University of Technology, Sweden), Irina Haesler (German Shipowners Association), John Maggs (Seas at Risk), Jorma Kämäräinen (Finnish Transport and Communications Agency, Finland), Laura De La Torre (Convention for the Protection of the Marine Environment of the North-East Atlantic), Martin Dorsman (European Community Shipowners Association), Michel Traa (Netherlands Environmental Assessment Agency, Netherlands), Nadia Deckert (United Nations Environment Programme — World Conservation Monitoring Centre), Océane Rignault (Ministry of the Sea, France), Paul Altena (Cruise Lines International Association), Philip Easthill (European Boating Industry), Poul Woodall (Clean Shipping Alliance), Sophie Delair (Euroshore), Tatjana Hema (United Nations Environment Programme — Mediterranean Action Plan), Tim Wilkins (International Association of Independent Tanker Owners), Tom Strang (Carnival Corporation), Valter Selen (European Sea Ports Organisation) and Yerzhan Nauruzbayev (Ecumene).

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Executive summary

The *European Maritime Transport Environmental Report* (EMTER) provides a factual analysis of the environmental pressures exerted by the maritime transport sector, presents up-to-date information on the relevant EU and international environmental standards and describes current and future actions to reduce the sector's impact on our environment. It highlights both the challenges and the opportunities facing the shipping sector, which are of relevance to fostering cooperation at European level.

Maritime transport activity in the EU

Maritime transport is an essential element of global trade and the economy and is therefore highly globalised. In the EU, it carries 77 % of external trade and 35 % of intra-EU trade. Although the sector brings substantial economic and social benefits to the EU, it also has an impact on the environment and the health of EU citizens.

In 2019, ships flagged in EU Member States made up almost one fifth of the total world fleet in dead weight tonnage, a measure of cargo carrying capacity. Over one third of the ships engaged in international trade are owned by individuals and businesses registered in the EU. The most frequent vessel types with EU flags are bulk carriers, oil tankers and container ships, accounting for more than 80 %. Half of all ships under EU flags are less than 15 years old, with bulk carriers and gas tankers the youngest (average age 9.5 years). Almost one quarter of ships registered under the flag of an EU Member State are over 30 years old. The EU's shipbuilding industry is relatively small, accounting in 2019 for less than 4 % of ships constructed by gross tonnage.

In 2019, almost half of maritime traffic (i.e. ships calling in port) in the EU was from ships engaged exclusively in domestic routes and voyages, mainly due to the frequent crossings made by roll-on, roll-off passenger ships/ferries. EU ports handled close to 4 billion tonnes of goods, accounting for around half of all goods by weight traded between the EU-27 and the UK, and the rest of the world. These numbers are set to slightly decrease in 2020 because of the COVID-19 pandemic, in which, during the first half of the year, the number of ships calling at EU ports declined by between 14.4 % and 29 %, compared with the same period in 2019. Shipping is also important for passenger transport, with 437 million people embarking (or disembarking) in EU ports in 2018. More than half of all EU port calls are made by roll-on, roll-off passenger and cruise ships.

EU maritime transport policy aims at supporting a thriving maritime industry, with high levels of safety, environmental and social standards. Indeed, safeguarding the health and wellbeing of citizens and the environment is a key prerogative and objective of the EU, underscored by the European Green Deal and existing EU environmental laws, which, among others, aim to reduce, prevent and remedy the pollution of air, oceans, freshwater and soil. Given the global nature of shipping, and the fact that pollution crosses borders and regions, addressing the maritime transport environmental impact further requires action at international level, in accordance with the Paris Agreement on Climate Change and the 2030 Agenda for Sustainable Development.

International and EU environmental standards for maritime transport

The International Maritime Organization (IMO), a specialised agency of the United Nations, is the global standard-setting authority for the environmental performance of international shipping. It has, since its foundation, adopted more than 50 international treaties regulating international shipping, of which 40 % focus on environmental protection. This number illustrates the international commitment to reducing the adverse impact of shipping on the environment. It should be borne in mind, however, that these instruments may take some years to become effective because their application to the fleet is often progressive.

Since the late 1990s, the EU has been consistently introducing stricter rules for both ships trading in EU waters and ships registered under the flag of an EU Member state. These regulations have contributed to reducing sulphur oxides and carbon dioxide emissions and oil and other sources of ship pollution, banned harmful chemicals used on ships' hulls to prevent fouling, required the safe disposal of waste in ports and enforced environmentally sound ship recycling. EU laws, such as the Marine Strategy Framework Directive, the Water Framework Directive and the Habitats Directive, also protect the marine environment, aiming to uphold good environmental status standards and to reduce air and other pollution in coastal communities and ports.

Environmental aspects of maritime transport

Despite progress in recent years, maritime transport continues to exert pressures on the environment. Greenhouse gas emissions as well as air pollution, in particular nitrogen and sulphur oxides, and particulate matter, from shipping and port activities contribute to global warming, leading, among others to an increase in extreme weather events and sea level rise. They can also be detrimental to the environment and human health, affecting almost 40 % of Europeans living within 50 km of the sea. Emissions from the sector also contribute to water acidification and changes in nutrient and oxygen levels.

When released into the environment, contaminants, such as waste and pollution, negatively affect marine fauna and flora. They can produce changes in the distribution of species, population size and migration. Pollution events, such as oil spills, can also have dramatic effects on the economy of the affected areas. Other discharges, such as marine litter, can impact marine fauna, entangle animals, lead to injuries or kill organisms. They can pose dangers to maritime safety. Communities may also need to rehabilitate their shorelines. In addition, ships create underwater noise. This noise can produce loss of hearing in marine species, a reduction in communication between individuals, a potential increase in stress levels and various behavioural changes. Maritime transport also accounts for the largest proportion of introductions of non-indigenous species in seas around the EU. Non-indigenous species and aquatic pathogens can pose a threat to local biodiversity and human health and severely damage local economies if they adapt to their new environment.

The marine habitats for which the greatest number of maritime transport-related pressures have been reported are estuaries, large shallow inlets and bays, and sandbanks slightly covered by seawater. These areas are identified as good locations for ports, as they are sheltered from waves and wind. The habitats most affected by the dumping of dredged material are those with sedimentary bottoms, such as sand or mud, which in general are more diverse and considered to be more productive.

Monitoring and reporting

Evaluating the extent of pressures from maritime transport and the impact of policy action taken at EU and international level requires gathering information from a considerable number of sources. EU Member States regularly report on changes of environmental status pressures, as well as the measures and programmes to combat them. In addition, EMSA operates several maritime enforcement activities, monitoring and reporting services, laid down in EU law, providing information to EU Member States, Iceland and Norway. These services provide effective tools and systems for port state control, casualties and incidents, ship source pollution, and vessel traffic information and exchange.

Since 2015, the number of inspections focussing on pollution prevention remains at 20 %, around 2 400 annual inspections in absolute terms. Results from over 60 000 inspections on ships confirm an effective implementation of maximum sulphur in fuel standards, with estimated compliance by the maritime transport sector at over 95 %.

Nonetheless, while part of the pressures from maritime transport on the seas are well documented, information on their exact impact on human health, the environment, or climate change remain difficult to establish. Important data and knowledge gaps remain, which need to be addressed at EU and global level.

Sustainable solutions and future maritime transport trends

The maritime transport sector is evolving, aiming at becoming more sustainable and responding to current environmental challenges, including the reduction of air pollution and its overall carbon footprint. Stricter environmental rules have enabled progress. For instance, sulphur oxides and particulate matter emissions from shipping are projected to drop substantially up to 2050. Notwithstanding, sea-based source nitrogen oxides emissions are expected to increase, which, combined with a projected decrease in land-based source emissions, means that maritime nitrogen oxides emissions will exceed land-based emissions after 2030. Efforts have also focused on increasing energy efficiency, with data revealing that most ships calling in the EU have reduced their speed up to 20 % compared to 2008, thereby reducing emissions.

Nevertheless, in light of future trends and scenarios which suggest a continued growth of maritime transport over the next decades, additional unrelented efforts will be needed at EU and international level to make the sector more sustainable — and more resilient. Indeed, the sector is particularly at risk from global warming, and rising sea levels, flooding and extreme weather events, requiring changes to ports infrastructure and shipping activities. Pressures are set to grow, unless effective mitigation measures are implemented.

In 2020, the IMO projected the sector's greenhouse gas emissions to increase from about 90 % of 2008 emissions in 2018 to 90-130 % of 2008 emissions by 2050 for a range of plausible long-term economic and energy scenarios. Even if these predictions do not take account of the effects of the COVID-19 pandemic, which could lower the growth of the maritime sector for several years to come, such growth in emissions is not compatible with the EU's 2050 climate-neutrality target.

Alternative fuels and sources of energy such as biofuels, synthetic fuels, hydrogen, ammonia or batteries, are emerging as alternatives to conventional fossil fuels. They have strong potential to reduce air pollution and greenhouse gas emissions, even if it will be important to assess their properties and environmental impact from production to final use. In the medium term though, conventional and low carbon fossil fuels are expected to continue being used, as the uptake of alternative fuels remains slow and poses technical challenges.

Onshore power supply is a promising solution to improve air quality in ports and coastal areas. In place of using fuel, ships 'plug in' at ports. If electricity supply relies on clean and renewable energy sources, onshore power supply can reduce emissions at berth to zero, and decrease noise levels. Close to 10 % of ships calling at ports of the EU are equipped with it, with numbers steadily growing.

To remain competitive while reducing pollution and climate impacts, EU maritime transport is and must continue further adapting and innovating, e.g. investing in sustainable new technologies, and adopting digital solutions and automation processes.

The European Union will continue to tackle these issues in partnership with Member States, industry partners and the research community, under the umbrella of the European Green Deal and other policies, such as the Sustainable and Smart Mobility Strategy (which includes a number of measures to incentivise the uptake of sustainable alternative fuels, e.g. through the FuelEU Maritime initiative), and the Zero Pollution Action Plan.

1
Introduction

This is the first edition of the *European Maritime Transport Environmental Report* (EMTER), published by the European Maritime Safety Agency (EMSA) and the European Environment Agency (EEA). The report provides a factual analysis of the environmental pressures exerted by the maritime transport sector, presents up-to-date information on the relevant EU and international environmental standards and describes current and future actions to reduce the sector's impact on our environment. It highlights both the challenges and the opportunities facing the shipping sector, which are of relevance to fostering cooperation at European level.

Maritime transport is essential for EU and global trade. It ensures the functioning of the EU economy's supply chains. In the EU, it handles 77 % of the EU's external trade and 35 % of all intra-EU trade by value, making it highly strategically important. This translates into close to 4 billion tonnes of cargo handled in EU ports and 400 million passengers per year, underlining its strategic importance. While the maritime sector brings significant economic and social benefits to the EU, meeting ever increasing demands, it also has a negative impact on the environment and contributes to global warming, affecting the health of EU citizens and the state of marine and coastal ecosystems.

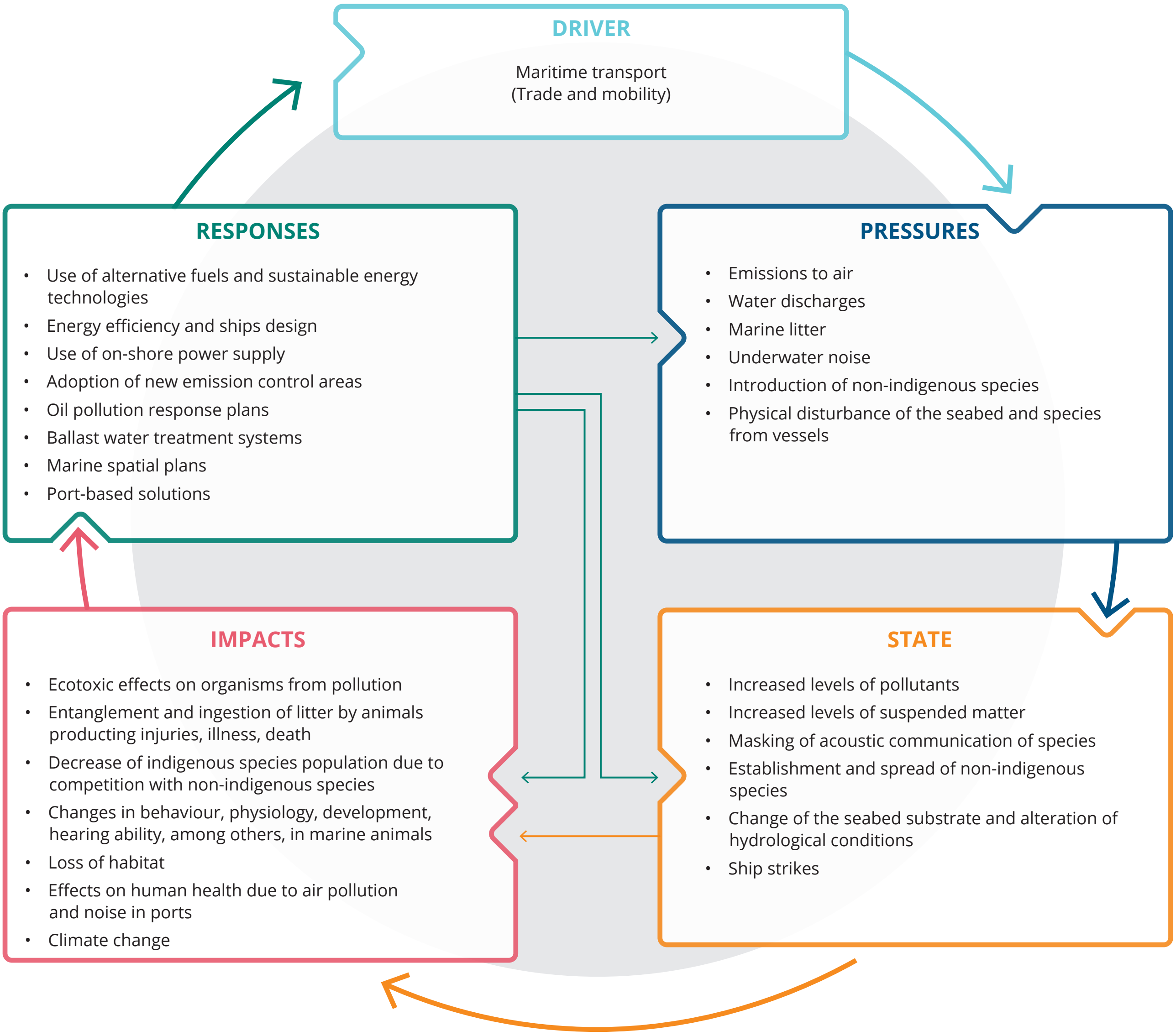
Some of these impacts are currently forecast to increase, partly due to the expected growth in global maritime transport, unless further action is taken. The European Green Deal of the European Commission and the United Nations 2030 Agenda for Sustainable Development promote a modern, resource-efficient and competitive economy, which includes the maritime transport sector. This includes the aim of reducing greenhouse gas emissions to reach a carbon-neutral EU by 2050. To achieve this, the EU supports the uptake of alternative fuels and sources of energy. An example of this is the Sustainable and Smart Mobility Strategy (EC, 2020a), which contains an action plan of 82 initiatives, including the forthcoming FuelEU Maritime initiative. In addition, these measures embrace the ambition to reduce, and where possible prevent, anthropogenic pollution of our environment, as detailed in the Zero Pollution Action Plan. Overall, the vision is for zero waste, zero pollution and zero accidents.

Innovative, smart and environmentally sustainable solutions to these challenges can provide an economic opportunity for the European maritime transport sector to increase its competitiveness in the global market. To seize this opportunity and overcome the challenges, the EU employs a comprehensive set of measures, some of which are summarised within the chapters of this report.

To describe the interactions between shipping and the environment and analyse the related environmental problems, the report uses the Drivers, Pressures, State, Impact and Response (DPSIR) approach (EEA, 2019e, Figure 1.1), and is structured accordingly. The Driving forces, such as social and economic developments, exert Pressures on the environment, such as pollution. This leads to changes in the State of the environment, for instance in biological systems, which then lead to Impacts on ecosystems and humans. To address the situation a societal Response is required to address the Drivers and Pressures. The Response can take the form of policies, laws, implementation measures and restrictions. Annex 2 includes a table with a detailed, though non-exhaustive, list of the elements within this approach, covered in this report.

Throughout the report, the term maritime transport is used to describe all shipping and port activities of a commercial or private nature linked to the transport domain. It is therefore important to note that fisheries and fishing activities have not been considered within the scope of this report, nor have activities related to offshore and other marine and maritime industrial platforms.

Figure 1.1 DPSIR framework for maritime transport



Source: EEA/EMSA (2021).

2 Environmental standards and international measures

Maritime transport can be considered only in its global dimension. Ships are European if they are registered in and flying the flags of EU Member States, or owned by EU companies but flagged in other countries. These ships trade domestically within an individual EU Member State, between EU Member States or internationally. Therefore, the environmental pressures arising from maritime activity are worldwide. The EU has laws in place to regulate shipping and its environmental impacts in Member States. While several international organisations regulate maritime transport, the International Maritime Organization (IMO), a United Nations specialised agency, plays the most important role. There are also several regional agreements that contribute to the protection of the marine environment in neighbouring and EU seas.

2.1 International rules

The IMO is the global standard-setting authority for the safety, security and environmental performance of international shipping. It provides a framework for cooperation among governments in order to regulate technical matters affecting shipping engaged in international trade. The IMO adopts standards in matters concerning maritime safety, efficiency of navigation and prevention and control of marine pollution from ships.

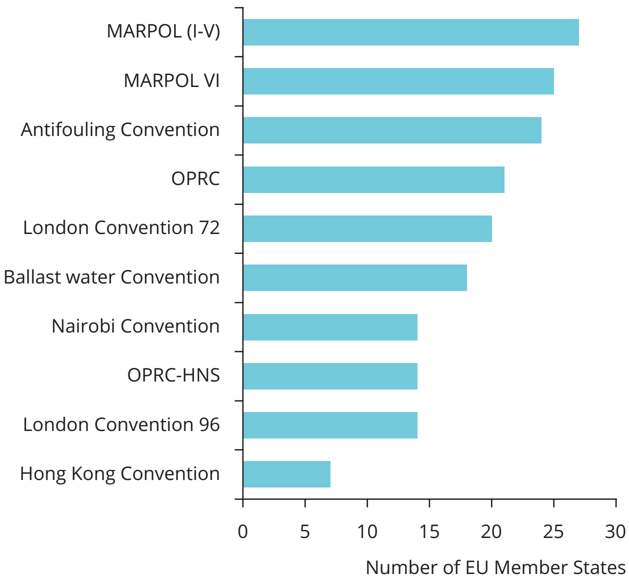
All EU Member States are members of the IMO, whereas the European Commission has observer status as an intergovernmental organisation. Therefore, the Member States participate in the main committees where the adoption of the relevant legislative measures and amendments to international conventions is discussed. Some of these treaties deal with issues in which the EU has exclusive competence.

An international maritime convention is not binding until it enters into force following its ratification by a minimum number of states (as established in the convention's articles; see Figure 2.1). In the case of IMO conventions, this requirement for a minimum number of state ratifications is also coupled to a requirement regarding the percentage of the world's merchant fleet that they represent. This means that the entry into force of a convention usually takes several years following its adoption, as is the case for the Ballast Water Management Convention, adopted in 2004 and entered into force in 2018 (BWM Convention, 2004). Some conventions still have not entered into force, such as the International Convention for the Safe and Environmentally Sound Recycling of Ships, which was adopted in 2009 (Hong Kong Convention, 2009).

IMO's Marine Environment Protection Committee

The Marine Environment Protection Committee is the International Maritime Organization's (IMO's) main technical body on marine pollution-related matters and is supported by several sub-committees (e.g. the Sub-Committee on Pollution Prevention and Response). Since its foundation, the IMO has adopted more than 50 international treaties regulating international shipping, of which 40 % are directly related to the environment (21 treaties).

Figure 2.1 Number of EU Member States ratifying IMO conventions



Note: MARPOL, International Convention for the Prevention of Pollution from Ships; OPRC, International Convention on Oil Pollution, Preparedness, Response and Co-operation; OPRC-HNS, Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances.

Source: IMO (2021).

Standards within conventions may also be phased in, retroactively applied to all ships, only applied to certain ships depending on their size or applied to ships already constructed after the specified date or entry into force of the requirement. In the case of ships constructed, this may be defined in the standards as 'ships the keels of which are laid, or which are at a similar stage of construction'. Such a definition may in some cases trigger unintended consequences, potentially further delaying the application of standards, as depicted in Figure 2.2, which shows when the keels of ships in service worldwide in the period 2000-2020 were laid.

In Figure 2.2, the peaks correspond to periods before the entry into force of major requirements (e.g. the largest peak corresponds to the last quarter of 2015, just before the entry into force of the nitrogen oxides (NO_x) emission control area (NECA) requirements in North America and the US Caribbean Sea). Although the construction of the ships in question is completed well after the entry into force of the new requirements, they will be subject to previous standards because their keels were laid before the entry into force. Another peak is expected in 2020, ahead of the entry into force of the Baltic and North Sea NECA in 2021.

2.1.1 International conventions

The United Nations Convention on the Law of the Sea (UNCLOS) was adopted in 1982 as a framework convention establishing rules governing all uses of the oceans and their resources. The UNCLOS provisions, being of a general kind, are implemented through specific rules in other international agreements (UNCLOS, 1982).

One of the first global instruments to protect the marine environment was the London Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, adopted in 1972. In force since 1975, it aims to promote effective control of all sources of marine pollution, including practical steps to prevent pollution by the dumping of waste (London Convention, 1972). With the advent of the 1996 London Protocol, most dumping was prohibited (London Protocol, 2006).

The main IMO tool to prevent pollution and protect the marine environment is the International Convention for the Prevention of Pollution from Ships (MARPOL). It was first adopted in 1973 and subsequently amended in 1978 and 1997 to strengthen its rules. The MARPOL convention, which currently applies to 99 % of the world's merchant tonnage, has greatly helped to decrease pollution from international shipping. It contains six annexes, each one dealing with a specific type of pollution. Annex VI, which entered into force in 2005, deals with the prevention of air pollution from ships (MARPOL, 1978).

In 1990, the IMO adopted the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC Convention). It provides the international framework for cooperation in and assistance for major oil spills. States are required to develop national systems for pollution response and to maintain adequate capacity and resources to address oil pollution emergencies (OPRC Convention, 1990). Examples of this cooperation framework include those established between EU Member States, EMSA and the European Commission Directorate-General for European Civil Protection and Humanitarian Aid Operations (DG ECHO), with a number of regional agreements, and those between EU Member States and non-EU Member States (e.g. the sub-regional contingency plan between Cyprus, Greece and Israel in the Mediterranean Sea). The Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances (OPRC-HNS) further extended the OPRC in 2000 to also address pollution incidents involving hazardous and noxious substances (OPRC-HNS Protocol, 2000).

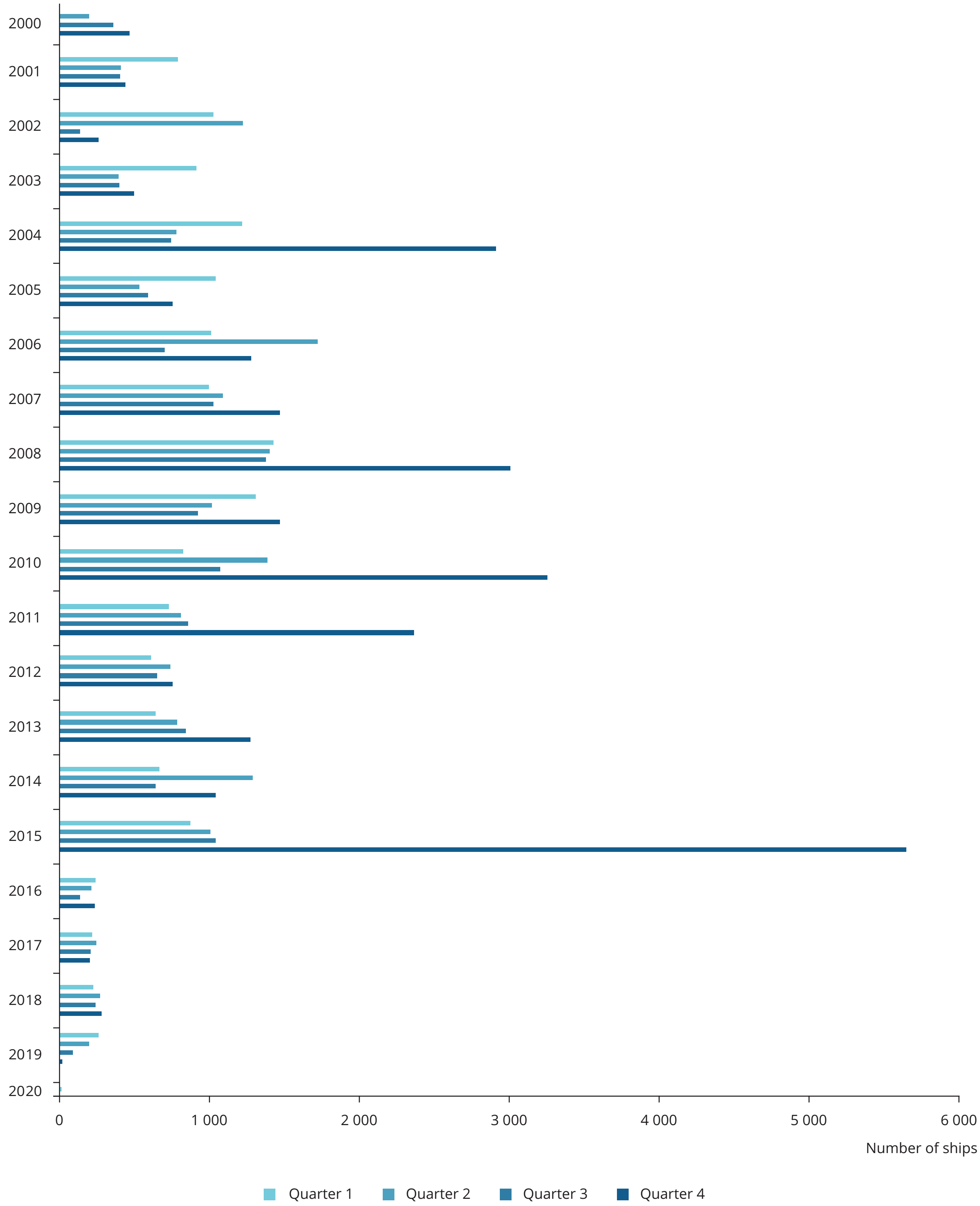
Thereafter, the International Convention on the Control of Harmful Anti-fouling Systems on Ships (AFS Convention) was adopted in 2001 and entered into force in 2008. It prohibits the use of certain harmful chemicals in anti-fouling paints used on ships' hulls to discourage barnacles and algae from settling, which would reduce ships' speed and efficiency. It also established a mechanism for avoiding the use of other harmful substances in anti-fouling systems in the future (AFS Convention, 2001).

The International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) was subsequently adopted in 2004 to avoid the spread of harmful aquatic species from one region to another in ships' ballast water. Under a phase-in scheme, ships engaged in international trade are required to manage their ballast water and sediments up to certain standards until 2024, when they will all have to have onboard ballast water treatment systems installed (BWM Convention, 2004).

In 2007, the Nairobi Convention on the Removal of Wrecks was adopted, completing the legal basis for states to remove shipwrecks that may have the potential to adversely affect maritime safety as well as the marine environment. It also covers the prevention, mitigation and elimination of hazards created by objects lost at sea from a ship, such as lost containers (Nairobi Convention, 2007).

The Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships was adopted in 2009 and represents the last environmental law adopted by the IMO. Although the Convention has not yet entered into force, it sets the standards to ensure that ships recycled at the end of their operational life do not pose any unnecessary risk to human health or to the environment (Image 2.1). Furthermore, the Convention takes a lifecycle approach, prohibiting the use of hazardous materials on ships during the construction phase (Hong Kong Convention, 2009).

Figure 2.2 **Ships in service worldwide in 2000-2020 by keel date**



Source: EMSA/THETIS (2021).

Image 2.1 Ship recycling activities in India

Source: © NGO Shipbreaking Platform.

For climate change mitigation, the IMO's Marine Environment Protection Committee (MEPC) in 2018 adopted an initial strategy for the reduction of greenhouse gas (GHG) emissions from ships. It makes specific reference to 'a pathway of carbon dioxide (CO_2) emissions reduction consistent with the Paris Agreement temperature goals'. The document calls for shipping emissions to peak as soon as possible and to be reduced by at least 50 % by 2050 compared with 2008 while pursuing efforts to phase them out (IMO, 2018a).

The IMO MEPC has also agreed an action plan that aims to enhance existing regulations and introduce new supporting measures to reduce marine plastic litter from ships. The IMO Action Plan to address marine plastic litter from ships, adopted in 2018, includes 30 measures to reduce marine plastic litter and microplastics from ships to be implemented in the short, medium, and long terms (IMO, 2018b).

2.1.2 Regional sea conventions

International conventions, such as the OPRC Convention and OPRC-HNS Protocol, already promote cooperation among the Parties through the establishment of bilateral and multilateral agreements. These multilateral agreements, adopted either by rim countries (Baltic Sea and North-East Atlantic Ocean) or under the auspices of the United Nations Environment Programme (UNEP) Regional Seas Programme (Mediterranean Sea and Black Sea), are key instruments for fostering cooperation between neighbouring countries around a sea basin in the protection of the marine environment. These instruments improve regional and cross-regional coherence in the implementation of laws at national level and establish structures for cooperation to increase the efficiency and effectiveness of national responses.

The Regional Agreements for the protection of the marine environment promote the ecosystem approach to the management of human activities to assess the relevance and efficiency of their strategies and action plans in achieving good environmental status of the marine environment, and this approach is acknowledged in the Marine Strategy Framework Directive.

There are four European regional sea convention treaties currently in force that include sustainable development as part of their guiding principles.

North-East Atlantic: OSPAR Convention

The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention, 1992) was signed in 1992 by the Contracting Parties — Belgium, Denmark, the EU, Finland, France, Germany, Iceland, Ireland, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom. The Convention unified the Oslo

Convention of 1972 against dumping and the Paris Convention of 1974 against marine pollution from land-based sources and the offshore industry. The North-East Atlantic environment strategy 2010-2020 undertakes the following thematic strategies through an assessment and monitoring programme:

- protection and conservation of marine biodiversity and ecosystems;
- eutrophication;
- hazardous substances;
- offshore oil and gas industry;
- radioactive substances.

The strategy also includes climate change in a wider context. Issues such as marine litter, underwater noise and shipping and ballast water are covered under the management of human activities and pressures. The OSPAR Commission agreed a Regional Action Plan for marine litter for the period 2014-2021 to fulfil the objective 'to substantially reduce marine litter in the OSPAR Maritime Area to levels where properties and quantities do not cause harm to the marine environment'. The Plan contains 23 national actions and 32 collective actions that aim to address both land-based and sea-based sources, as well as education and outreach and removal actions.

Bonn Agreement

The OSPAR Convention, the regional sea convention for the North-East Atlantic, shares a Secretariat with the Bonn Agreement, which was signed in 1969. The Bonn Agreement is a cooperation mechanism, established in the Greater North Sea and its wider approaches, for marine pollution prevention of, preparedness for and response to pollution from oil and other harmful substances and includes aerial surveillance. The Contracting Parties to the Bonn Agreement are Belgium, Denmark, the EU, France, Germany, Ireland, the Netherlands, Norway, Sweden and the United Kingdom. In 2019 the Bonn Secretariat agreed to the accession of Spain and to extend the scope of application of the Agreement with a view to cooperation on surveillance of emissions to air from shipping with respect to the requirements of Annex VI to the MARPOL Convention.

Baltic Sea: Helsinki Convention

The Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area was signed in 1974 and updated in 1992. The Convention was established to protect the marine environment of the Baltic Sea from all sources of pollution through intergovernmental cooperation and to promote the health and the good ecological status of the Baltic Sea environment by supporting a wide range of sustainable economic and social activities. It has 10 Contracting Parties, namely Denmark, Estonia, the EU, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. It is governed by the Helsinki Commission (HELCOM), an intergovernmental organisation.

HELCOM develops common environmental objectives and actions, often supplementing IMO laws, as the Baltic Sea is especially vulnerable to pollution. It ensures that environmental standards are fully implemented throughout the Baltic Sea area, resulting in strong regional cooperation to prevent and respond to pollution from ships. In addition, in 2015 HELCOM approved its Regional Action Plan for marine litter, setting the standard by which each HELCOM member country would address 12 regional and 10 voluntary national actions on sea-based sources of marine litter (HELCOM, 2015). An equivalent Regional Action Plan for coordinated actions to address the adverse effects of underwater noise on marine species is also currently being discussed.

HELCOM and OSPAR contributed to the IMO designation of the Baltic and North Seas as emission control areas for sulphur oxides (SO_x) and nitrogen oxides (NO_x). The Baltic Sea has also become the world's first special area for sewage discharges from passenger ships (Helsinki Convention, 1992).

Barcelona Convention

Since 1975, Mediterranean countries and the EU have been working together to protect the Mediterranean Sea under the Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean. Initially, 16 states adopted the Mediterranean Action Plan. Today there are 22 Contracting Parties: Albania, Algeria, Bosnia and Herzegovina, Croatia, Cyprus, Egypt, the EU, France, Greece, Israel, Italy, Lebanon, Libya, Malta, Monaco, Montenegro, Morocco, Slovenia, Spain, Syria, Tunisia and Turkey.

The main objectives of the Mediterranean Action Plan are the protection of the marine environment and coastal zones, the elimination of pollution from land and sea sources, and the protection of the natural and cultural heritage. One of the key elements of the regional strategy for prevention of and response to marine pollution from ships (2016-2021) is the future designation of the Mediterranean Sea as a SO_x emission control area and addressing NO_x emissions in the next stage (Barcelona Convention, 1976), for which a roadmap was agreed in December 2019 by the Contracting Parties (REMPEC, 2019). Furthermore, under the auspices of the Mediterranean Acton Plan, in 2013 the Contracting Parties also adopted a regional plan for the marine litter management in the Mediterranean, consisting of six specific actions for the prevention of marine litter from sea-based sources (UNEP, 2013).

The Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC)

REMPEC is a regional activity centre of the Barcelona Convention, initially established under the 1976 Emergency Protocol and whose role was extended under the 2002 Prevention and Emergency Protocol of the Barcelona Convention to assist the Mediterranean coastal states in ratifying, transposing, implementing and enforcing international maritime conventions. REMPEC is also an emergency centre to assist the Contracting Parties in dealing with a pollution incident.

Bucharest Convention

The Bucharest Convention on the Protection of the Black Sea Against Pollution was signed in Bucharest in April 1992 and ratified by the Black Sea countries, Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine, at the beginning of 1994. It is the main legal framework for regional cooperation to protect the coastal and marine environment in the Black Sea.

The Convention obliges the Contracting Parties to prevent, reduce and control pollution by hazardous substances, land-based sources, vessels, dumping, and exploration for and exploitation of natural resources in the Black Sea in order to protect and preserve the marine environment, marine biodiversity and the marine living resources. In 2018, the Contracting Parties also adopted the Black Sea marine litter regional action plan for the implementation of activities and measures to reduce and prevent sources of sea-based marine litter (Black Sea Commission, 2018).

The EU has officially expressed its wish to become a full Party to the Bucharest Convention, but it is not possible under the current treaty (Bucharest Convention, 1992).

2.2 EU environmental laws

Since the late 1990s, the EU has adopted an increasingly comprehensive body of EU rules applying to ships trading in EU waters or sailing to or from EU ports. Unlike the IMO's rules, on which they are often based, the laws also apply to ships on domestic voyages. They are generally 'flag blind', requiring compliance from all ships, irrespective of the country they are registered in. These EU laws are coherent with the international framework, and some go beyond the environmental standards set by the IMO, as the EU is prominent in pushing for more global ambition. An example of this is waste reception facilities in ports. Others ensure early implementation of newly adopted IMO rules that are not yet in force in the EU policy framework. In certain cases, the differences between the IMO and EU rules have disappeared over time as the international standards have become more stringent. As a result of the overall framework for implementation monitoring and enforcement, which is enshrined in the EU treaties, the EU laws, as opposed to international treaties, often provide stronger and clearer enforcement obligations, hence contributing effectively to increased maritime safety and environmental protection and a level playing field among the EU Member States.

EU environment policy is based on Articles 11 and 191-193 of the Treaty on the Functioning of the European Union. The underpinning objectives and principles, which are binding on all EU Member States, embody more than 200 laws and acts under the following broad categories: air quality, waste management, water quality, nature protection, industrial pollution control, chemicals, noise, climate change, industrial risk management, and civil defence and other horizontal legislation.

A subset of these laws (directives and regulations) provide the rules and standards for the prevention of pollution from all ships registered under flags of EU Member States, sailing to or from EU ports or trading domestically in EU waters and for the protection and conservation of the marine environment by EU Member States. The sections below provide an overview of these laws.

In December 2019, the European Commission published the communication on the European Green Deal. It addresses the climate and environmental challenges that Europe and the world are facing and provides an initial roadmap of the key policies and measures needed. This includes the maritime community in the context of the need to adopt a new growth strategy requiring a modern, resource-efficient and competitive maritime transport sector. Reducing emissions of GHGs by 2050 and decoupling the sector's economic growth from resource use are central to this. Among others, the Green Deal, through the 2030 Climate Target Plan (EC, 2020a), specifically mentions the possible extension of the EU Emissions Trading System (ETS) to the maritime sector. It formulates the ambition to ramp up the production and deployment of sustainable alternative fuels and the need to have cleaner transport, including requiring the use of onshore power supply at berth and potentially limiting the access of the most polluting ships. Other pillars of the European Green Deal are the Zero Pollution roadmap for air, soil and water (EC, 2019a) and the Sustainable and Smart Mobility Strategy (EC, 2020a).

2.2.1 Air emissions

Air pollution

Air pollution has been one of Europe's main environmental political concerns since the late 1970s. The Ambient Air Quality Directive provides the current overall rules for the control of ambient concentrations of air pollution in the EU (EU, 2008a). The control of emissions from mobile sources, improving fuel quality, and promoting and integrating environmental protection requirements into the transport and energy sector are part of these aims. The National Emissions reduction Commitments (NEC) Directive transposes the reduction commitments for 2020 agreed under the Gothenburg Protocol (part of the Convention on Long-range Transboundary Air Pollution, or LRTAP Convention). It 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 Directives (EU, 2016a).

Within this context, the Sulphur Directive, relating to a reduction in the sulphur content of certain liquid fuels, establishes limits on the maximum sulphur content of gas oils, heavy fuel oil used in land-based applications and marine fuels. The Directive also contains some additional fuel-specific requirements for ships calling at EU ports, obligations related to the use of fuels covered by the Directive and the placing on the market of certain fuels (e.g. marine gas oils). The Directive was first published in 1999 and last amended in 2012 to further adapt it to the developments at international level under MARPOL Annex VI (EU, 2016b).

The pan-European Convention on Long-range Transboundary Air Pollution (LRTAP)

The LRTAP Convention is one of the key means for protecting the environment (LRTAP Convention, 1979). Over the years, it has served as a bridge between different political systems and as a stable factor in years of political change. It has substantially contributed to the development of international environmental law and has created the essential framework for controlling and reducing the damage to human health and the environment caused by transboundary air pollution. It is a successful example of what can be achieved through intergovernmental cooperation.

The origins of the Convention can be traced back to the 1960s, when scientists demonstrated the interrelationship between sulphur emissions in continental Europe and the acidification of Scandinavian lakes. The 1972 United Nations Conference on the Human Environment in Stockholm signalled the start of active international cooperation to combat acidification. Between 1972 and 1977 several studies confirmed the hypothesis that air pollutants could travel long distances before deposition and damage occurred. This also implied that cooperation at the international level was necessary to solve cross-border problems such as acidification.

Since 1 January 2015, the Directive has set stricter sulphur limits for marine fuel in sulphur emission control areas (SECAs) (0.10 %) and in sea areas outside the SECAs (3.50 %). In addition, a 0.10 % maximum sulphur requirement for fuels used by ships at berth in EU ports was introduced from 1 January 2010. Furthermore, up until January 2020, passenger ships operating on regular services to or from any EU port could not use marine fuels with a sulphur content exceeding 1.50 % in sea areas outside the SECAs. From 1 January 2020, the global maximum content of sulphur allowed in fuels is 0.50 % for all kind of ships (MARPOL Annex VI, 2006). However, the Directive's scope is still wider than that of Annex VI of the MARPOL Convention, as it continues to set a maximum of 0.10 % sulphur content for fuels used in ships at berth in ports in the EU.

Another law that is relevant for the prevention of air pollution is the Directive on the deployment of alternative fuels infrastructure (Alternative Fuels Directive). This Directive defines 'alternative fuels' as types of fuels or power sources that serve, at least partly, as a substitute for fossil fuel oil sources in the energy supply for transport and which have the potential to contribute to its decarbonisation and enhance the environmental performance of the transport sector. The development and use of alternative fuels and appropriate infrastructure in the European territory are essential to meet the requirements of the Sulphur Directive and to reduce the dependence of transport on oil (EU, 2014a).

The development of a competitive market for alternative fuels will cut the dependence on oil and contribute to improving the security of Europe's energy supply and reduce GHG emissions from transport. To be effective, this market needs to be supported by new technological and commercial advances, provide appropriate consumer information on alternative fuels and set up adequate infrastructures.

Emission control areas (ECAs)

ECAs are sea areas created by the relevant riparian states under the MARPOL Convention. These areas can apply limits to reduce sulphur oxides or nitrogen oxides emissions or both. Currently, four of these areas exist under the MARPOL Convention, two of them in the EU: the Baltic Sea area (MARPOL Annex I, 2006) and the North Sea area (MARPOL Annex VI, 2006). Domestic emission control areas can also be set up by states to improve the air quality of coastal areas and inland rivers.

Greenhouse gases

The European Commission's 2011 White Paper (EC, 2011) on transport suggested that the EU's CO_2 emissions from maritime transport should be cut by at least 40 % of 2005 levels by 2050, and if feasible by 50 %. In June 2013 the European Commission set out a phased strategy for progressively integrating maritime emissions into the EU's policy for reducing its domestic GHG emissions. The strategy consists of three consecutive steps: (1) monitoring, reporting and verification of CO_2 emissions from large ships using EU ports; (2) GHG reduction targets for the maritime transport sector; and (3) the development of further measures in the medium to long term (EC, 2011).

To this end, and as a first step, the EU Regulation on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport (MRV Regulation) was adopted in 2015. These standards have applied since 2018 to large ships (above 5 000 gross tonnage) and their CO_2 emissions released on voyages to, from and between ports in the EU. This has created EU-wide rules for the monitoring, reporting and verification of CO_2 emissions, together with additional information on maritime transport related to its fuel consumption. These standards are the first of several steps in the EU's efforts to include maritime transport in its overall policy to reduce GHG emissions. Through this law a number of obligations for companies, Member States and the European Commission have been introduced (EU, 2015). Together with the Alternative Fuels Directive, the EU Renewable Energy Directive (RED II) also contributes to the reduction in GHG emissions by requiring fuel suppliers to ensure by 2030 that a minimum mandatory share of 14 % of the energy consumed in the transport sector is renewable energy. In this context, renewable fuels supplied to the maritime transport sector (except those produced from food and feed crops) may also be considered for compliance (EU, 2018).

In its 2030 climate target plan, the European Commission further proposed to raise the EU's ambition on reducing GHG emissions to at least 55 % below 1990 levels by 2030, including at least intra-EU maritime transport in the EU ETS. This target has been translated into a legal obligation as part of the proposal for a Climate Law (EC, 2020b) (EC, 2020c) endorsed by the European Council in December 2020 (EC, 2020d).

In addition, and in line with the European Green Deal communication and the Sustainable and Smart Mobility Strategy, delivering on the climate neutrality objective by 2050 will require an 80-82 % reduction in emissions by the EU's international seagoing maritime transport sector by 2050 relative to 1990 (i.e. equivalent to an 88-89 % emission reduction relative to 2008).

2.2.2 Marine and maritime environment protection

The Marine Strategy Framework Directive (MSFD) is the main European legal instrument for protecting and conserving the marine environment and ecosystems. The Directive enshrines in its rules the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use. In addition to this umbrella Directive, there are a number of other EU laws directly establishing standards in specific areas for the protection of the marine environment (EU, 2008b).

Ecosystem-based laws

Three directives contribute to the achievement of the good status of the marine environment. Each of them follows a DPSIR (Drivers, Pressures, State, Impact, Response) framework, in which Member States have to define the environmental objectives (good status) and targets to achieve them; assess the pressures, status and impacts on the environment; regulate their activities through the implementation of programmes of measures to reduce the pressures or improve the status; and put in place programmes for monitoring the status of the marine environment.

Good environmental status

'Good' status is defined differently across standards. Under the Marine Strategy Framework Directive (MSFD), '''good environmental status'' means the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, and the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations' (Article 3(5) of the MSFD; EU, 2008b).

The most important goal of the MSFD is achieving good environmental status (GES) in EU marine waters by 2020 and protecting the resource base upon which marine-related economic and social activities depend. This must be done for a number of quality descriptors and considering the cumulative impact of pressures caused by human activities that take place in the sea, including shipping. The descriptors for which GES has to be achieved are either related to the state of the environment (biodiversity, food webs and sea floor integrity) or to pressures and their impacts (non-indigenous species, commercially exploited fish and shellfish, eutrophication, pollution in the environment and in seafood, marine litter and underwater noise) (EU, 2008b).

To achieve GES, Member States must put in place programmes of measures that can help achieve and maintain this status and report them to the European Commission. The programmes that have been reported include measures related to the management of ballast waters and hull fouling (in many cases linked to the implementation of the IMO BWM Convention or the biofouling guidelines); others address water pollution from shipping (in many cases linked to the implementation of the MARPOL or other international conventions, but also national measures, such as rules for discharges related to the use of scrubbers), impacts on species from shipping or impacts on the sea floor related to shipping activities (EU, 2008b). The European Commission and the EU Member States work together in specific technical groups to support the MSFD's implementation and more specifically to identify methodologies and thresholds for the GES descriptors. These include the technical groups on marine litter (D10), underwater noise (D11) and integrity of the seabed (D6).

The Water Framework Directive (WFD) establishes rules for action in the field of water policy. Under the WFD, Member States have to achieve, at the latest by 2027, good ecological status of their waters (including transitional and coastal waters) and good chemical status of their waters (including transitional, coastal and territorial waters). Member States must develop river basin management plans in which the pressures on water bodies should be tackled with appropriate programmes of measures. The programmes of measures can address maritime shipping-related measures where those can contribute to achieving good water quality. This is particularly relevant in port areas, which can be badly affected by the pollution from shipping (EU, 2000a).

The Habitats Directive on the conservation of natural habitats and of wild fauna and flora is the most relevant instrument for protecting Europe's natural capital. It lists several species and habitats of community interest that need to be protected, and for which conservation measures need to be put in place to achieve favourable conservation status. The measures need to address the pressures identified by the Member States as threats to achieving this objective (EU, 2014b).

The 2014 Maritime Spatial Planning Directive establishes rules for maritime spatial planning. It defines it as 'a process by which the relevant Member State's authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives'. Member States must approve maritime spatial plans for their waters by 2021, at the latest, including the 'maritime transport routes and traffic flows', which is listed as one of the activities to be spatially addressed. According to the Directive, 'maritime spatial planning should apply an ecosystem-based approach with the aim of ensuring that the collective pressure of all activities is kept within levels compatible with the achievement of good environmental status and that the capacity of marine ecosystems to respond to human-induced changes is not compromised, while contributing to the sustainable use of marine goods and services by present and future generations' (EU, 2014c).

Maritime-based laws

Marine litter and ship waste

Several directives address the prevention of marine litter entering our seas. While the MSFD provides the main driver in the EU for the monitoring and evaluation of marine litter to support policies and achieve good environmental status, there is a specific law to address how ships should manage their waste and the control regimes applicable to the management of waste.

A great proportion of litter in the marine environment originates from land-based sources, but addressing waste discharges from ships also plays an essential role in efforts to preserve marine and coastal ecosystems. Based on international standards (i.e. the MARPOL Convention), EU law requires vessels to land the waste they generate on voyages at waste reception facilities in port and obliges EU ports to provide facilities for landing this waste for ships using the port.

In 2019, the EU adopted a revised Directive regulating the availability of port reception facilities and the delivery of waste to those facilities, aiming to substantially reduce discharges of ship-generated waste and cargo residues into the sea. This Directive covers all waste from all ships (including relevant fishing vessels and recreational craft), including residues from exhaust gas cleaning systems and passively fished waste (collected in nets during fishing operations) and ensures the availability of adequate port reception facilities by requiring segregated collection of waste in ports (EU, 2019a).

Port reception facilities

Delivery of waste in ports is incentivised through a cost recovery system based on a fixed indirect fee for waste and passively fished waste, irrespective of the quantities delivered. The mandatory delivery requirement, based on waste receipts issued upon delivery, is controlled and recorded electronically (except in small unmanned or remote ports).

The Waste Framework Directive and the Regulation on shipments of waste establish procedures and control regimes for the shipment of waste, depending on the origin, destination and route of the shipment, the type of the waste and the type of treatment to be applied to the waste at its destination. These regulations apply to shipments of waste between Member States or in transit to third countries and to waste imported from or exported to third countries or in transit in the EU from or to third countries (EU, 2006b, 2008c).

The EU Regulation on ship recycling rules aims to reduce the negative impacts linked to the recycling of ships registered under the flag of an EU Member State and to ensure that, as of 31 December 2020, ships calling at EU ports or anchorages either possess an inventory certificate (for ships registered under the flag of an EU member state), or a certificate of compliance (for ships flagged in non-EU Member States). These prove that the ship in question has an approved inventory of hazardous materials on board. This Regulation lays down requirements that ships and recycling facilities must fulfil to make sure that ship recycling takes place in an environmentally sound and safe manner. According to the new rules, the installation or use of certain hazardous materials on ships, such as asbestos, ozone-depleting substances, polychlorinated biphenyls (PCBs), perfluorooctanesulphonic acid (PFOS) and anti-fouling compounds, is prohibited or restricted. Each ship, irrespective of its flag, is required to have on board an inventory of hazardous materials approved by its flag state by 2020. From 2019 onwards, large commercial seagoing vessels flying the flag of an EU Member State may be recycled only in safe and sound ship recycling facilities included in the European List of ship recycling facilities (EU, 2013a).

The EU Directive on single-use plastics sets out EU-wide rules targeting the 10 single-use plastic products most often found on Europe's beaches and seas. It also targets lost and abandoned fishing gear. Together these constitute 70 % of marine litter items. The Directive aims to reduce the impact of plastic products on the marine environment, and prevent and tackle marine litter by, among other things, introducing extended producer responsibility schemes, establishing collection targets and introducing market restrictions for certain single-use plastic products (EU, 2019b).

Non-indigenous species

Although at present there are no direct EU standards on ballast water discharges, the Regulation on the prevention and management of the introduction and spread of invasive alien species recognises the IMO BWM Convention as one of the instruments for the control of invasive species of concern. The MSFD considers invasive alien species and their environmental impact as one of the descriptors for assessing GES (EU, 2014d).

Sea pollution

An EU Regulation on the prohibition of organotin compounds on ships, based on the IMO's AFS Convention, stopped their use in anti-fouling systems from July 2003 (EU, 2003). The ban aims to reduce or eliminate the negative effects of organotin compounds on the marine environment and human health. It applies to ships flying the flag of EU Member States and to all ships sailing to or from EU ports. Since 2008, EU ships and other ships visiting EU ports have been obliged either not to bear anti-fouling systems containing such compounds or to bear a coating that forms a barrier to prevent such compounds leaching from a non-compliant underlying antifouling system.

The use of organotin in AFS paints in the EU is also controlled by the prohibition of the marketing and use of organostannic compounds (EU, 2006a) and by further rules requiring ships flying the flag of a third country to demonstrate their compliance and procedures for control (EU, 2008d).

To reduce sea pollution, the EU adopted the Directive on ship-source pollution and on the introduction of penalties for infringements (EU, 2005). It incorporates international standards for ship-source pollution into EU law to ensure that those responsible for discharges are subject to adequate penalties, including criminal penalties. The law's aim is to improve maritime safety and to protect the marine environment from pollution by ships. It is applied without limitations to discharges of polluting substances (i.e. MARPOL Annexes I and II) from any ship (i.e. irrespective of its flag) in the territorial sea of a Member State; in the exclusive economic zone (or equivalent zone) of a Member State, established in accordance with international law; in the high seas, but also in straits used for international navigation subject to the regime of transit passage; and in the internal waters, including ports, of a Member State, insofar as the MARPOL Convention regime is applicable (EU, 2005; MARPOL Annex I, 2006; MARPOL Annex II, 2006).

To improve situational awareness in the maritime domain and to provide tailor-made solutions to authorities, the Vessel Traffic Monitoring Directive, establishing the EU maritime information and exchange system, was developed (EU, 2014e). Otherwise known as SafeSeaNet, this system enables the receipt, storage, retrieval and exchange of information for the purposes of maritime safety, port and maritime security, marine environment protection and ensuring the efficiency of maritime traffic and maritime transport. The Directive sets up a system to monitor the EU's surrounding seas, provide maritime surveillance and situational awareness (ship positions), support EU countries in their operational tasks and enable the exchange of 'pollution reports' (PolReps) and 'lost and found object incident reports' between all Member State administrations (EU, 2014e).

3
Maritime transport in the EU

This chapter analyses maritime transport trends in the EU, looking at traffic, trades and fleet composition, as well as related activities, such as ports, ship building and recycling, with a view to enabling a better understanding of the related environmental pressures, and providing a sound basis for policy action addressing those pressures.

3.1 Composition of the fleet in the EU

Analysing the composition of the EU fleet and its characteristics is relevant to understanding the various key features that influence the pressures that maritime transport exerts on the environment. In order to have a global perspective, this also needs to be compared with the world fleet.

Size has a direct influence on the various emissions from ships; cargo carrying capacity in particular is very relevant when assessing, for instance, carbon dioxide (CO_2) emissions and the technical energy efficiency of a ship. In 2019, ships registered under the flag of an EU Member State represented 17.6 % of the total world fleet measured in dead weight tonnage (DWT). In terms of ownership, registered owners domiciled in EU Member States accounted for 36.4 % of the worldwide DWT (Figure 3.1).

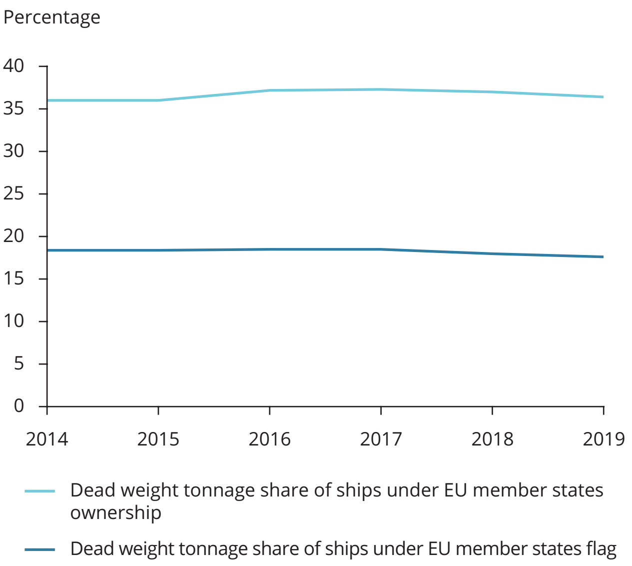
The total gross tonnage (GT) of ships registered to flags of EU Member States steadily increased at a rate of approximately 4 % a year between 2014 and 2017, 1 % in 2018 and 2.5 % in 2019. In absolute terms, there were 18 000 ships registered under EU flags in 2019, accounting for 266 million GT (Figure 3.2).

In 2019, passenger ships registered to EU flags could carry up to 1.3 million passengers, representing 40 % of the world's passenger transport capacity.

Calculating ship size

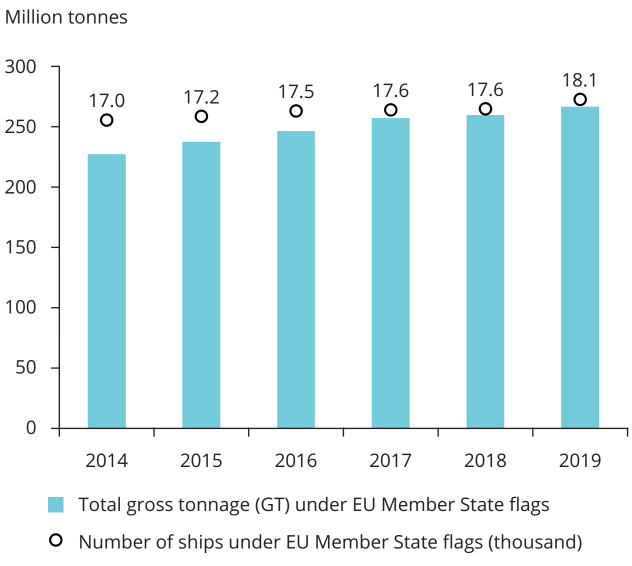
Ship sizes are typically expressed in terms of gross tonnage (GT), which is a non-linear measure of a ship's overall internal volume. An additional parameter used to describe a ship's size is the deadweight tonnage (DWT), which gives an indication of its cargo carrying capacity, as it sums the weights of cargo, fuel, freshwater, ballast water, provisions, passengers and crew.

Figure 3.1 Worldwide share of ships under EU Member State flags and owners



Source: Compiled from EMSA Services data.

Figure 3.2 Number of ships and total GT of ships under EU Member State flags



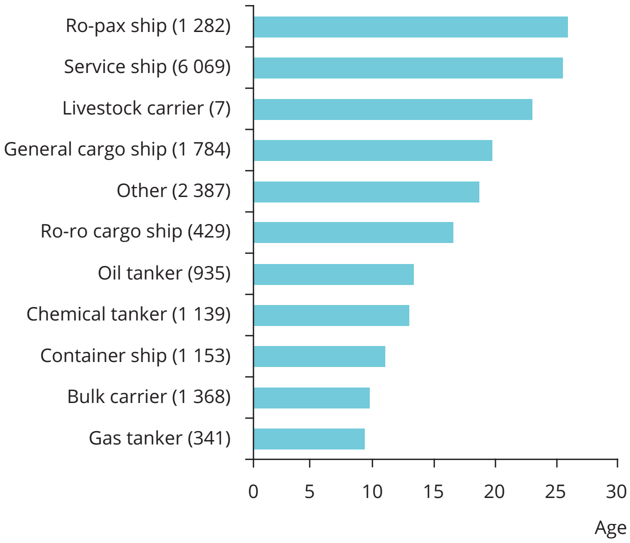
Source: Compiled from EMSA Services data.

The age of ships is also relevant in the context of pressures on the environment, as younger vessels tend to be generally more efficient because they have the most advanced engines and equipment on board. Half of all the ships registered to flags of EU Member States are less than 15 years old, with bulk carriers and gas tankers the youngest (average age 9.5 years; Figure 3.3). Almost one quarter of ships registered under the flag of an EU Member State are over 30 years old. Of these, roll-on, roll-off passenger (Ro-pax) ships represent one of the oldest segments, with an average age of 26 years, which may be explained by the implementation of retrofitting programmes prolonging their service life.

The ship type is also highly relevant. It can point towards an area of trade and time at sea, therefore giving an idea of where the pressures on the environment are mostly exerted. For instance, roll-on, roll-off (Ro-ro) and passenger ships often operate on fixed, short-distance itineraries. Moreover, each ship type is characterised by a different average engine power rating and operational pattern, which has an influence on fuel consumption and related air emissions. Container ships, meanwhile, tend to have more powerful engines and operate at higher speeds than bulk carriers.

General cargo ships represent 10 % of all ships registered to flags of EU Member States, while bulk carriers, container ships and tankers individually make up less than 10 % (Figures 3.4 and 3.5).

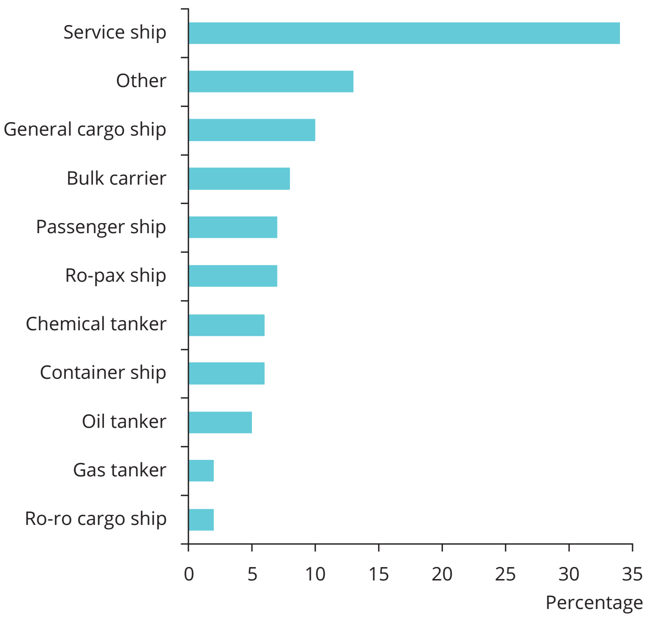
Figure 3.3 Average age per ship type (ships registered under EU Member State flags)



Note: Values in brackets: number of ships.

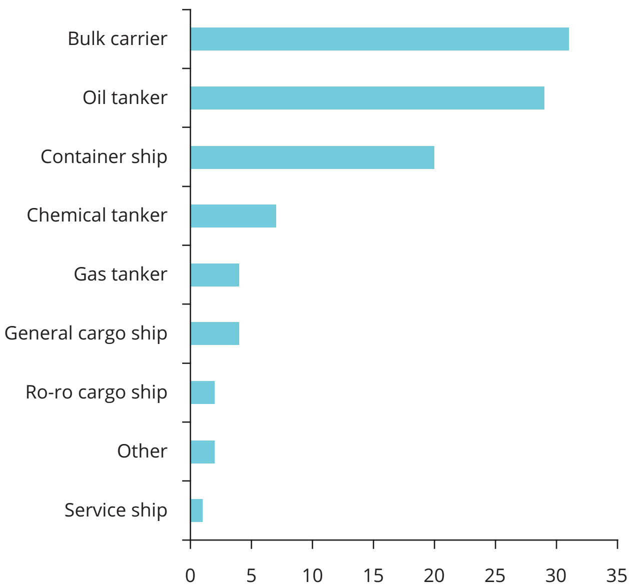
Source: Compiled from EMSA Services data.

Figure 3.4 Ships registered under flags of EU Member States by type (percentage of total number)



Source: Compiled from EMSA Services data.

Figure 3.5 Ships registered under flags of EU Member states by type (in DWT)



Note: Dead weight tonnage (DWT).

Source: Compiled from EMSA Services data.

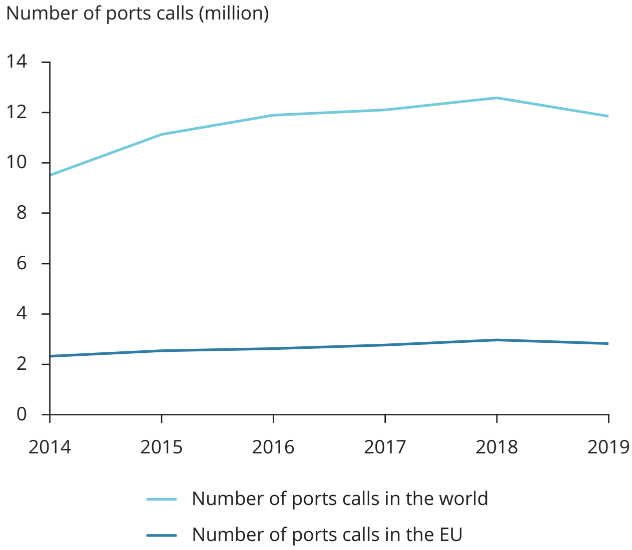
3.2 Maritime traffic in the EU

When secured at berth, ships also exert pressures, such as emissions to air and on the surrounding environment, as they need to operate machinery for loading and unloading cargo or to provide hotel services to passengers and crew. In terms of port calls made in the EU, maritime traffic has been slowly growing in recent years with a small peak in 2018. This is not exclusive to the EU but aligned with the rest of the world. A decrease of 6 %, however, was observed in 2019 compared with 2018 (Figure 3.6).

The main ports in terms of port call activity are Rotterdam, Antwerp, Algeciras, Piraeus and Messina, while in terms of gross weight of goods handled, Rotterdam, Antwerp and Hamburg remained the top three ports in 2019. Eighteen ports in the EU account for more than a quarter (26.7 %) of the port call activity in the EU.

In general, EU ports are very heterogenous in size and roles. There are many small ports and a number that act as energy, transport or industry hubs. Whereas most EU ports receive port calls from all main ship types, other ports are very specific in terms of the types of ships visiting them. Rotterdam and Antwerp can be included in the former category, with port calls from container ships, bulk carriers, Ro-ro ships, general cargo, etc. In the latter category, Piraeus is very relevant for oil tankers, Messina is the main port receiving Ro-pax ships and Barcelona is the number one port for cruise liners (Table 3.1) ([1]).

Figure 3.6 Trend in port calls in EU Member States from 2014 to 2019



Source: IHS Markit (2020).

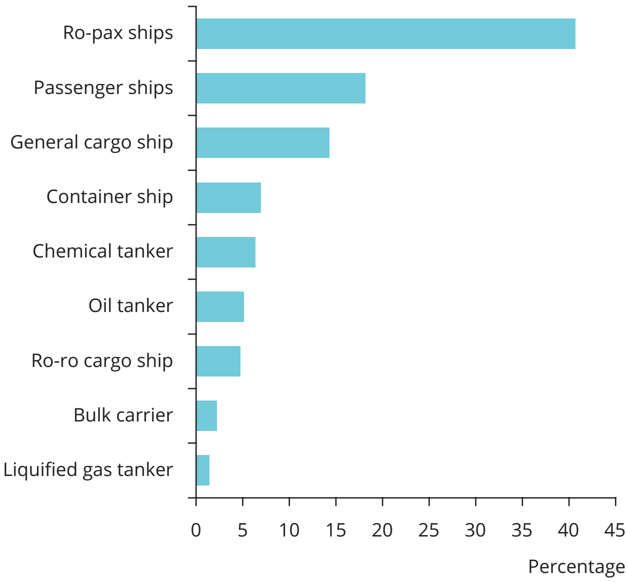
Table 3.1 The five main EU ports by port calls from different ship types in 2019

Cruise ship		Oil tanker		Ro-pax ship		Gas carriers		Container ship	
Barcelona	3.5 %	Piraeus	6.4 %	Messina	3.6 %	Antwerp	15.2 %	Rotterdam	13.0 %
Civitavecchia	3.2 %	Antwerp	5.8 %	Algeciras	3.1 %	Honningsvag	6.8 %	Hamburg	7.9 %
Dubrovnik	2.8 %	Gothenburg	5.1 %	Calais	2.6 %	Rotterdam	4.9 %	Antwerp	6.8 %
Piraeus	2.8 %	Algeciras	4.6 %	Patras	2.1 %	Augusta	3.8 %	Algeciras	4.2 %
Palma	2.6 %	Rotterdam	4.1 %	Rodbyhavn	1.9 %	Terneuzen	3.4 %	Piraeus	3.8 %
Bulk carriers		**Ro-ro cargo ship**		**General cargo ship**		**Chemical tanker**		**Ferries**	
Costantza	4.0 %	Zeebrugge	8.5 %	Karmsund	3.5 %	Antwerp	11.8 %	Naples	6.1 %
Rotterdam	3.9 %	Rotterdam	6.4 %	Antwerp	3.3 %	Rotterdam	11.1 %	Stavanger	5.5 %
Antwerp	3.6 %	Antwerp	6.2 %	Rotterdam	3.3 %	Augusta	4.2 %	Ibiza	5.4 %
Augusta	3.5 %	Dublin	3.6 %	Hamburg	1.7 %	Amsterdam	2.7 %	Lisbon	4.5 %
Volos	2.5 %	Livorno	3.5 %	Klaipeda	1.5 %	Le Havre	2.2 %	Oslo	3.4 %

Source: Compiled from EMSA Services data.

([1]) For this analysis, only ships assigned an International Maritime Organization number and over 100 GT are considered (excluding service ships such as tugs, dredgers, offshore supply, military and governmental ships, or fishing vessels). Ports with a share of port calls in EU ports of less than 1 % are not included in the analysis.

Figure 3.7 **Port call distribution in EU ports by ship type**

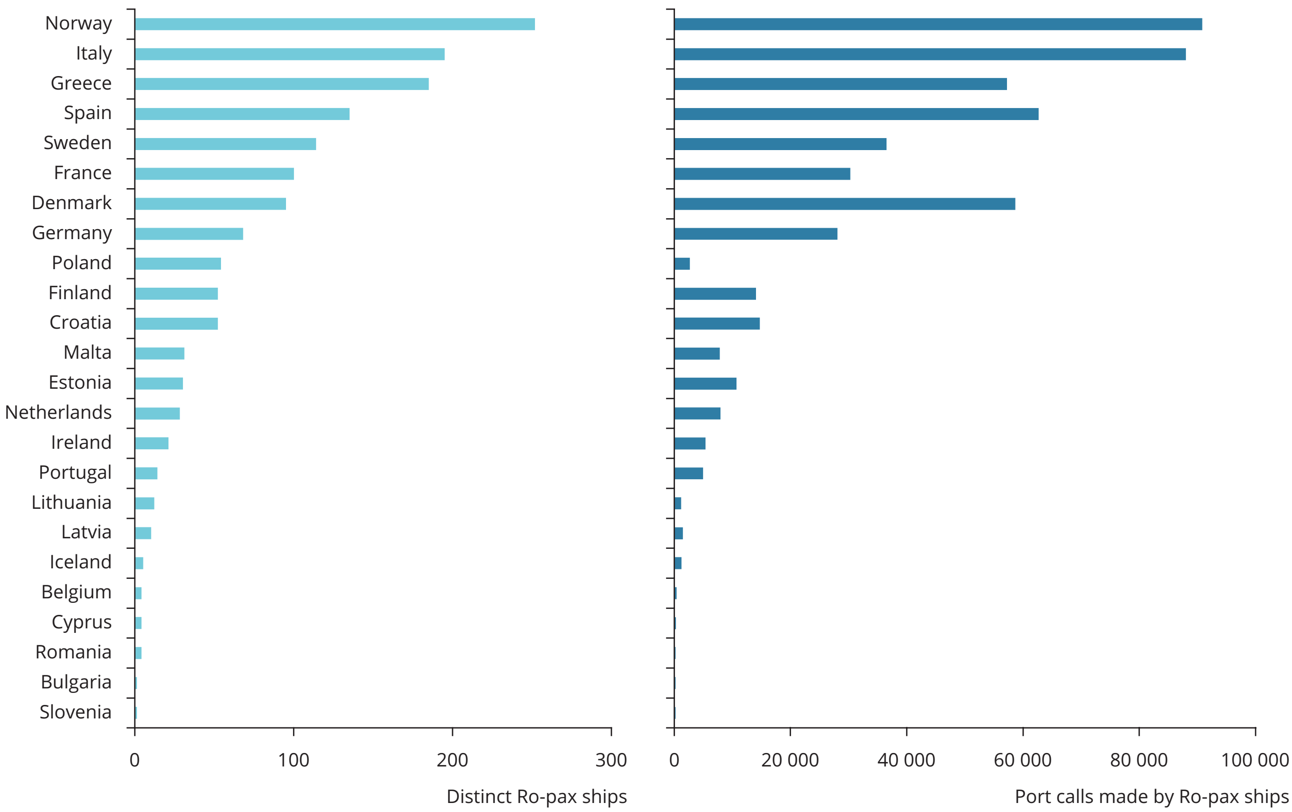


Source: Compiled from EMSA Services data.

In 2019, most of the port calls in the EU were made by Ro-pax ships (41 %) and passenger ships (18 %), such as ferries, cruise ships and other smaller passenger ships (Figure 3.7). Altogether, these two ship types covered more than half of the port call activity (59 %). General cargo ships registered 14 % of the port calls. This means that almost three quarters (73 %) of the shipping activity (in terms of number of port calls) in the EU is accounted for by Ro-pax ships, passenger ships (i.e. ferries) and general cargo ships.

In 2019, 46 % of the maritime traffic in terms of port calls in the EU was from ships engaged exclusively in domestic voyages (i.e. within the same EU Member State). This is because of the frequent crossings made by Ro-pax ships (also known as ferries) in Denmark, Greece, Italy, Spain and Sweden. Ro-ro and Ro-pax ships in 2018 reported around 20 million tonnes of CO_2 emissions, primarily concentrated in the Baltic, the North Sea and the Mediterranean (Figure 3.8).

Figure 3.8 **Number of Ro-pax ships calling in each EU Member State and total number of port calls by EU Member State**



Source: Compiled from EMSA Services data.

3.3 Seaborne passengers and freight

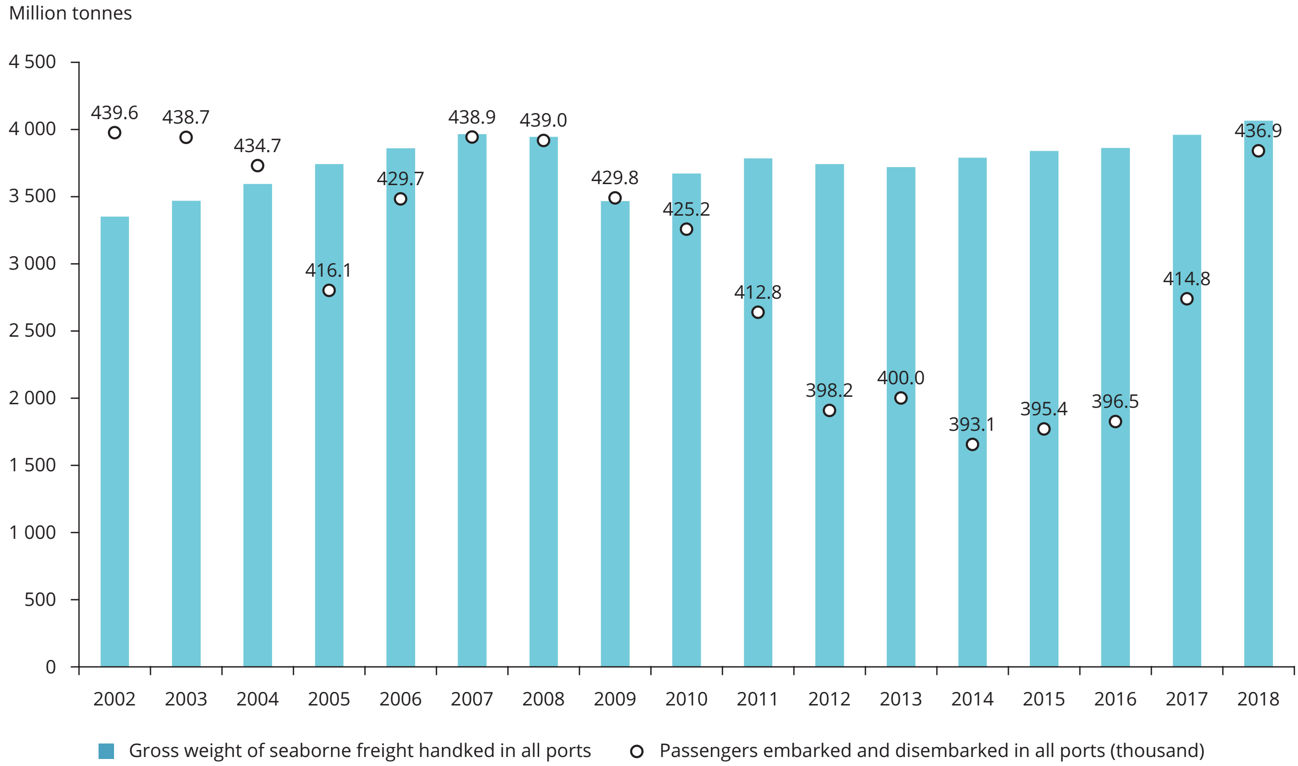
The total number of passengers embarking and disembarking in EU ports increased by 5.3 % between 2017 and 2018 to 437 million passengers, after a decade in which numbers consistently fell (Figure 3.9). With over 85 million passengers passing through its ports, Italy was the major seaborne passenger country in Europe in 2018, followed by Greece with 72.5 million passengers. These two countries accounted for more than one third of maritime passenger transport in the EU (Eurostat, 2020a).

Unlike the movement of goods, where broadly 60 % of goods are unloaded and 40 % loaded in EU ports, the difference between the number of passengers disembarking ('inwards') and embarking ('outwards') in EU ports is generally small. This reflects the fact that seaborne passengers in Europe are mainly carried by national or intra-EU ferry services, with the same passengers being counted twice in the port throughput statistics (once when they embark the ferry in one EU port and once when they disembark the same ferry in another EU port).

The total gross weight of goods handled in EU ports was estimated at over 4 billion tonnes in 2018, an increase of 3.2 % from 2017. According to the latest figures, EU port freight activity seemed to resumed a slow path towards recovery beginning in 2013 (Figure 3.9). The gross weight of freight increased in the first quarter of 2019 but reverted to a rate of growth in the second quarter similar to that seen in the same period of 2018. The gross weight of goods handled in EU ports in 2018 was very close to the volumes handled (Eurostat, 2020a).

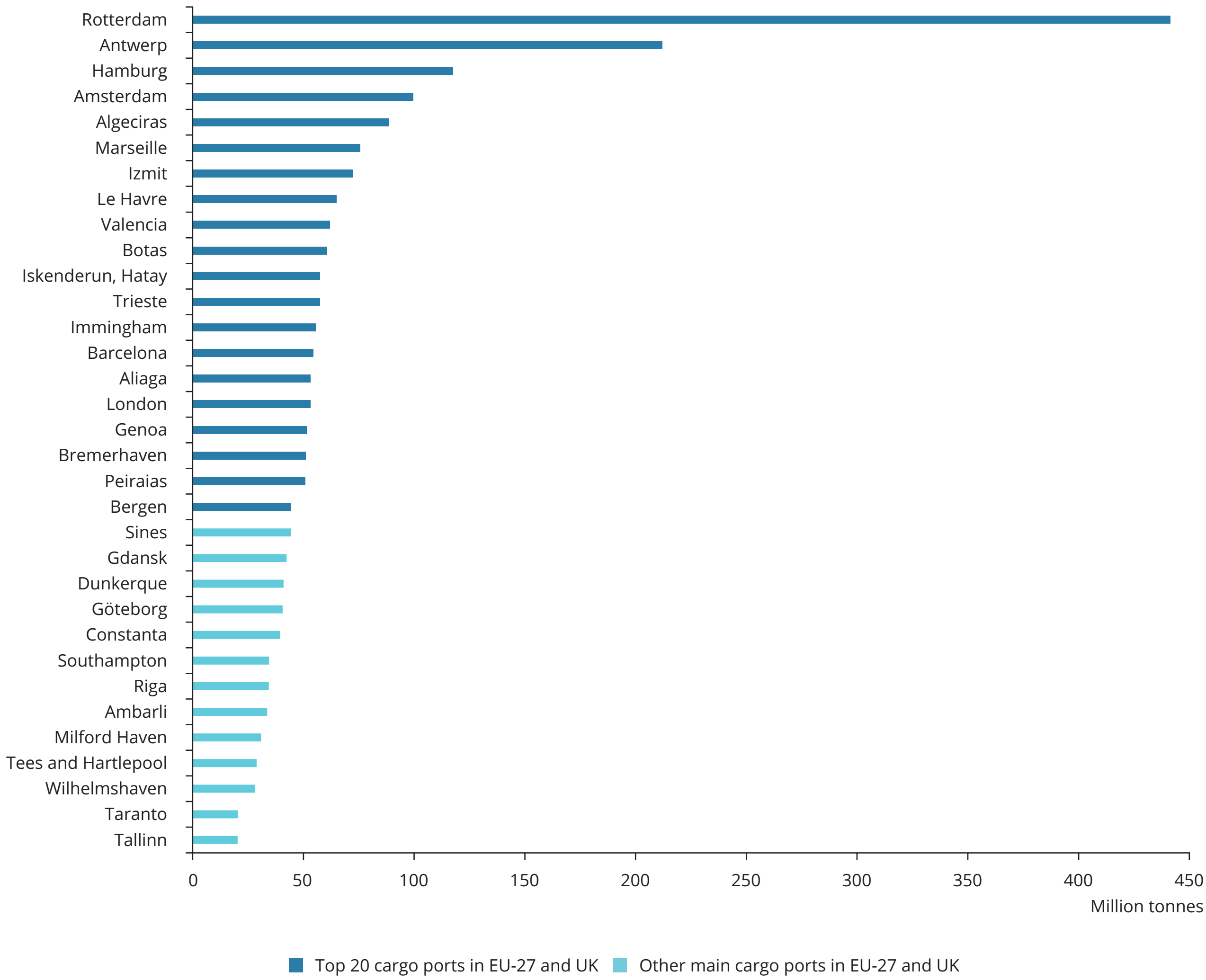
The Netherlands reports the largest volume of seaborne freight handled on a yearly basis in the EU (Eurostat, 2020a). At 605 million tonnes, the volume of seaborne goods handled in Dutch ports represented 16.8 % of the EU total in 2018 (Figure 3.10). This was followed by Spain and Italy, with 14.4 % and 13.9 % of the EU total, respectively.

Figure 3.9 Seaborne passengers embarked and disembarked (thousands) and gross weight (millions of tonnes) of seaborne freight handled in all ports, EU-27 and the UK



Source: Eurostat (2020a).

Figure 3.10 **Top 20 cargo ports and other main cargo ports in the EU in 2018 on the basis of gross weight of goods handled**

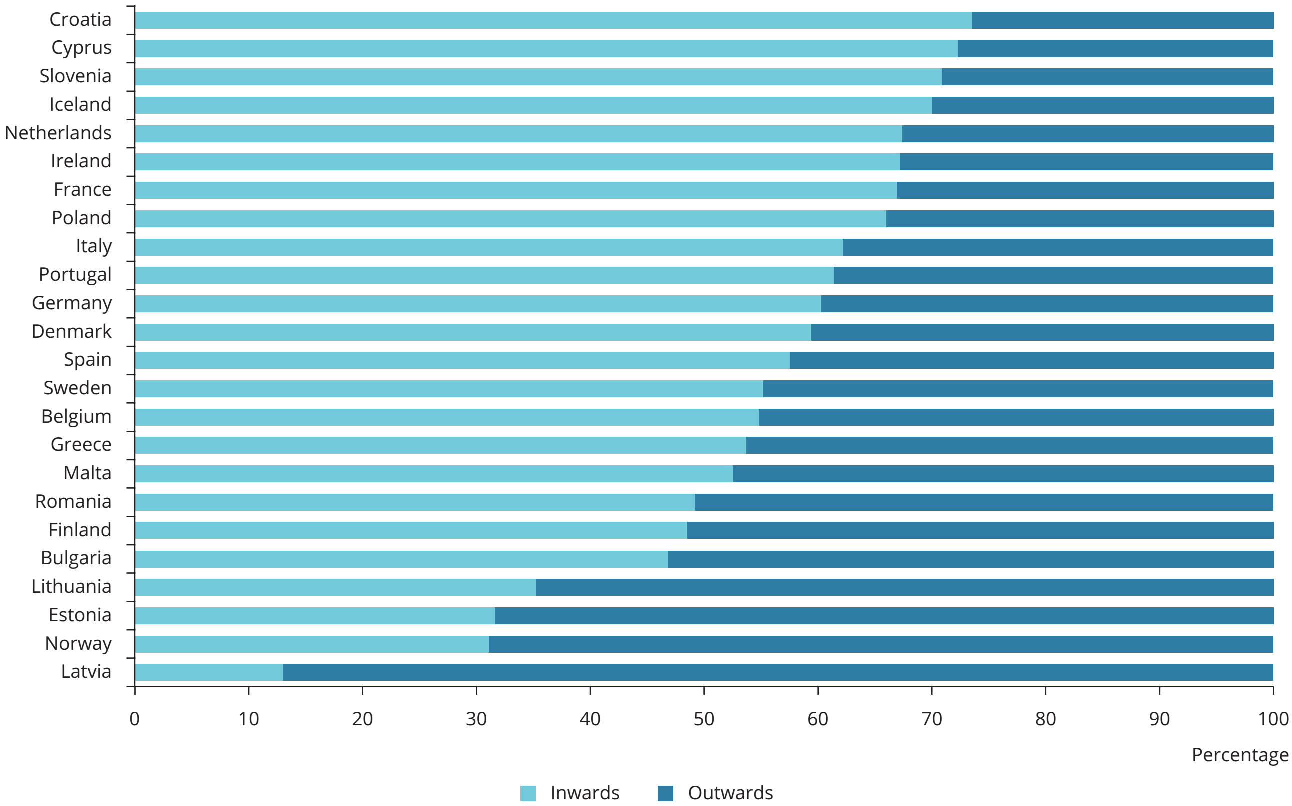


Source: Eurostat (2020a).

More seaborne goods are unloaded from than loaded onto vessels in the majority of EU countries (Figure 3.11), resulting in slightly more emissions to air from incoming international ship voyages than from outgoing voyages (Eurostat, 2020a). Croatia and Cyprus had the highest shares of goods unloaded in 2018, at 74 % and 72 %, respectively, of the total tonnage of seaborne goods recorded as inward movements to their ports. Iceland (a member country of the European Economic Area) also had a high share at 70 %. In contrast, Latvia, Norway (also a member of the European Economic Area), Estonia, Lithuania, Bulgaria, Finland and Romania all had high shares of outward movements of goods from their ports.

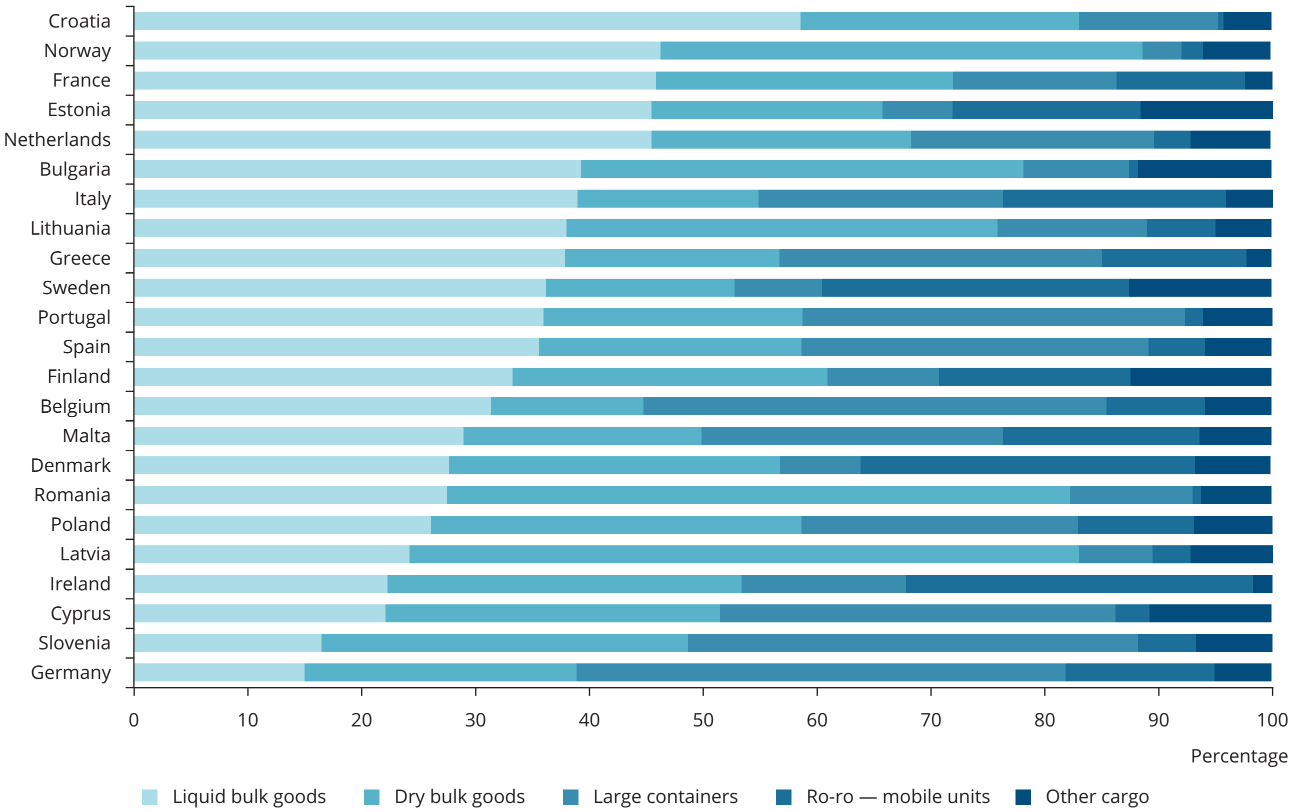
Liquid bulk goods represent the biggest share of cargo handled in EU ports (35 %), followed by dry bulk cargo and containerised goods with nearly the same share (close to 25 % each), while Ro-ro mobile units and other cargo represent a lower share (close to 15 %) (Figure 3.12).

Figure 3.11 **Inward and outward gross weight of seaborne freight handled in main ports in 2018 (% share)**



Source: Eurostat (2020a).

Figure 3.12 **Gross weight of seaborne freight handled in main ports by type of cargo in 2018 (% share)**



Source: Eurostat (2020a).

3.4 Ship building and recycling

Ship building and recycling are intrinsically related to maritime transport. They also exert pressures on the environment related to the management of hazardous wastes, wastewater, stormwater, and emissions to air generated by vessel construction, maintenance, repair and dismantling activities (EBRD, 2021).

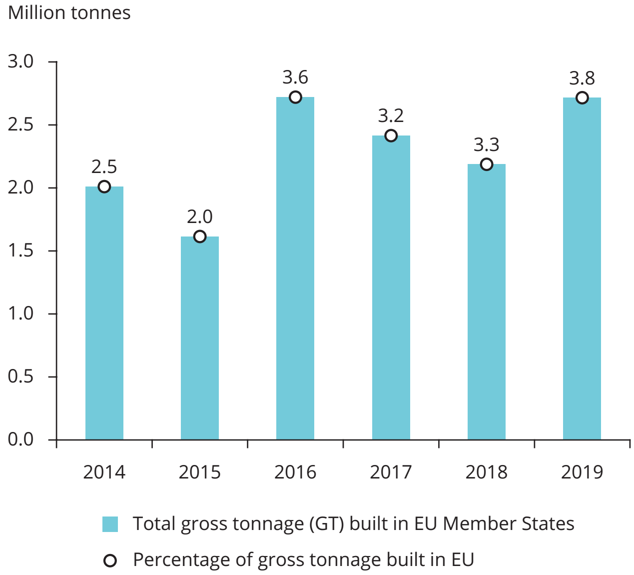
3.4.1 Ship building

Shipyards are often located in environmentally sensitive areas. Oil spills may occur during fitting operations, which may contaminate the waters surrounding the shipyard. Metals can enter the water through the discharge of anti-fouling paint chips and paint removal materials during vessel maintenance activities. Air, drainage systems and coastal waters are vulnerable to contamination from the blasting process used in shipyards. Wash water, oily water from bilges and tank cleaning, and engine fluids, such as oil, hydraulic fluids, lubricants and anti-freeze, are among the waste liquids generated during shipyard maintenance activities.

Based on the latest available information on ship building in the EU, 9.6 % of the total number of new builds in 2019 were constructed in shipyards based in the EU, which corresponds to 3.8 % of the total worldwide gross tonnage built in that year (IHS Markit, 2020). Between the years 2000 and 2008, the annual average number of individual new builds in the EU represented roughly 20 % of the worldwide annual average number of new builds. This clearly indicates a decrease in ship building activity in EU Member States from the early years of this century to recent times. The sector has, however, increased production in recent years, with new build increasing from 2.5 % in 2014 to 3.8 % in 2019) (Figure 3.13).

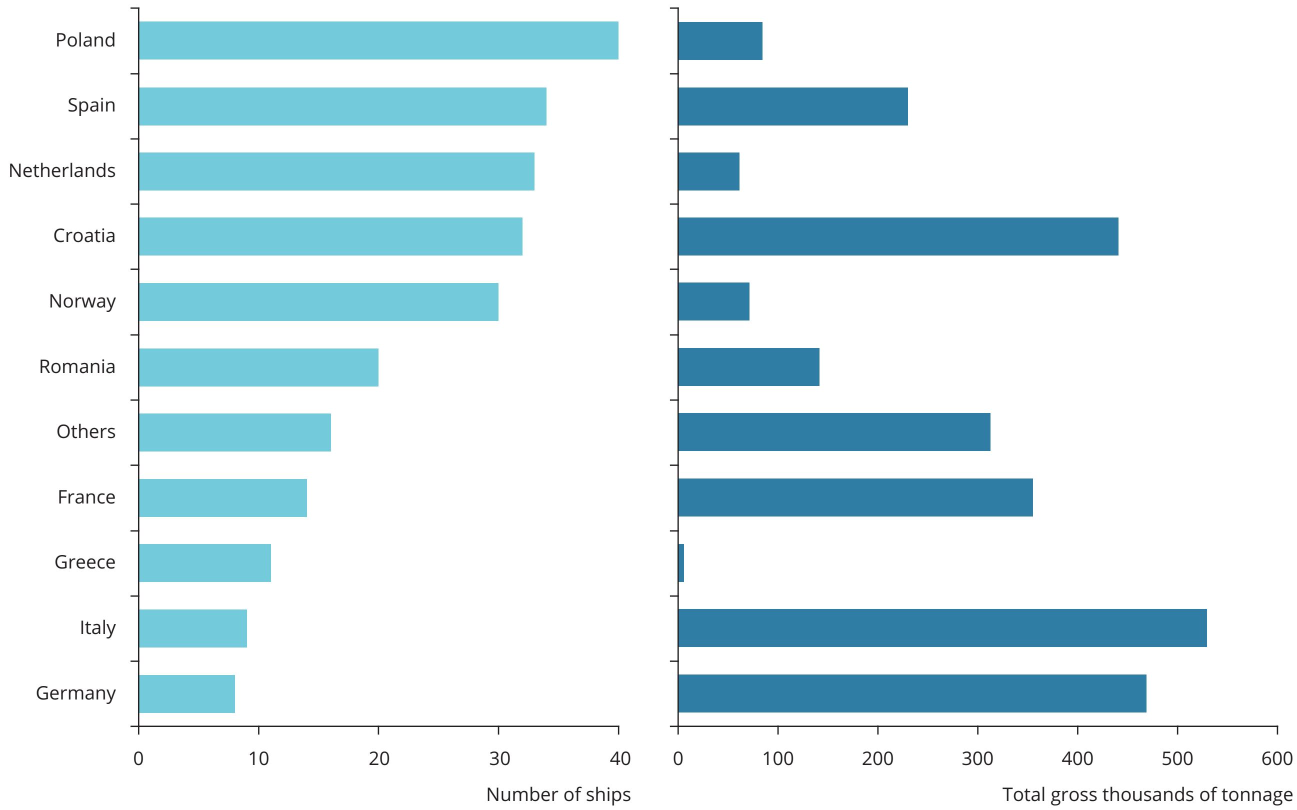
The EU (and European Free Trade Area) Member States where the highest number of ships were constructed in 2019 were Poland, Spain, the Netherlands, Croatia and Norway, representing 65 % of all new builds in European shipyards in 2019 (Figure 3.14). However, Italy, Germany, Croatia and France concentrate on the construction of large ships, accounting for 66 % of all GT built in EU shipyards in 2019.

Figure 3.13 Total GT built in EU countries and percentage of worldwide GT built in the EU



Source: Compiled from EMSA Services data.

Figure 3.14 **GT and number of new ships built in EU Member States and Norway in 2019**



Source: Compiled from EMSA Services data.

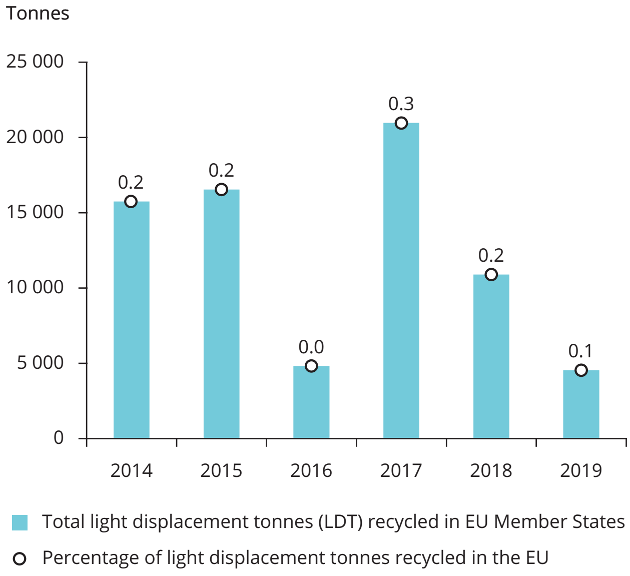
3.4.2 Ship recycling

Many large ships are dismantled in ship recycling facilities located outside the EU, some of which operate under poor environmental standards and safety conditions. Some of the techniques may involve so-called 'tidal beaching', by which the ship is taken ashore on a high tide and therefore becomes easily accessible from the beach. This process exerts pressures on the environment, as hazardous materials that may be present on board, such as oils, asbestos or toxic paints, could be released into the local environment, disrupting biodiversity. There have been local attestations of significant pollution of the surrounding environment from such activities and its resultant impacts on wildlife, farming and communities (DNV GL, 2013).

Ship recycling in the EU registered a peak in 2017 (with 40 ships recycled, equalling a total of 21 000 LDT, or light displacement tonnes); however, that amount was reduced to 4 500 LDT in 2019. A total of 211 ships were recycled in EU facilities between 2014 and 2019, mainly in Denmark and Belgium (Figure 3.15).

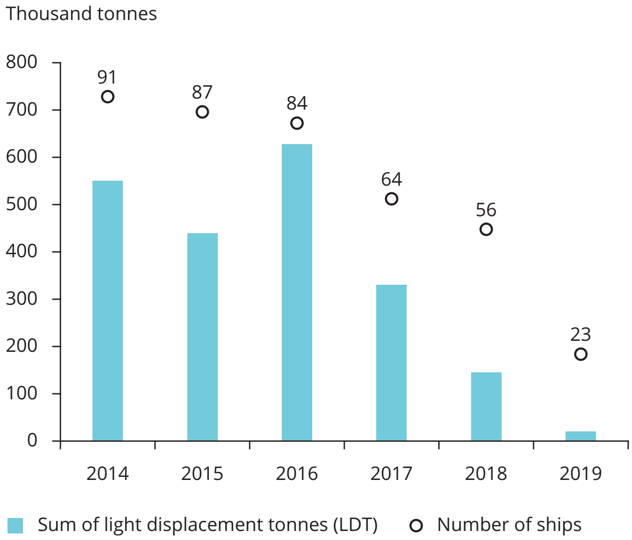
Since 2018, large commercial seagoing vessels registered under the flag of an EU Member State may only be recycled at authorised safe and environmentally sound ship recycling facilities, which are included in the European list of ship recycling facilities (EU, 2020b). However, since 2016 the number and size of ships registered under the flag of an EU Member State, at the time of recycling, has been steadily declining. In 2019, the total LDT of ships registered under the flag of an EU Member State at the recycling phase was 20 600 LDT, as opposed to the 628 000 LDT in 2016. Furthermore, the total LDT of ships with a registered owner domiciled in an EU Member State was roughly four times the LDT of ships registered under the flag of an EU Member State at the time of recycling. Figures 3.16 and 3.17 suggest that ships registered under flags of EU Member States may, for economic reasons, be flagged out to registries in third countries to avoid being recycled in the facilities included in the European list of ship recycling facilities. However, it should be noted that the European list is still developing, so that the ship recycling facilities included can fully serve all ship sizes and the international market (Jorgensen, 2020).

Figure 3.15 **Total LDT recycled per year in EU Member States and percentage of LDT recycled in the EU**



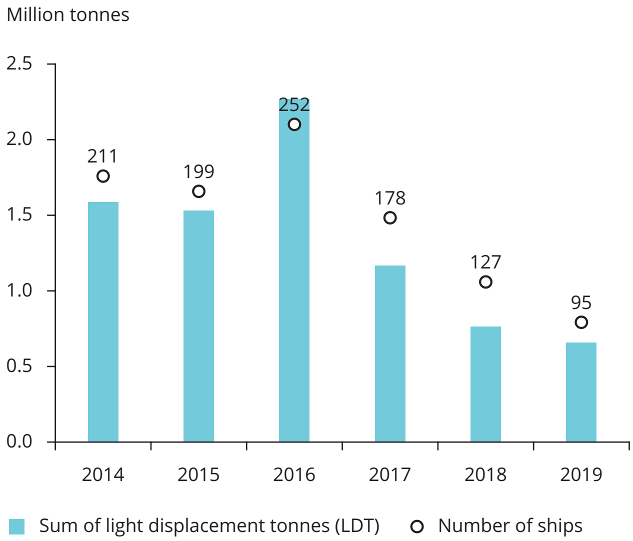
Source: Compiled from EMSA Services data.

Figure 3.16 **Recycled ships under the flag of an EU Member State during the period 2014-2019**



Source: Compiled from EMSA Services data.

Figure 3.17 **Recycled ships with an owner domiciled in an EU Member State during the period 2014-2019**



Source: Compiled from EMSA Services data.

4
Environmental aspects of maritime transport

The maritime transport sector exerts pressures on the marine environment that may lead to changes in its state. In turn, this may lead to impacts on human health and ecosystems. Identification and quantification of the various pressures is fundamental to potentially undertaking timely and effective responses where and when these are needed. Evaluating the extent of the pressures from maritime transport requires gathering information from a considerable number of sources. However, this information is not always available or complete. Because of the lack of related data, and as these data are often contributed from various sectors (i.e. not only the maritime sector), it is often even more challenging to understand the actual impacts of these pressures.

This chapter therefore provides state-of-the-art information, detailing the various pressures and impacts resulting from maritime transport.

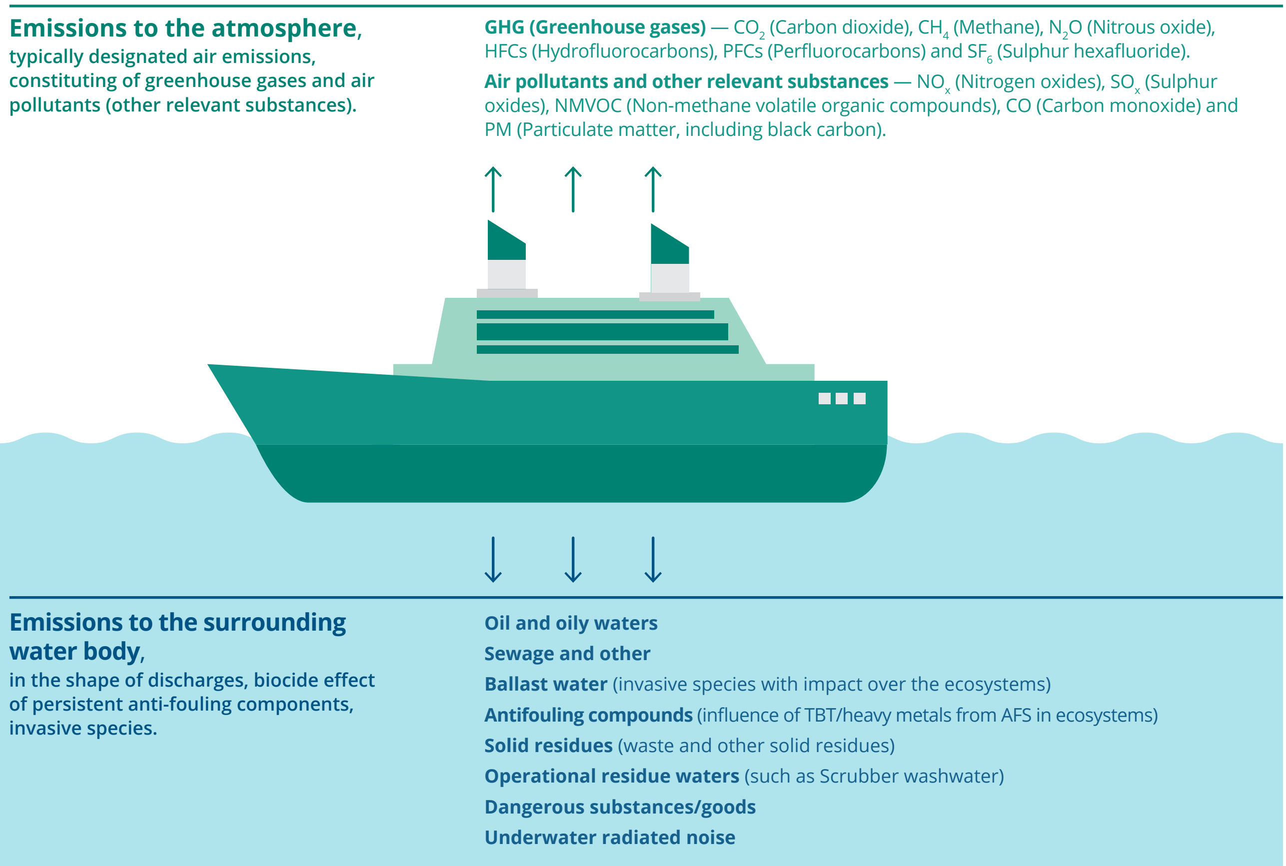
4.1 Pressures on the environment exerted by the maritime transport sector

Shipping is one of the modes of transport with the lowest carbon dioxide (CO_2) emissions per distance and weight carried. Despite this, pollution derived from maritime shipping activities has profound implications for air and water quality and marine and estuarine biodiversity. Different ship types, operational profiles, cargoes carried, fuels consumed, materials used, arrangements and control systems make vessels highly complex systems. As they move over the surface of the sea, their impacts on both air and water need to be addressed to achieve sustainability. Figure 4.1 shows the various types of pollutant emissions possible from a generic ship.

The data presented in this chapter are from various sources. When available, observational, monitoring and reporting data, as provided by EU Member States' competent authorities, have been used. Information from EU monitoring and reporting tools and services (see Chapter 6) has also been included, as it provides direct measurements of the pressures. In addition, data from various modelling services have also been used extensively to fill in gaps where no direct information is available, at the necessary spatial or temporal level. Lastly, in other instances data from the peer-reviewed literature is presented.

One of the models used throughout this chapter is the Ship Traffic Emission Assessment Model (hereafter referred to as STEAM (Jalkanen et al., 2009, 2012, 2016, 2018; Johansson et al., 2013, 2017; Scipper project, 2019-2022; Emerge project, 2020-2024). STEAM provides fully dynamic ship emission inventories based on vessel positions and characteristics, for a variety of parameters, including air emissions, air quality, water discharges and underwater noise. This model is a component of the Copernicus Atmospheric Monitoring Service (CAMS) air emission service product portfolio (ECMWF, 2018).

Figure 4.1 Pollutant emissions to the atmosphere and water body from a generic ship



Source: EMSA/EEA (2021).

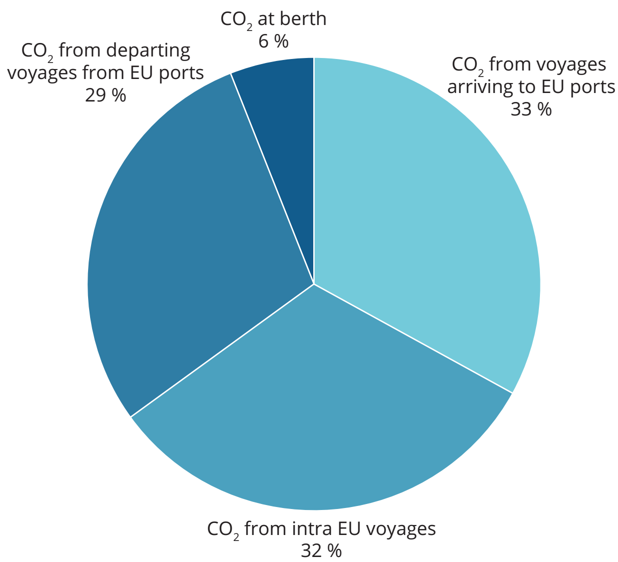
4.1.1 Air emissions

Greenhouse gases

In 2018, ships calling at EU and European Economic Area ports emitted around 140 million tonnes of CO_2. This represents 18 % of the global CO_2 emissions from international shipping (STEAM). The ships that are considered are those above 5 000 GT (gross tonnage) and engaged in commercial activities in the EU, which are responsible for approximately 90 % of the CO_2 emissions (EMSA, 2018).

Of the total CO_2 emissions, around 40 % arise from voyages between ports of EU Member States and while the ships are at berth (EMSA, 2018). 60 % are produced during voyages into and out of the EU (Figure 4.2).

Figure 4.2 Emissions from ships calling at EU and European Economic Area ports in 2018



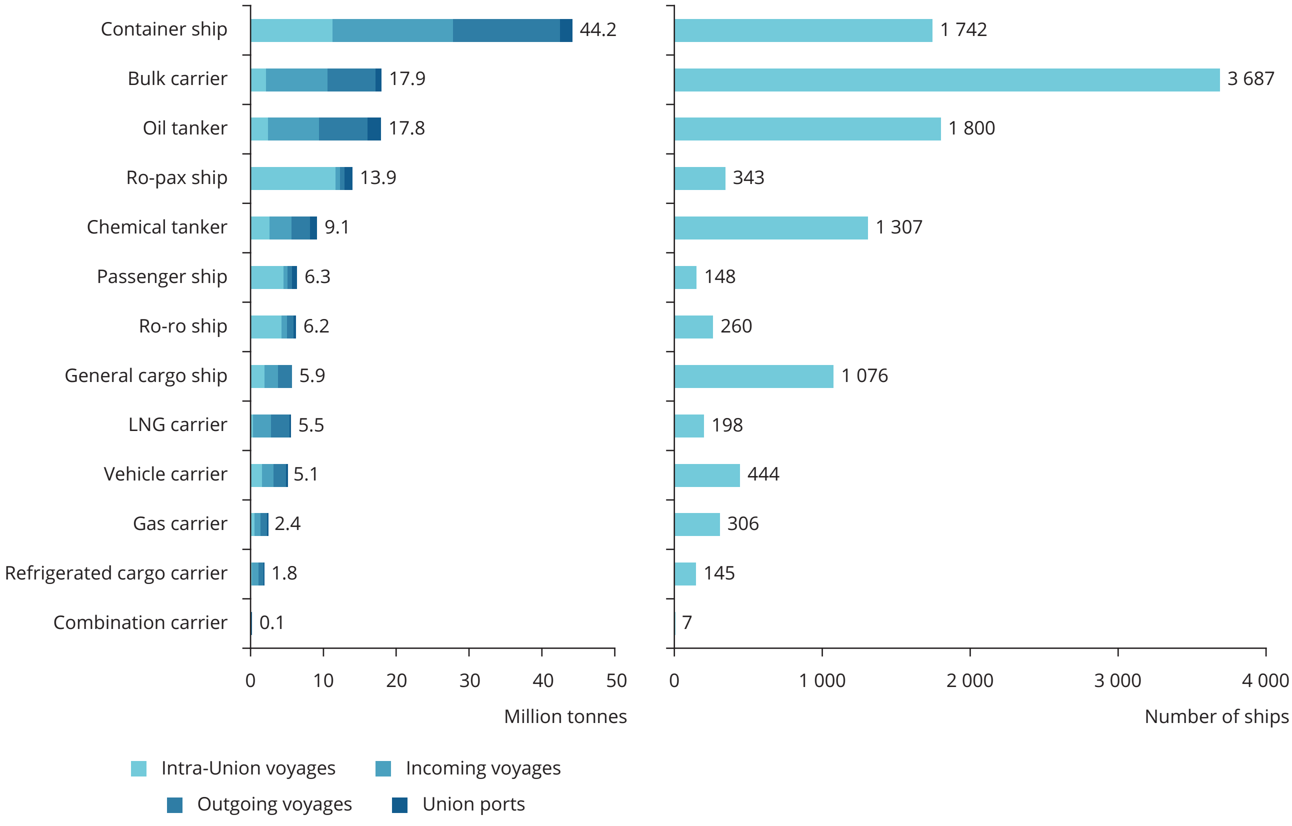
Source: EMSA/THETIS-MRV (2018).

Greenhouse gases (GHGs)

GHGs coming from ships include for the most part carbon dioxide (CO_2) as the result of the combustion of mainly fossil fuels in the ship's combustion machinery (e.g. engines, auxiliary engines, boilers). Methane (CH_4) may be emitted to the atmosphere by ships using gas or dual fuel engines or from the cargo tanks in liquefied natural gas carriers. Refrigerants are used in various types of machinery, including those for air conditioning and cargo cooling processes, and various gases are used including hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). All of these GHGs affect global warming and climate change.

Container ships account for around one third of shipping's CO_2 emissions, which are equally distributed between intra-EU, incoming and outgoing voyages. While bulk carriers account for 13 % of CO_2 emissions, these ships represent one third of the total number of ships considered. Taken together, passenger and roll-on, roll-off passenger (Ro-pax) ships also account for a substantial share of the total CO_2 emissions, which are predominantly reported under intra-EU voyage and at EU port categories. This is due to their trading pattern of fixed and regularly served routes within the EU (Figure 4.3).

Figure 4.3 Total amount of CO_2 emissions by ship type, 2018



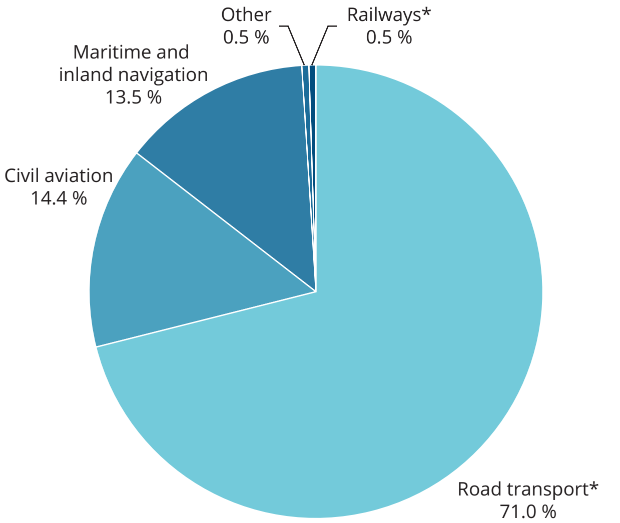
Note: Ro-ro, roll-on roll-off.

Source: EMSA/THETIS-MRV (2018).

When looking at the EU's greenhouse gas (GHG) inventory, which is produced under the United Nations Framework Convention on Climate Change (UNFCCC), maritime transport contributed 13.5 % of the total EU GHG emissions from transport in 2018 (roughly the same share as aviation, although the transport work performed by each mode of transport is not considered). This percentage already includes international traffic departing from the EU (Figure 4.4). It should be noted that the monitoring, reporting and verification module of EMSA's Thetis database (Thetis-MRV) and the EU's GHG inventory data (UNFCCC) are not directly comparable. In addition to not having a 5 000 GT threshold, emission inventories are based on all fuel sold for domestic and international waterborne navigation purposes. The split between domestic and international waterborne navigation is then estimated based on information on the port of departure and port of arrival. Emissions from waterborne navigation between the ports of different EU Member States are counted as international emissions for the purpose of the GHG inventory.

Since the start of the GHG emissions reporting, the total combined maritime and inland navigation emissions have increased by roughly 19 % compared with 1990 levels (start of the reporting). They reached a peak in 2008, after which they remained on a downward trajectory until 2015. This period largely coincides with an economic downturn in Europe, and globally that reduced transport demand. Since 2015, shipping emissions have been increasing again, but they are still 20 % below their 2008 peak (Figure 4.5).

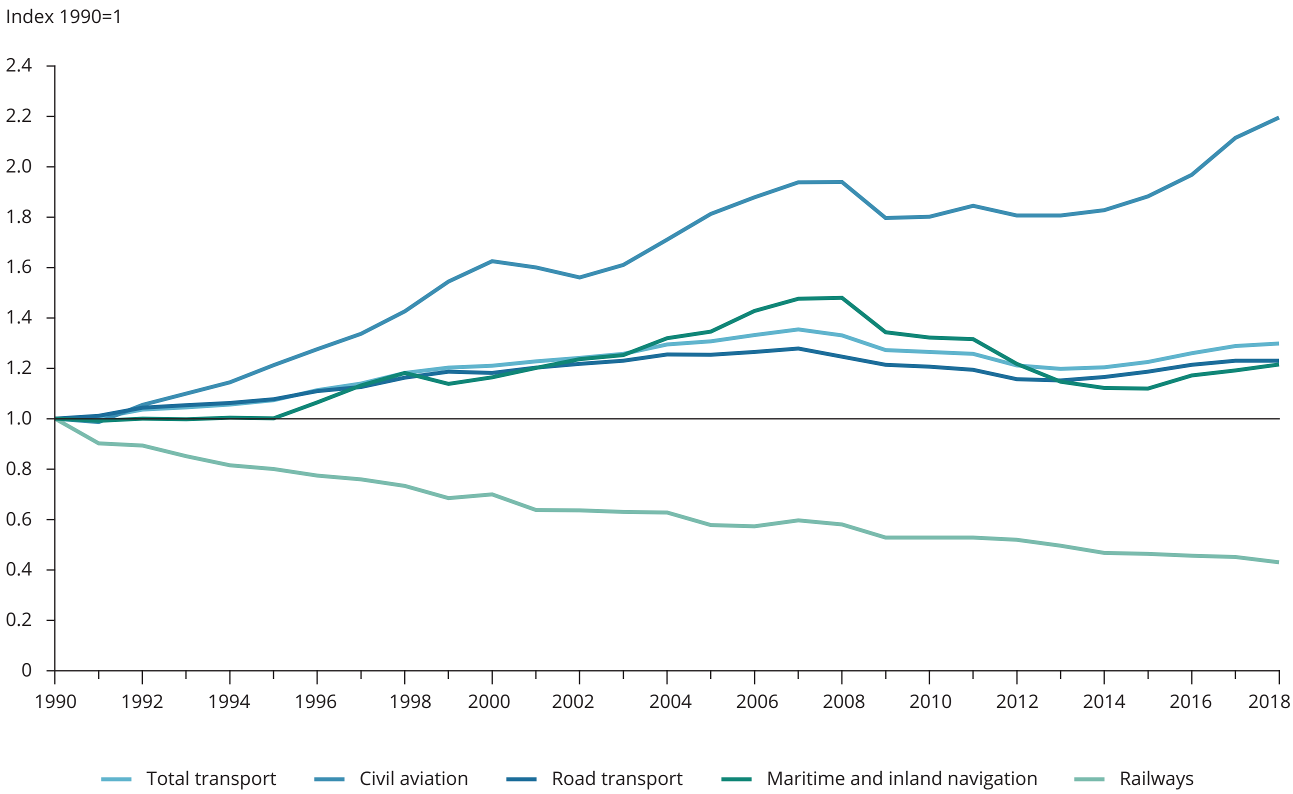
Figure 4.4 Share of total EU transport GHG emissions by mode, 2018



Note: *Excluding indirect emissions from electricity consumption.

Source: EEA (2020a).

Figure 4.5 EU GHG emissions from transport by mode, including international bunkers, relative to 1990



Source: EEA (2020a).

Although GHG emissions from shipping are significantly below their peak levels, it should be noted that the share of waterborne navigation in the EU's total GHG emissions has grown over the years. This is due to the sector's continued reliance on fossil fuels. Together with road transport and aviation, maritime and inland navigation emissions have been one of the drivers of this.

In more detail, CO_2 emissions from international maritime transport in the EU decreased by 17 % between 2005 and 2015. They are, however, projected to go up by 18 % by 2030 relative to 2015 and by 39 % by 2050. Relative to 2005, this is equivalent to a stabilisation of emissions by 2030 and a 16 % increase by 2050, which is not in line with the economy-wide climate neutrality objectives. The EU's CO_2 emissions from inland and domestic navigation have decreased over time (to about 26 % below 1990 levels) and are currently about 16 million tonnes of CO_2. This decrease is related to the renewal of the fleet and the increase in energy efficiency since EU standards for inland waterways were put in place in 2003 (EC, 2020a).

Air pollution

As a result of various onboard combustion and energy transformation processes, most markedly for propulsion and energy production, ships emit various air pollutants to the atmosphere. The main ones are sulphur oxides (SO_x), nitrogen oxides (NO_x), particulate matter (PM) and carbon monoxide (CO). Other air pollutants emitted by ships vary as a result of the nature of their operation, and include, albeit to a much lesser extent, non-methane volatile organic compounds (NMVOCs) and ozone depleting substances (ODSs). These ship-generated emissions can sometimes be significant in areas of heavy maritime traffic and can also travel long distances.

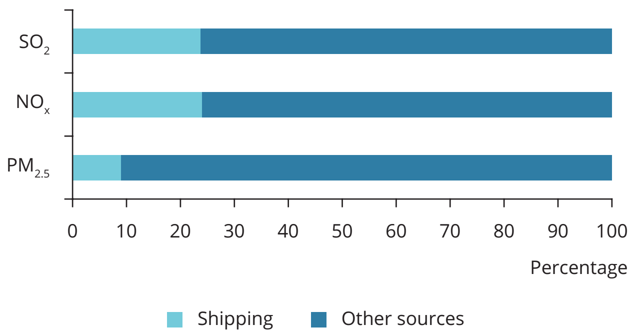
EU Member States must calculate the national emissions of several air pollutants and report them under the National Emission reduction Commitments (NEC) Directive. The EU then reports to the Convention on Long-range Transboundary Air Pollution (LRTAP Convention). The emissions are reported on a yearly basis, by pollutant and sector, and both international and national maritime transport are considered. Emissions from international maritime transport are, however, not added to the national totals. In 2018, the proportion of emissions produced by the waterborne transport sector, including international, domestic and inland water navigation, represented 24 % for NO_x, 24 % for SO_x and 9 % of $PM_{2.5}$ (PM with a diameter of less than 2.5 µm) of the emissions from all the sectors considered (Figure 4.6).

A closer look at the air pollutant emissions from the maritime transport sector for the period 2014-2019 shows that emissions generally stabilised in all European seas. However, SO_x emissions largely decreased from 2015 in the North and Baltic Seas following the introduction of the SECAs, although not in the Mediterranean Sea where a SECA is not in place.

Categorising air pollutants

Air pollutants may be categorised as primary, i.e. those which are directly emitted to the atmosphere, or secondary, which are formed in the atmosphere from precursor pollutants. Key primary air pollutants include primary particulate matter, black carbon, sulphur oxides, nitrogen oxides (includes both nitrogen monoxide and dioxides), ammonia, carbon monoxides, methane, non-methane volatile organic compounds, benzene, certain metals and polycyclic aromatic hydrocarbons. Secondary air pollutants include secondary particulate matter, ozone and nitrogen dioxide.

Figure 4.6 Proportion of air pollutant emissions from shipping versus other sectors for the EU-27 and the UK, 2018



Note: No_x, nitrogen oxides, $PM_{2.5}$, particulate matter with a diameter of less than 2.5 µm, SO_2, sulphur dioxide.

Source: EEA (2020b).

Similarly, NO_x emissions remained stable in all European seas (Figure 4.7). In the long-term, a decrease is expected in the North and Baltic Seas, after the introduction of nitrogen oxide reduction for new ships in the area at the start of 2021.

Air quality impacts from emissions from shipping are greater along the coastline. It has been shown that up to one third of all ship emissions arise within 12 nautical miles of the shoreline and a substantial part of the remaining two thirds from shipping corridors within 200 nautical miles of the shoreline. Operations in ports also represent a share of all emissions from shipping, albeit to a smaller extent. However, significant impacts from shipping emissions occur in large port cities (Cofala et al., 2018).

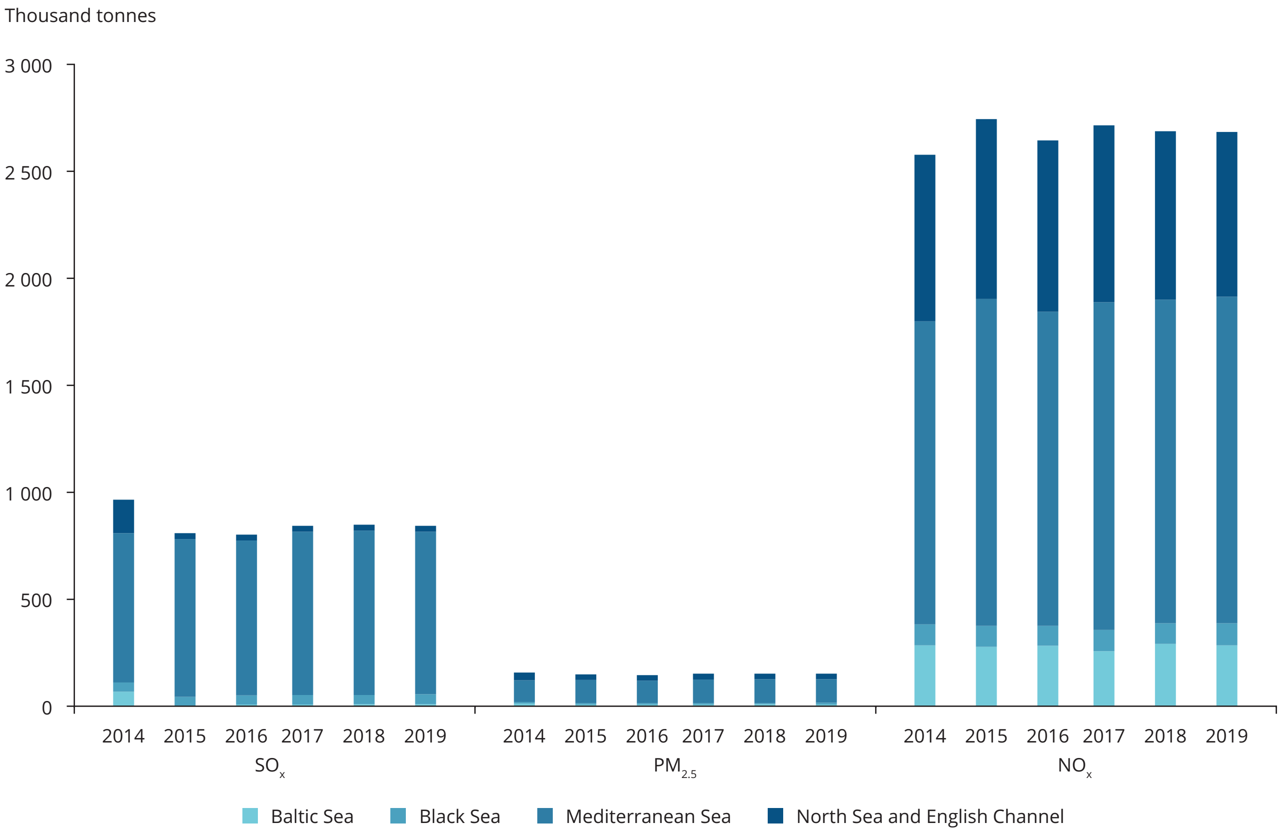
Sulphur oxides

In 2019, sulphur dioxide (SO_2) emissions from ships calling at EU and European Economic Area ports amounted to around 1.63 million tonnes. This represents approximately 16 % of the global SO_2 emissions from international shipping (STEAM, 2021).

The combustion of marine fuels containing sulphur contributes to air pollution in the form of SO_x and PM, which harm human health and the environment. Combustion of oil and coal, in which sulphur is naturally present in small quantities, has for decades been recognised as the dominant source of SO_2 emissions. The main SO_x emission from ships is SO_2 resulting from the use of marine fuels in the main and auxiliary engines but also in other combustion machinery on board, such as oil-fired boilers.

SO_2 is a pollutant that can affect the respiratory system and the functions of the lungs, and it causes irritation of the eyes (WHO, 2018a); it also contributes to acid deposition, which, in turn, can lead to potential changes in soil and water quality. The subsequent impacts of acid deposition can be significant, including adverse effects on aquatic ecosystems in rivers and lakes and damage to forests, crops and other vegetation. Acid rain falling in cities may cause significant damage to buildings and the architectural heritage. As a secondary PM precursor, SO_2 also contributes to the formation of particulate aerosols in the atmosphere. PM is an important air pollutant because of its adverse impacts on human health, and SO_2 is therefore also indirectly linked to effects on human health.

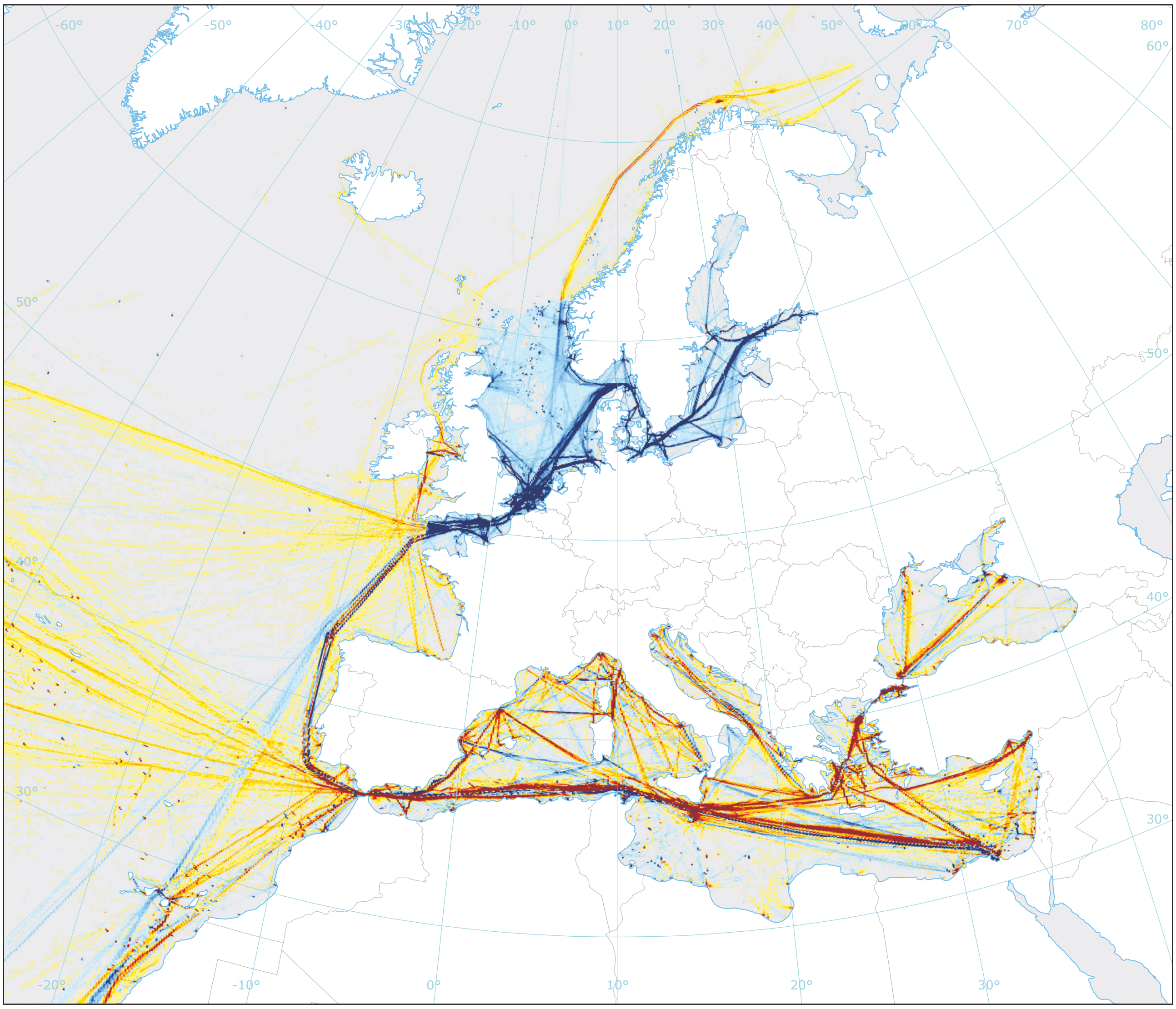
Figure 4.7 Trends in total main air pollutant emissions from ships by European sea area



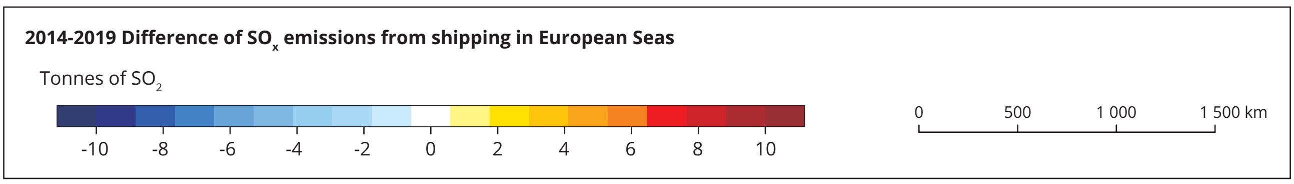
Source: STEAM (2021).

To reduce SO_2 emissions from ships, the sulphur content of marine fuels has been regulated in the EU since 1999 and continuously reduced since then. In a significant step forward, since 2010 ships at European berths have been required to use fuels with a maximum sulphur content of 0.1 % m/m (mass by mass) and passenger ships operating under regular service fuel with a maximum sulphur content of 1.50 % m/m (the regular maximum content is 3.50 % m/m). In 2015, sulphur emission control areas (SECAs) were introduced in the North and Baltic Seas, further requiring ships to use fuels with a maximum sulphur content of 0.10 % m/m in these areas. Map 4.1 shows the difference in SO_2 emissions in European shipping areas between the years 2014 and 2019. It can be seen that in 2019 SO_2 emissions from shipping in the English Channel and the North and Baltic Seas are much lower compared to 2014 than those in areas outside the SECAs, including the Mediterranean Sea, where SO_2 emissions have remained largely unaltered or increased.

Map 4.1 Difference in SO_2 emissions in European shipping areas between 2014 and 2019



Reference data: ©ESRI

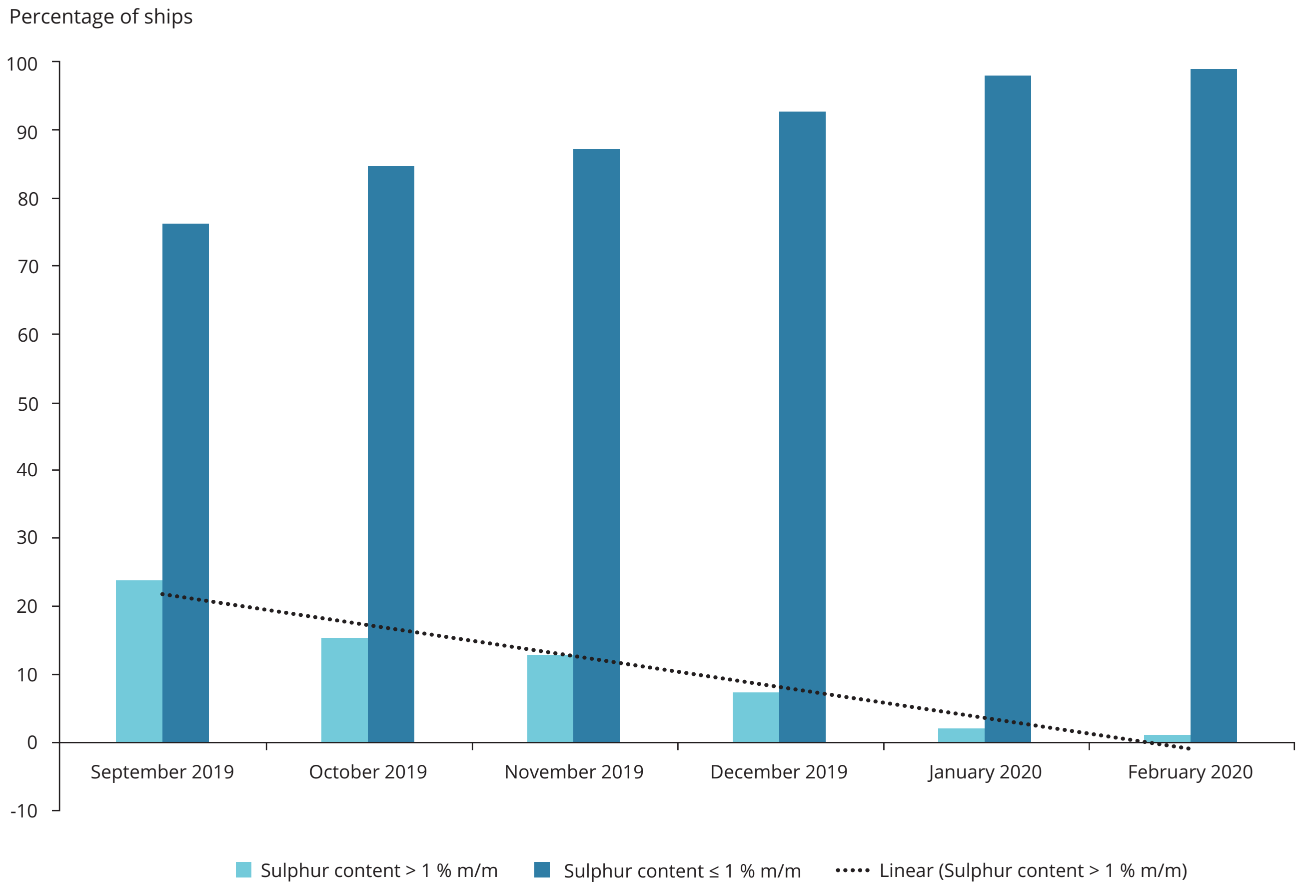


Source: STEAM (2021).

The EU SECAs have proven to effectively contribute to achieving the purpose of reducing SO_2 emissions from ships to the environment. Most ships in the SECAs respected the strict sulphur regulations, which led to a significant reduction in SO_2 concentrations in ambient air in regions bordering the SECAs. For example, reductions of up to 60 % have been observed in Denmark (Danish Ministry of Environment and Food, 2016), 50 % on the German North Sea island of Neuwerk (Kattner et al., 2017) and the Swedish islands of Öland (Ottenby) and Gotland (Hoburgen) (IVL, 2015), and over 20 % in the Rotterdam-Rijnmond region (DCMR, 2015).

In 2020 another regulatory step to limit sulphur in fuel was introduced globally with the entry into force of the International Maritime Organization (IMO) MARPOL Convention on the prevention of pollution from ships. This requires ships trading outside SECAs to use 0.50 % m/m maximum sulphur content fuels. This requirement, already established in EU legislation, is expected to reduce SO_2 concentrations in ambient air in all other coastal regions in the EU (particularly in the Mediterranean Sea). Since 2019, the percentage of ships bunkering high-sulphur fuels has been constantly declining in the EU. The percentage in September 2019 was 23.8 %, while by February 2020 it had fallen to 1.1 % (based on bunkering activity information obtained from inspections recorded in EMSA's databases). In contrast, during the same period, there was a continuous increase in the percentage of ships bunkering low-sulphur fuels (i.e. from 0.10 % up to 0.50 % m/m), which rose from 76.2 % in September 2019 up to 98.9 % of all ships in February 2020 (Figure 4.8). This was due to the IMO MARPOL Convention ban on the carriage for use of high-sulphur fuels applied in March 2020.

Figure 4.8 Monthly percentage of ships using residual fuels vs distillates



Source: Compiled from EMSA Services data.

A closer look into the ships still bunkering high-sulphur fuels (1.1 % in February 2020) in the period from November 2019 to January 2020 revealed that it mostly corresponded to ships equipped with alternative equivalent emission abatement methods.

Nitrogen oxides

In 2019, nitrogen dioxide (NO_2) emissions from ships calling at EU and European Economic Area ports amounted to around 4.46 million tonnes (Map 4.2). This represents approximately 22 % of the global NO_2 emissions from international shipping (STEAM, 2021).

NO_x emissions cause or add to regional problems, including acid rain and health problems in local areas such as harbours.

NO_x contribute to eutrophication, caused by excessive amounts of nutrient nitrogen and which can disrupt terrestrial and aquatic ecosystems.

Nitrogen oxides (NO_x) international control standards

Annex VI of the MARPOL Convention on the prevention of pollution from ships introduces NO_x control requirements on ships with marine diesel engines of over 130 kW output power. The specific controls are applied in three levels (tiers), based on the ship's construction date and operation area. Within a tier, the actual NO_x limit value is determined based on the specific engine's rated speed. The most stringent control limits, tier III, apply only to ships operating in nitrogen emission control areas (NECAs) and constructed after their entry into force. Tier III represents almost an 80 % reduction in NO_x emissions compared with tier II limits but only applies to new ships and in restricted sea areas (MARPOL Annex VI, 2006).

NO_2 is also a precursor gas, forming new particles in the air or condensing on to pre-existing particles to form secondary PM (i.e. secondary inorganic aerosols).

NO_x are formed from nitrogen and oxygen precursors during the combustion process in the ship's main engines. Together, these two compounds constitute 99 % of the engine's intake air. Oxygen is consumed during the combustion process, with the amount of excess oxygen available being a function of the air and fuel ratio that the engine is operating under. Nitrogen largely remains in the combustion process; however, a small percentage will be oxidised to form various NO_x. When measured in the exhaust duct of a marine diesel engine, NO_x emissions would normally comprise nitric oxide (NO; about 95 %) and NO_2 (about 5 %). The latter, initially formed as NO, further oxidises after combustion of fuel in the engine. The formation rate of the majority of NO is largely dependent on the peak temperatures achieved in the engine cylinders (the higher the combustion temperature, the peak pressure, the compression ratio and the rate of fuel delivery, the greater the amount of NO_x formation). Because of this, the control of NO_x emissions requires engine adaptation or the use of after-treatment technologies.

NO_x emissions from ships are regulated at international level in Annex VI of the MARPOL Convention (MARPOL Annex VI, 2006). At EU level, current laws in the field of marine water and air quality set out obligations to be achieved by Member States covering a whole range of pollutants, including NO_x. The existing international requirements will affect NO_x shipping emissions in the EU at a slow pace. This is mainly because the more stringent MARPOL Annex VI NO_x standards (tier III) will apply only to ships constructed on or after 1 January 2021 and operating in the EU nitrogen emission control areas (NECAs) in the North and Baltic Seas. The benefits of tier III standards in the NECAs in the Baltic and North Seas and of the tier II standards in other seas may be partly offset by increases in fuel consumption (Cofala et al., 2018).

Particulate matter

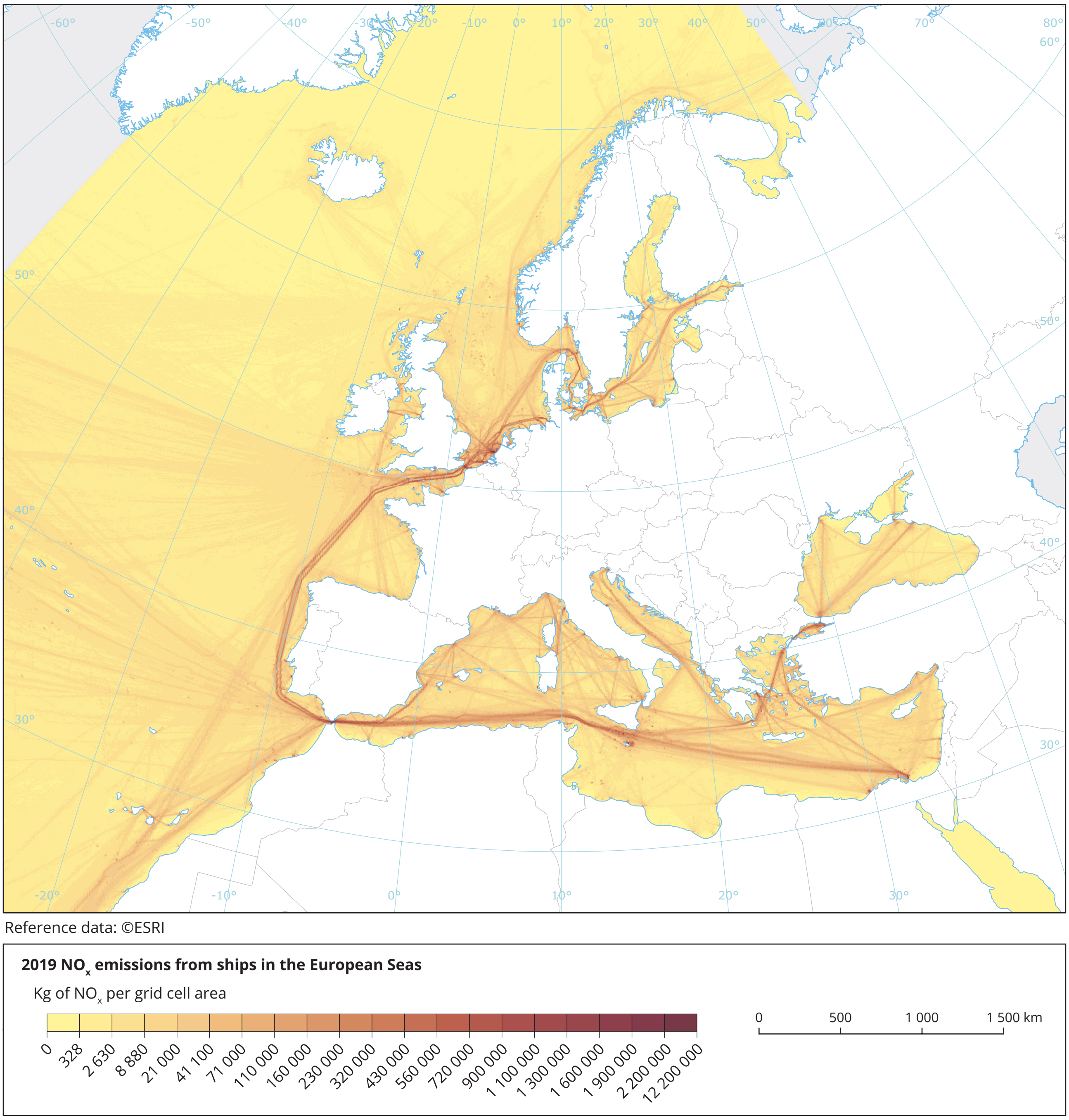
In 2019, $PM_{2.5}$ emissions from ships calling at EU and European Economic Area ports amounted to around 0.27 million tonnes (Map 4.3). This represents approximately 18 % of the global $PM_{2.5}$ emissions from international shipping (STEAM, 2021).

$PM_{2.5}$ from shipping forms during the various combustion processes on board. In ports an increase in PM_{10} (PM with a diameter of 10 μm or less) and $PM_{2.5}$ concentrations can also be observed due to loading, unloading and bunkering operations.

There is a direct relationship between the SO_x and NO_x emitted by ships and the resulting PM. A fraction of SO_2 emitted from the engines reconverts into SO_3 which almost immediately forms sulphates ($PM_{2.5}$). In the atmosphere, SO_2 is also transformed into particulate sulphate ($PM_{2.5}$).

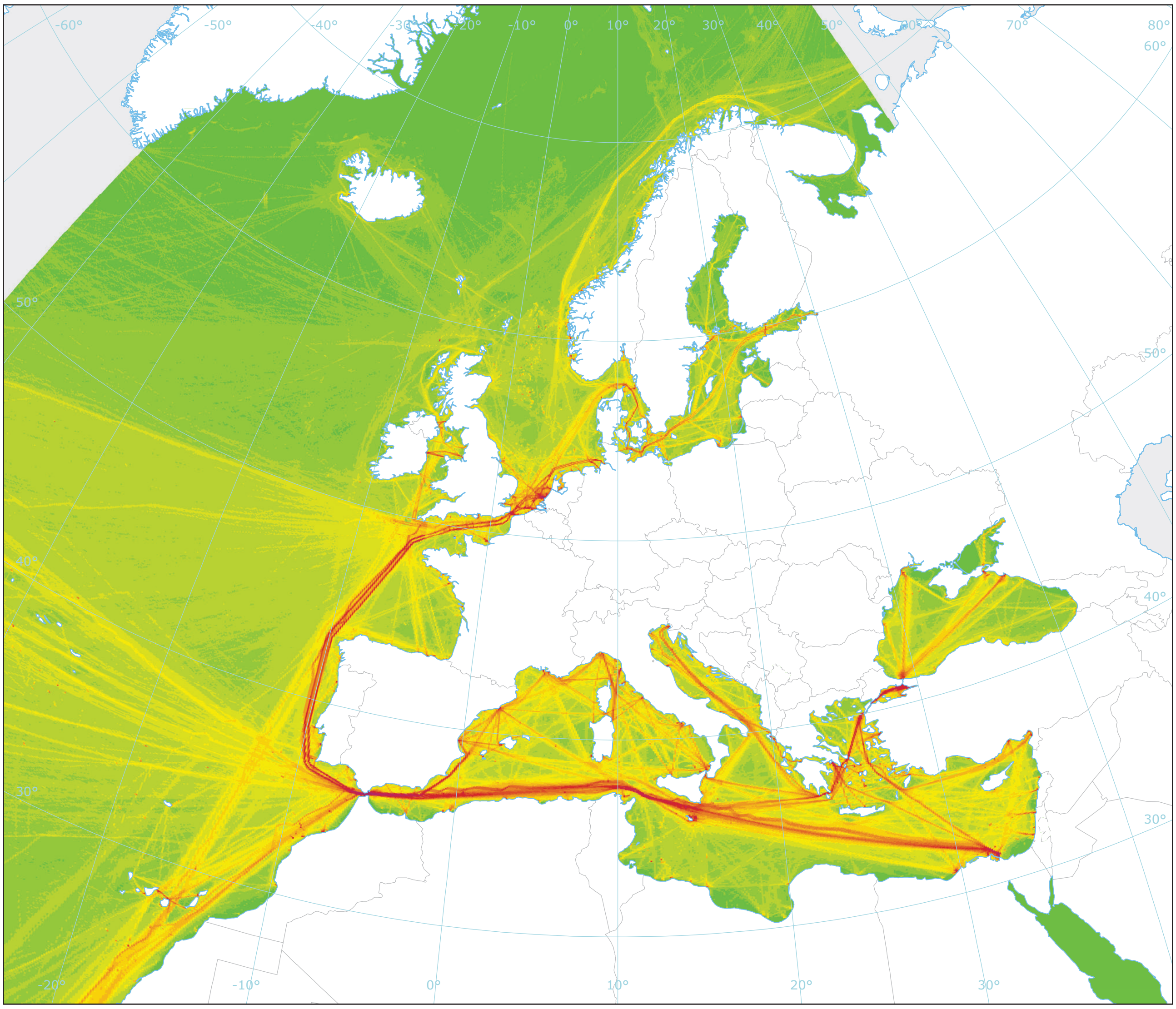
Current regulations on the sulphur content of marine fuels and NO_x emission controls also affect trends in $PM_{2.5}$ emissions. In particular, lower sulphur content marine distillate fuels should also reduce $PM_{2.5}$ emissions.

Map 4.2 **NO_x emissions from shipping in the European seas**

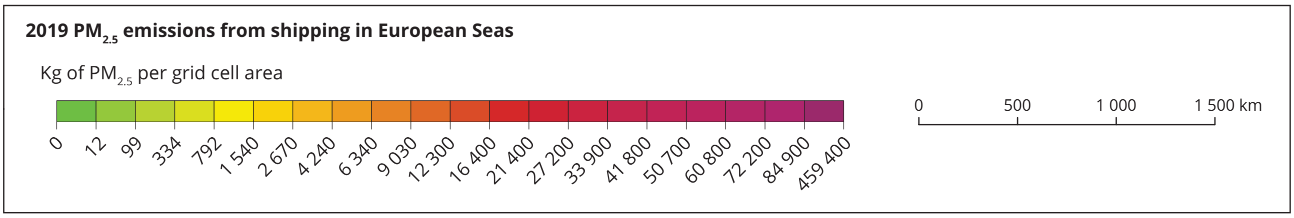


Source: STEAM (2021).

Map 4.3 **$PM_{2.5}$ emissions from shipping in European seas**



Reference data: ©ESRI



Source: STEAM (2021).

Air pollution in ports

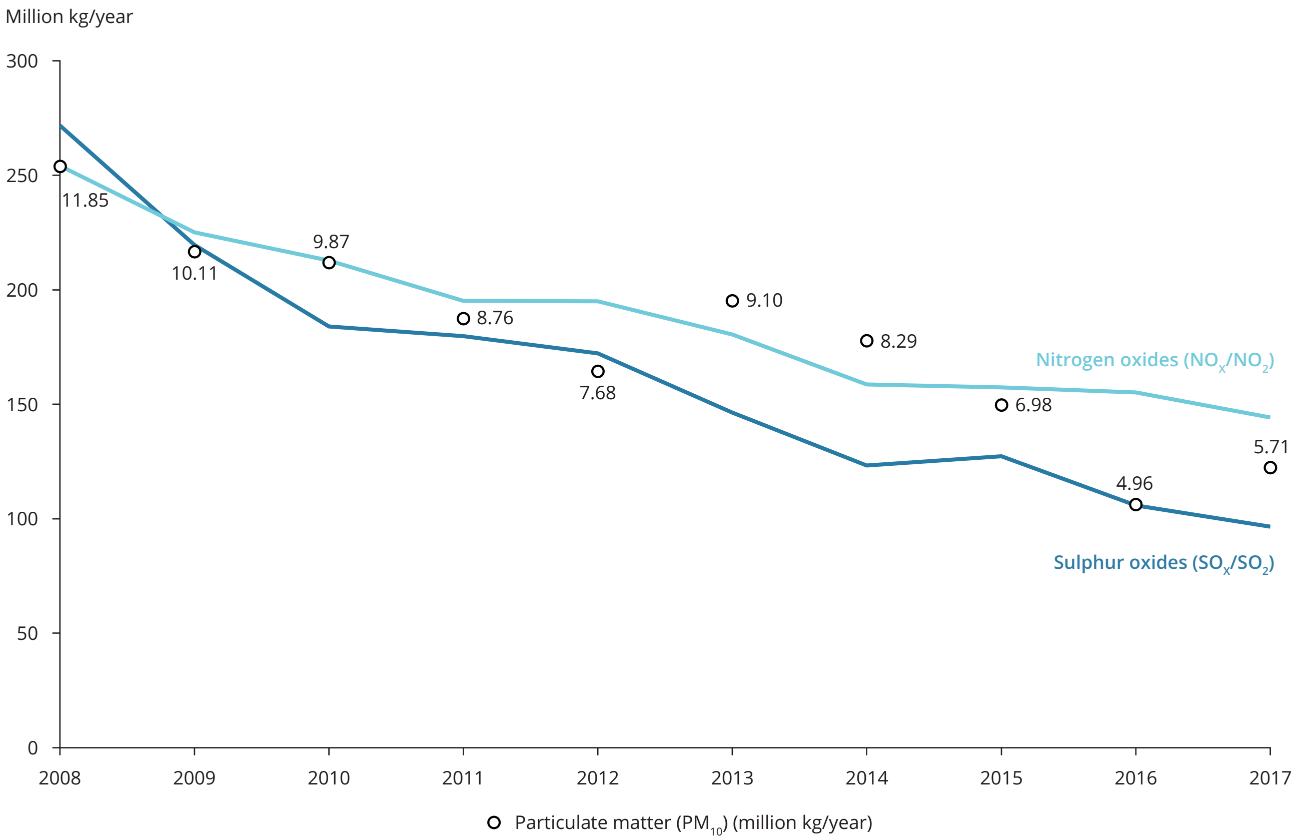
What is particulate matter (PM)?

PM includes a wide variety of solid and liquid particles, some visible, such as dust, pollen, soot or smoke, and others microscopic. A broad classification can be made as follows: PM_{10}, inhalable particles of 10 µm diameter and smaller; $PM_{2.5}$, fine particles of less than 2.5 µm diameter; and $PM_{0,1}$ ultra-fine particles of less than 0.1 µm diameter. An average human hair is about 70 µm in diameter. Of these, $PM_{2.5}$ (which by definition includes the ultrafine particles) poses the greatest risk to health and is often the cause of reduced atmospheric visibility.

Air quality in ports is highly dependent on the various port activities. Although the impacts of these activities on air pollutant emissions may not be very significant in terms of national totals, they can be significant locally in the regions and urban areas where the ports are located. Air pollutant emissions from ships while in port are produced when the ships are in transit into and out of the port, when manoeuvring, when undergoing unloading and loading operations, and when at anchor. Ships' auxiliary engines and boilers are often running at berth. Air pollutant emissions in port also arise from road transport linked to the port's activities, such as heavy-duty vehicle and passenger transport traffic coming to and from the port and the use of port machinery, such as cranes or heavy machinery, as well as from ship navigation close to coastlines (especially NO_x). Industries located in port areas, such gas and oil refineries or chemical plants, also contribute to poor air quality.

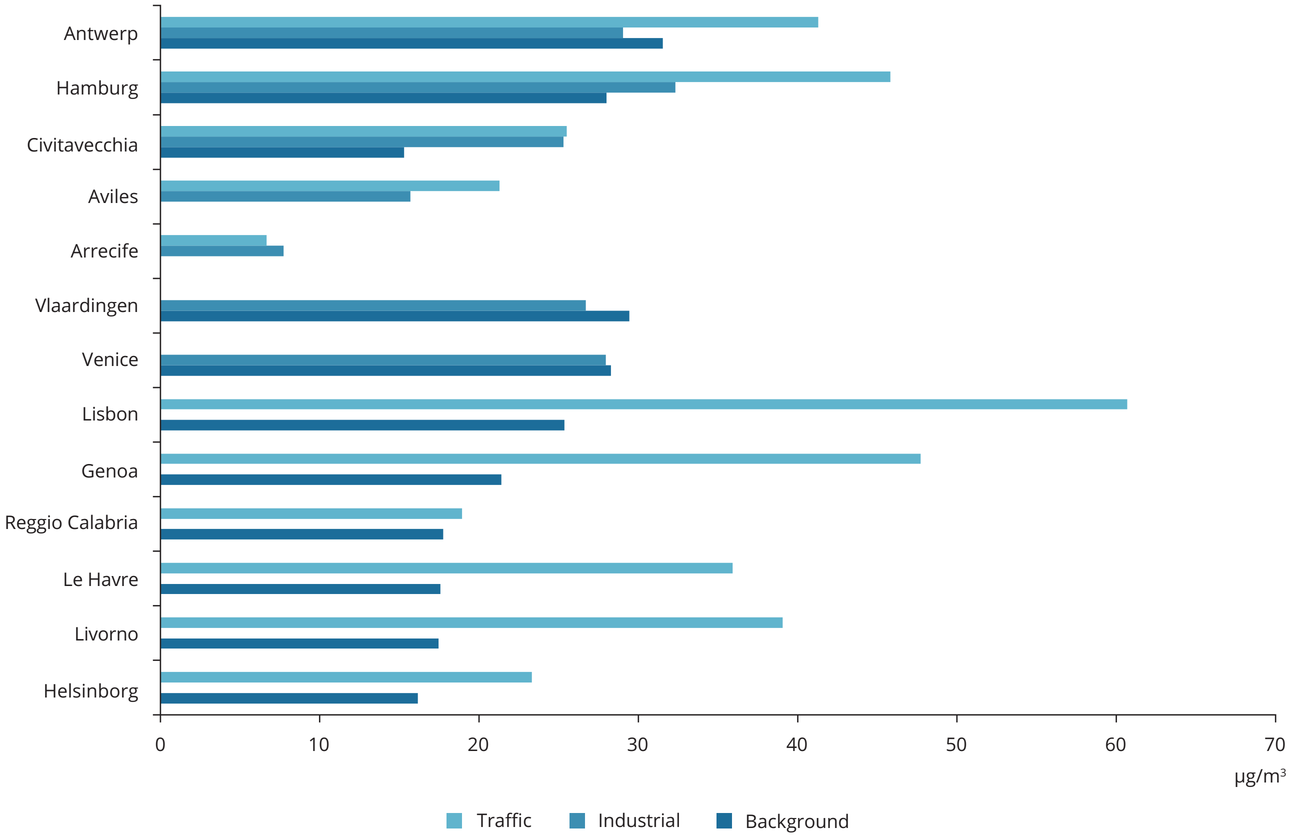
Shipping, road traffic and non-road traffic, as well as inland and domestic maritime transport, are sectors for which emissions are estimated and reported under the LRTAP Convention and reflected in national emissions inventories. Nevertheless, it is not possible to further disaggregate the various emissions in port to quantify, for instance, those related to maritime transport only. However, based on industrial emissions reported to the European Pollutant Release and Transfer Register (E-PRTR), a decrease can be observed during the period 2008-2017 regarding SO_x (around 65 %), NO_x (around 43 %) and PM_{10} (more or less halved) emissions from E-PRTR-listed facilities located within 2 km of ports (Figure 4.9).

Figure 4.9 Total quantity of air pollutant emissions from E-PRTR-listed facilities located within 2 km of ports



Source: EEA (2020c).

Figure 4.10 **Average of the annual mean NO_2 concentrations recorded at air quality monitoring stations (by station type) located within a 2 km radius of some EU ports, 2018**



Source: EEA (2020c).

Still, further understanding of the specific contribution made by the various port-related activities to air quality in and around ports is not possible with current air quality monitoring stations. Monitoring stations classified as 'industrial' measure pollution levels that are dominated by a single industrial source or industrial area, such as a port. 'Traffic' monitoring stations are located near a single major road, and the levels recorded are dominated by traffic sources. 'Background' stations are representative of a wider area, as pollution levels are not dominated by a single source. Comparing industrial, traffic and background levels within 2 km of a port is, however, not enough to achieve sufficient discrimination between the different sources of air pollution in ports, including those from maritime transport alone, as Figure 4.10 shows indicatively for NO_2.

Black carbon

Black carbon (BC) is a small, strongly light-absorbing dark particle emitted following the incomplete combustion of organic carbon-based fuels. With a diameter between 20 nm and 50 nm, it is one component of $PM_{2.5}$ mass, the contribution of which is dependent on the combustion source.

As a result of its dark colour, BC absorbs a high proportion of incoming solar radiation, directly warming the atmosphere, where it has a short atmospheric lifetime — days to weeks — before sinking to the ground or being washed out by rain. The strength of this light absorption varies with the composition, shape, size distribution and mixing state of the particle (IMO, 2012a). As a fraction of PM, BC also contributes to the adverse impacts of PM on human health (IPCC, 2013). When BC settles on snow or ice, it darkens them and reduces their ability to reflect sunlight, leading to increased heat absorption and melting (Lack et al., 2015).

The climate change effects of BC emissions from shipping are increasingly well understood. Estimates indicate that BC was responsible for 6.85 % of the global warming contribution from shipping in 2018, while CO_2 contributed 91.32 % (IMO, 2020a). The impact on warming at a regional level can be more pronounced. This is the case in the Arctic, where direct emissions of BC from ships contribute more to warming than elsewhere. This adds to temperature increases in the Arctic that are already much faster than in other parts of the world (Lack et al., 2015).

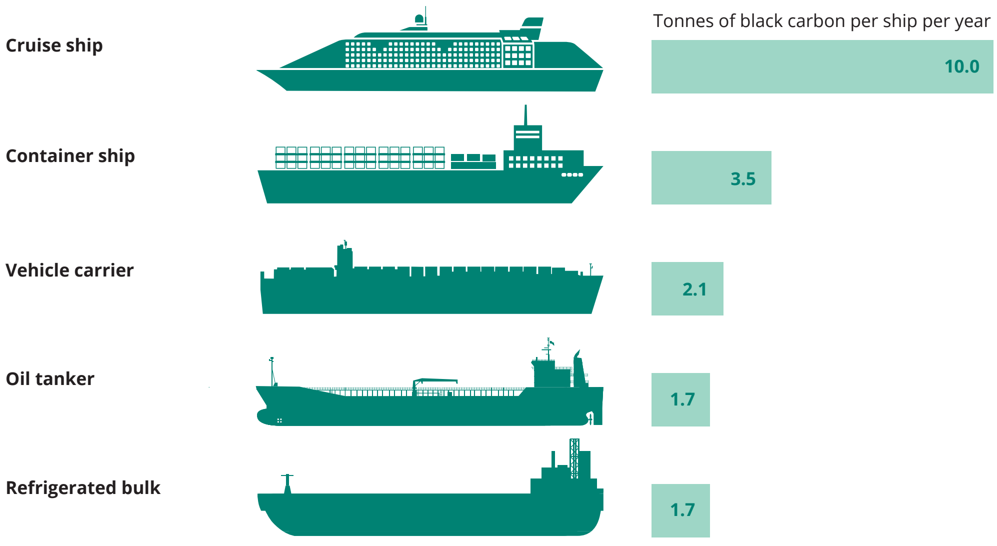
The largest sources of BC emissions from maritime transport are fossil fuel, biomass and biofuel combustion. BC from biomass burning comprises 2-5 % of the total PM mass, whereas BC from engines burning ultra-low-sulphur heavy fuel oils can range from 65 % to 75 % of the PM mass. International maritime transport is thought to contribute to about 1-2 % of global BC. Its release by ships is mainly influenced by the type of fuel used, engine characteristics (e.g., two-stroke, four-stroke) and load. Low-sulphur distillate fuels have been estimated to provide 30-80 % reductions in BC emissions compared with using conventional high-sulphur fuels (Lack et al., 2012). However, potential reductions in BC emissions may also be dependent on the proportion of aromatic compounds in the fuels used, in addition to their sulphur content, and on the type and size of engine.

Currently, BC mass emission data from ships' engines and relative measurements of BC mass before abatement technologies are still scarce and imprecise.

Studies have estimated that larger ships are responsible for most BC emissions. Container ships, bulk carriers and oil tankers together emit 60 % of all BC emissions. Within this group, container ships, which make up 7 % of the global fleet (14 % in dead weight tonnage), emit most BC (26 % of the global total). Cruise ships account for 6 % of BC emissions despite accounting for less than 1 % of the global fleet (Comer et al., 2017).

BC emissions are currently not directly regulated at international level. At EU level, current laws cover BC emissions from the maritime sector in a broader sense. However, both the Arctic Council and the IMO are actively considering the impacts of BC in the Arctic (AMAP, 2021). As part of these activities, the IMO agreed a reporting protocol and measurement methods for BC emissions with a view to investigating policy options. A potential ban on the carriage and use of heavy fuel oil by ships in the Arctic is also being prepared with a view to applying it in 2024 (IMO, 2020b).

Figure 4.11 Annual global BC emissions by ship type in tonnes



Source: Comer et al. (2017).

4.1.2 Water pollution

Water pollution is caused by different sources and types of ship operations, including the use of antifouling biocides on hulls, as well as accidents resulting in acute pollution events. On top of this, the same pollutants emitted to the air can also enter the marine environment through atmospheric deposition, and therefore contribute to the contamination and eutrophication of the marine environment.

The direct impact of shipping on the contamination status of the marine environment is difficult to estimate because of the complex dynamics of pollutants and the various other existing sources of pollution (e.g. direct discharges from land, run-off, atmospheric deposition or other activities at sea, such as the exploration and exploitation of hydrocarbons offshore or deep sea mining). However, the contamination of the seas surrounding the EU continues to be a large-scale challenge (EEA, 2019a). Therefore, further commitments to reduce discharges or accidental pollution of all types (including from shipping) are needed to achieve a clean and non-toxic marine environment.

Oil and hazardous and noxious substances spills

Oil spills are one of the most concerning sources of marine pollution, as they are difficult to clean up and can last for long periods of time in the marine environment. They can severely pollute marine and coastal habitats, causing damage to the natural environment and the economy. This can also result from inappropriate clean-up operations after an oil spill. Oil spills can originate from deliberate operational discharges, from negligence, such as poor maintenance of equipment, or from the consequences of an accident or incident, such as a vessel collision or grounding or a pipeline rupture.

While the amount of oil transported by sea has been steadily growing for the last 30 years, with a consequent increase in the risk of potential oil spills, the total amount of oil accidentally spilt from oil tankers has been constantly declining. Figure 4.12 shows this decreasing trend between 1990 and 2006, for medium (7- 700 tonnes) and large (> 700 tonnes) oil spills. Additional statistics analysing the number of tanker spills versus the growth in crude and other tanker trade loaded from 1970 to 2018 conform this declining trend (ITOPF, 2019).

Following a series of accidents in the 1990s (Table 4.1), the last major oil spill in European waters was caused by the sinking in bad weather of the 26-year-old structurally deficient oil tanker MV *Prestige* in November 2002, about 100 km off the coast of Galicia, Spain. This resulted in a heavy fuel oil spill stretching for more than 150 km of coastline (Figure 4.12).

Oil pollution in the high seas

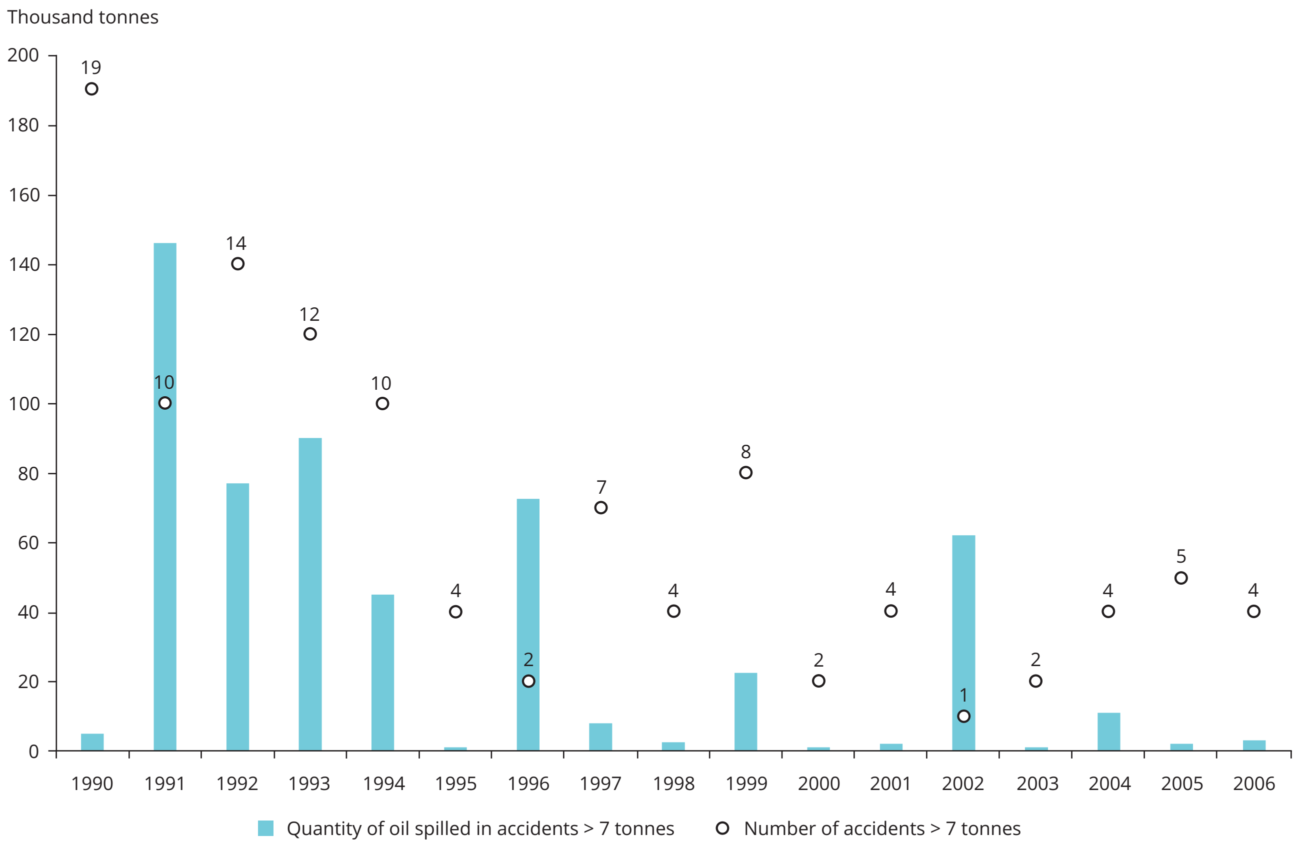
The MARPOL Convention on the prevention of pollution from ships requires ships to develop and maintain a ship oil pollution emergency plan (SOPEP) and to immediately notify the nearest coastal state of any pollution incident. However, in cases of spills exceeding the capacity of the ship to contain them, the International Convention Relating to Intervention on the High Seas in Cases of Oil Pollution Casualties, 1969, established the right of a coastal state to take such measures on the high seas as necessary to prevent, mitigate or eliminate danger to its coastline or related interests from pollution by oil or the threat thereof, following a maritime casualty. Experience has shown that states alone could not deal with major oil spills and the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC Convention), created in 1990, provides the basis for international assistance between states in the case of a spill. The principles laid down in the Convention are also implemented within the framework of the regional cooperation agreements and often further defined in sub-regional contingency plans.

Table 4.1 Top oil spill accidents in the EU since 1990

Ship name	Year	Location	Oil lost (tonnes)
MT *Haven*	1991	Genoa, Italy	144 000
MV *Braer*	1993	Shetland Islands, UK	85 000
Aegean Sea	1992	La Coruña, Spain	74 000
MT *Nassia*	1994	Black Sea, Turkey	33 000
MV *Sea Empress*	1996	Milford Haven, UK	72 000
MV *Erika*	1999	Off Brittany, France	20 000
MV *Prestige*	2002	Off Cape Finisterre, Spain	63 000

Source: EEA (2010).

Figure 4.12 Accidental oil tanker spills in EU waters



Source: EEA (2010).

Table 4.2 Number of oil spills from oil tankers in the EU and outside the EU and percentage of total in the EU

Location	Year										
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
EU	1	2	1	1	0	1	0	1	1	0	8
Outside EU	8	3	6	7	5	7	5	5	5	3	54
Total	**9**	**5**	**7**	**8**	**5**	**8**	**5**	**6**	**6**	**3**	**62**
Percentage in the EU	**11 %**	**40 %**	**14 %**	**13 %**	**0 %**	**13 %**	**0 %**	**17 %**	**17 %**	**0 %**	**13 %**

Source: ITOPF (2019).

Recent data collected by the International Tanker Owners Pollution Federation (ITOPF) confirmed the positive trend over the 10 years from 2010 to 2019. In the EU, the number of oil spills from tankers is marginal in comparison with the global numbers. Indeed, according to the ITOPF data, from 2010 to 2019, only 13 % of oil tanker spills, eight spills out of a total of 62, occurred in EU waters (Table 4.2).

Oil spills may be divided into two categories: medium (7-700 tonnes) and large (> 700 tonnes) oil spills. Out of the total of 44 medium-size oil spills in the world since 2010, only five were located in EU waters (11 %), and out of a total of 18 large oil spills, only three were located in the EU (17 %) (Table 4.3).

Table 4.3 Number and percentage of oil spills from tankers inside and outside the EU by spill size, 2010-2019

Location	Oil spill size		
	Large (> 700 tonnes)	Medium (7-700 tonnes)	Total
EU	3	5	8
Outside EU	15	39	54
Total	18	44	62
Percentage in the EU	17 %	11 %	13 %

Source: ITOPF (2019).

Aside from medium and large size oil spills, small oil spills (< 7 tonnes) represent the largest occurrence of oil spills in the marine environment. However, obtaining reliable statistics for this category of oil spills is difficult.

Marine chemical spills, hazardous and noxious substances (HNS) spills, are less frequent than oil spills; however, they can have devastating effects on public health and safety and on the environment. The Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances (OPRC-HNS Protocol, 2000) defines HNS as 'any substance other than oil which, if introduced into the marine environment, is likely to create hazards to human health, to harm living resources and marine life, to damage amenities or to interfere with other legitimate uses of the Sea'. This covers a wide group of substances with a different hazards and different behaviours once spilled in the marine environment.

The environmental impact of marine chemical spills will depend on the characteristics of the substances spilled, namely their hazardousness to the aquatic environment regarding acute and chronic toxicity effects. It will also depend on the dispersion of the material once released into the wider environment (e.g. if it floats, dissolves, sinks or evaporates). This fate is determined by the physical properties of volatility, density and solubility of the released substance.

Each incident is unique and several factors will influence the impact of the HNS spill, such as the dispersion and the hazardous nature of the substance or substances involved, the quantity of the substances involved, existing containment systems and the safety standards of the vessel (EMSA, 2007).

Detecting oil spills through satellite monitoring

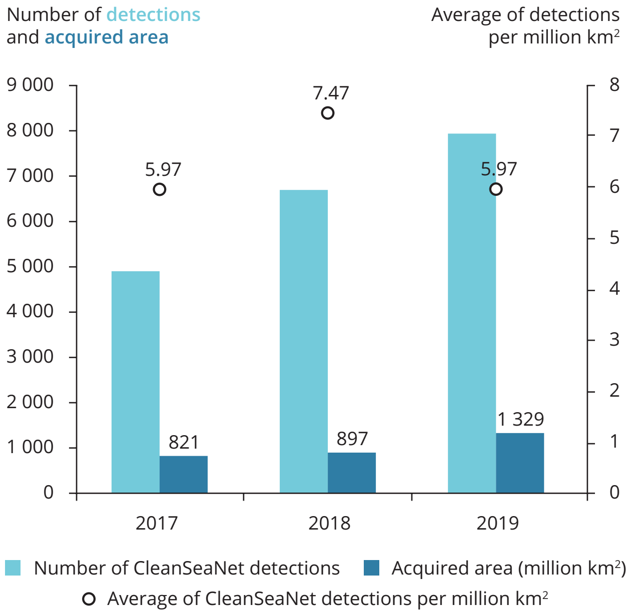
Satellite monitoring caters for the rapid detection of small oil spills through routine monitoring of the sea. Moreover, in the case of large oil spills, satellite acquisitions can track the spread of oil and support cleaning operations.

Figure 4.13 shows the total number of CleanSeaNet (EMSA's European satellite-based monitoring system for marine oil spill detection) and possible spills detected from 2017 to 2019. Because of the increase in the area monitored by CleanSeaNet, the number of potential spills detected has been steadily rising in absolute values. However, despite the increase in the area monitored, in 2019 the average number of detections per million km^2 decreased again to 2017 values.

In 2019, from a total of 7 731 satellite images analysed, 7 939 possible spills were identified. Of these, approximately 30 % were later verified in situ by the relevant authorities. The outcome of these verifications often resulted in the confirmation of the presence of oil in the water but also in the identification of other natural phenomena, such as algae blooms, areas with low wind speeds or sandbanks (often referred to as false positives). The results of in situ verifications are clearly dependent on the interval between the time of the satellite image acquisition and the verification itself. The longer this interval, the higher the percentage of 'nothing observed' occurrences. In this sense, it should be highlighted that only 5 % of the verifications in 2019 were performed within 3 hours of the satellite observation. This resulted in a 42 % effective detection rate by the CleanSeaNet satellite service, calculated as all mineral or other substances (such as vegetable or fish oil; Map 4.4) confirmed cases, divided by the total number of oil spills that have been verified (Figure 4.14). Although most of these spills are in EU waters (where there is a higher density of satellite image acquisition), the results address detections worldwide, including Greenland, Montenegro and Turkey and neighbouring countries currently engaged through EMSA projects, such as Azerbaijan, Morocco and Tunisia. In addition, spills detected during emergency support in any sea area around the world are also included.

Although the source of the spills sometimes cannot be identified, in the majority of cases when it is identified, it corresponds to vessels (Figure 4.15).

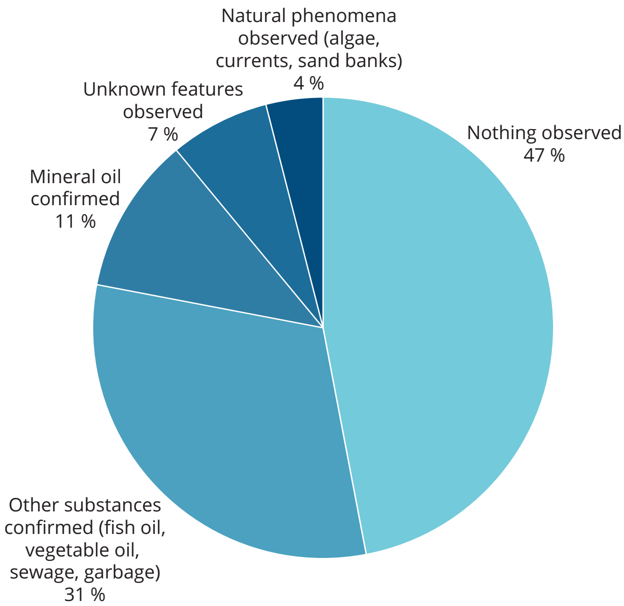
Figure 4.13 CleanSeaNet possible spills detected



Note: Data show absolute number of detections and number of detections normalised to the area (detections per million km²).

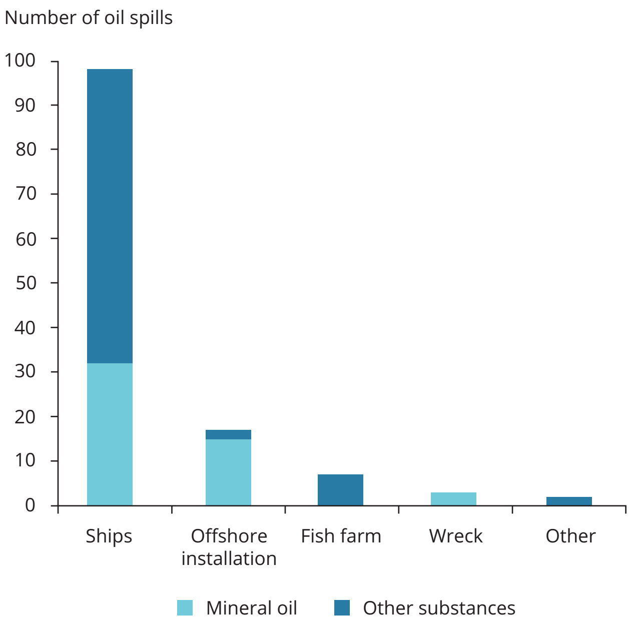
Source: Compiled from EMSA Services data.

Figure 4.14 Verification results for 2019 oil spill detections undertaken within 3 hours of satellite image acquisition



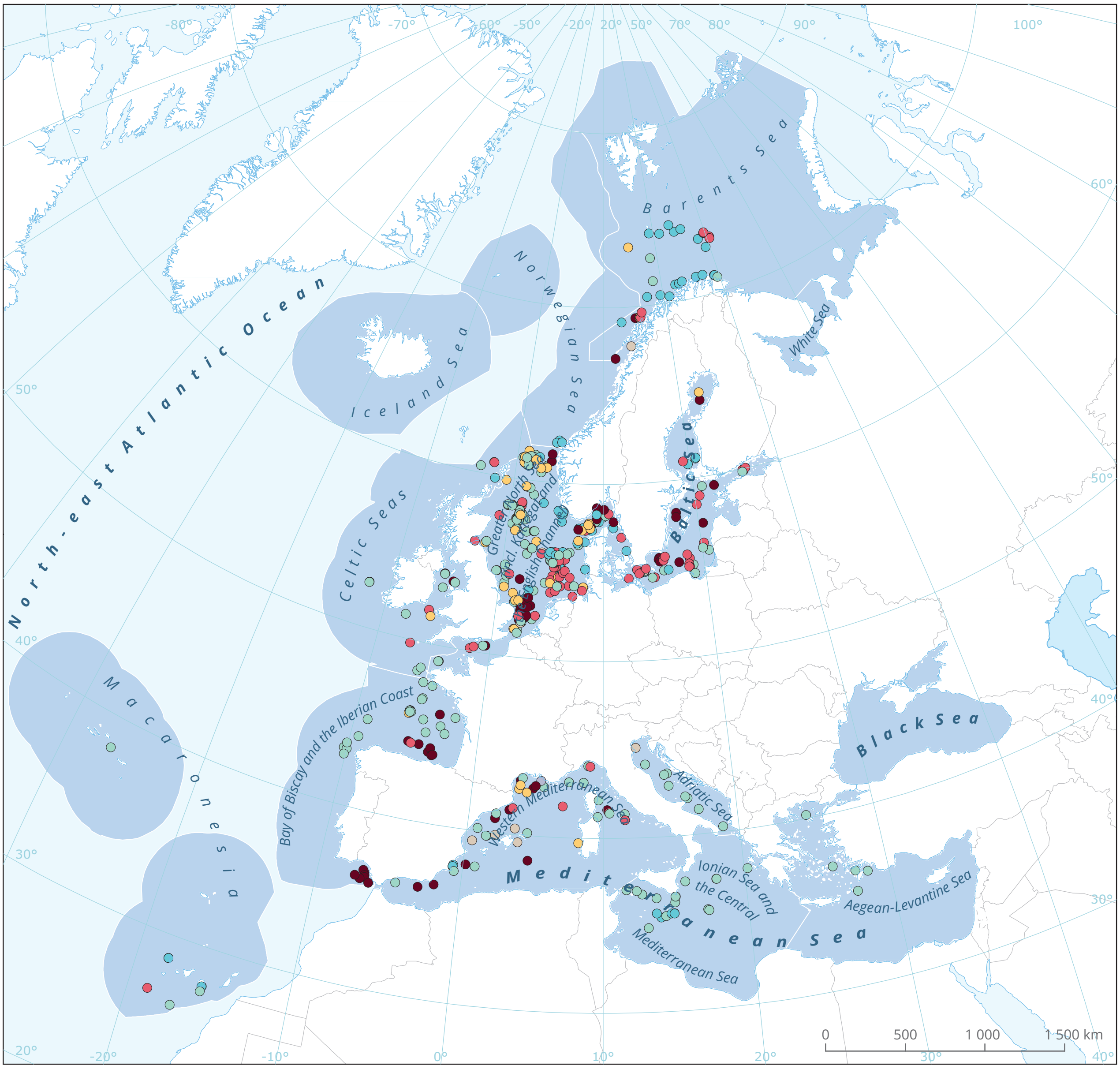
Source: Compiled from EMSA Services data.

Figure 4.15 Distribution of possible sources of oil spills verified as mineral oil or other substances, as reported by CleanSeaNet, 2019



Source: Compiled from EMSA Services data.

Map 4.4 **Oil spills detected in 2019 confirmed by CleanSeaNet users as mineral oil and/or other substances**



Reference data: ©ESRI

Oil spills detected in 2019 and confirmed as mineral oil or as other substance

Type of in/situ observation

Mineral oil · Fish oil · Garbage · Sewage · Vegetable oil · N/A · Unknown substance · Marine regions

Source: Compiled from EMSA Services data.

Water discharges

Water pollution from ship operations is generated by various subsystems on board ships, which produce discharges that may contain several pollutants (e.g. discharge of black and grey waters, bilge water and tank cleaning water or discharges from the operation of exhaust gas cleaning systems (EGCSs); Figure 4.16).

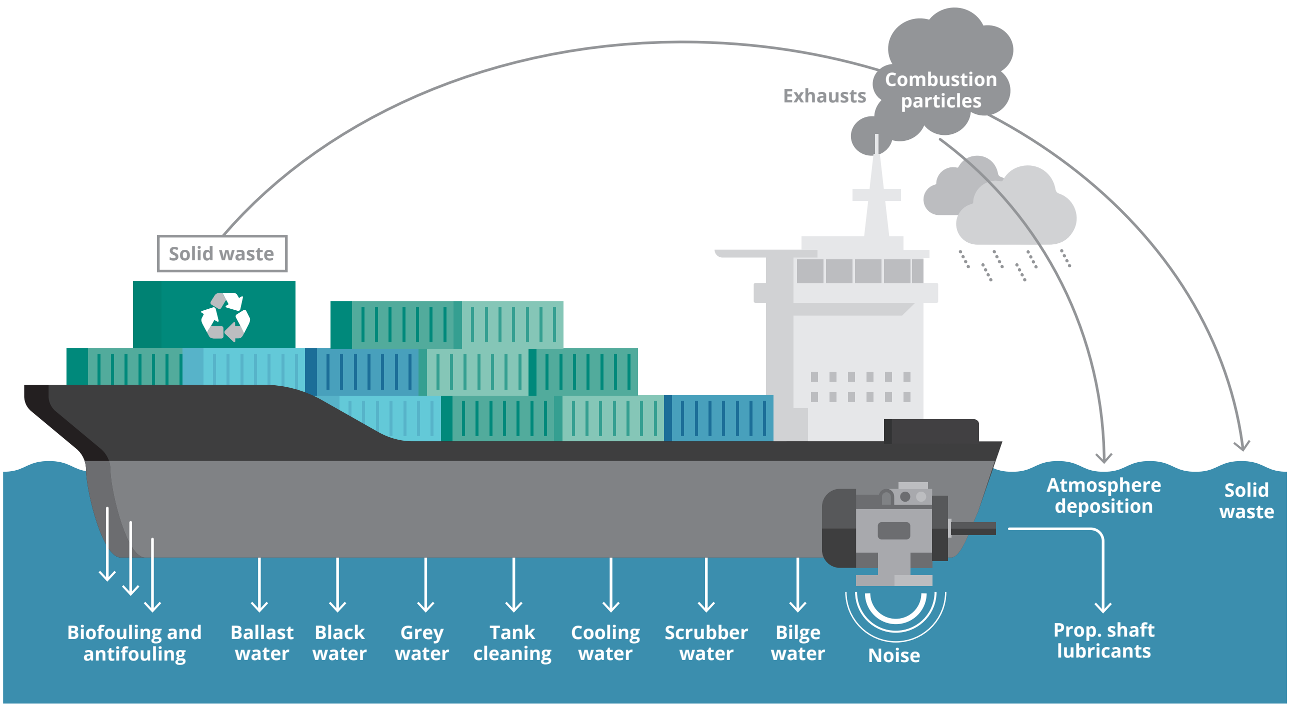
An analysis of data on ship movements in European waters reveals that, excluding ballast water, in terms of volume the largest water discharges from ships come from open-loop EGCSs (77 %) (Figure 4.17). This is followed by grey waters (16 %) and to a lesser extent by sewage, bilge waters and other discharges.

The discharge of waters from open-loop EGCSs installed on ships increased significantly after 2015 as a result of the new standards on the use of low-sulphur fuels (0.10 % m/m) in SECAs (Figure 4.18). In general, for Ro-pax ships and vehicle carriers, the increase was quite substantial. More increases may again be expected from 1 January 2020, after the introduction of further reductions in the sulphur limits in fuels used in non-SECAs (0.50 % m/m). When using open-loop EGCSs, the wash water used in the cleaning of the exhaust gases from the ship's engines is discharged into the sea. This discharge water can contain heavy metals and aromatic hydrocarbons and could therefore be potentially harmful to marine organisms. This can be especially concerning in high traffic density areas, as well as in ports (usually located close to environmentally sensitive areas, such as estuaries and bays) and in areas already exposed to high concentrations of hazardous substances. At IMO, work is progressing on the evaluation and harmonisation of rules and guidance on the discharges of residues from EGCSs into the aquatic environment, including conditions and areas (IMO, 2019b).

Nitrogen discharges, which are mainly from sewage, can also have a significant impact in eutrophic environments (e.g. the Baltic Sea), as they can contribute to nutrient over-enrichment, worsening the eutrophication level. Eutrophication can lead to increased plant growth, changes in the balance of organisms and water quality degradation. This can produce shifts in species composition and species displacement. Oxygen consumption in bottom waters, especially those with low flushing rates, increases and can result in a reduction in oxygen levels in water (hypoxia). Hypoxia results in a deterioration in the affected ecosystems and the loss of marine life. On top of this, toxins released from harmful algal blooms due to eutrophication can have socio-economic impacts affecting fish stocks and causing shellfish poisoning in humans.

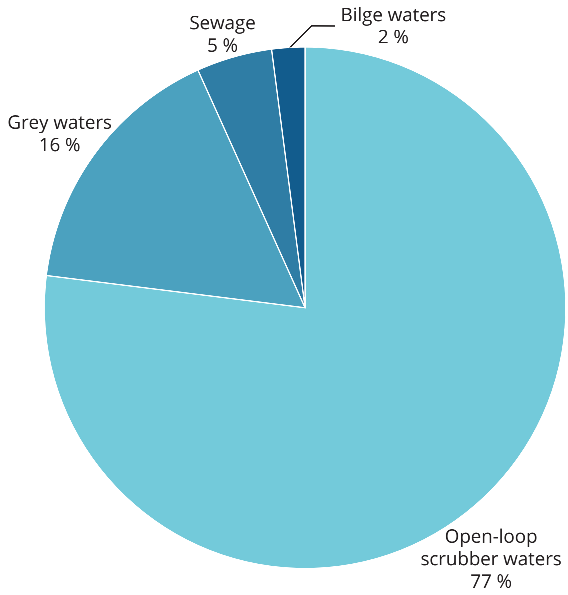
Projections show that Ro-pax ships are generating the greatest discharges of nitrogen from sewage (Figure 4.19) and this has been increasing in recent years, especially in the summer period (Figure 4.20), which is consistent with the increase in seaborne passengers.

Figure 4.16 Subsystems on board ships that produce water pollution



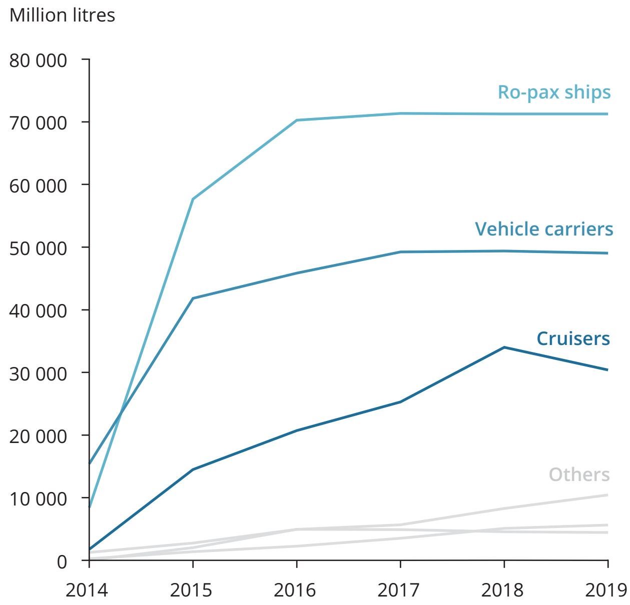
Source: SHEBA project (2018).

Figure 4.17 **Share of estimated water discharges from ships, 2019**



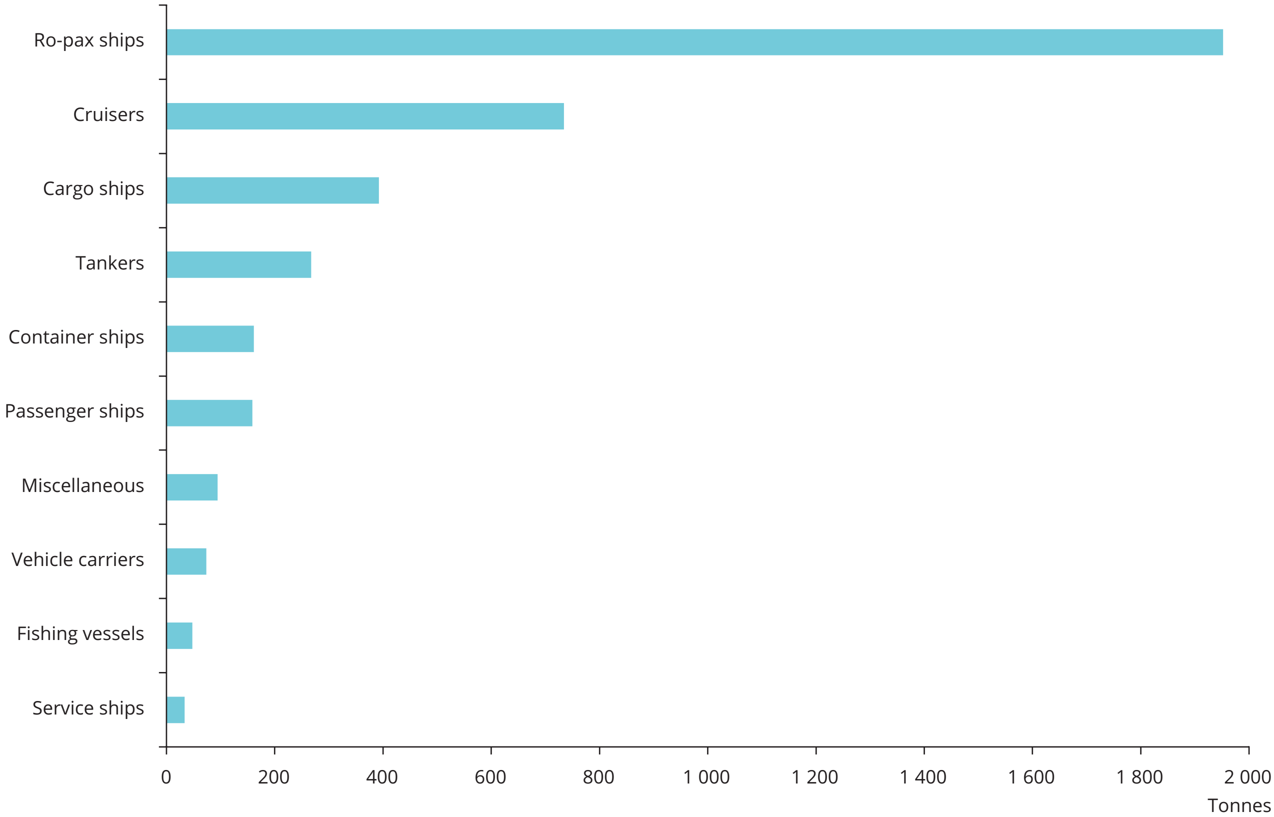
Source: STEAM (2021).

Figure 4.18 **Open-loop scrubber (EGCS) estimated water discharges**



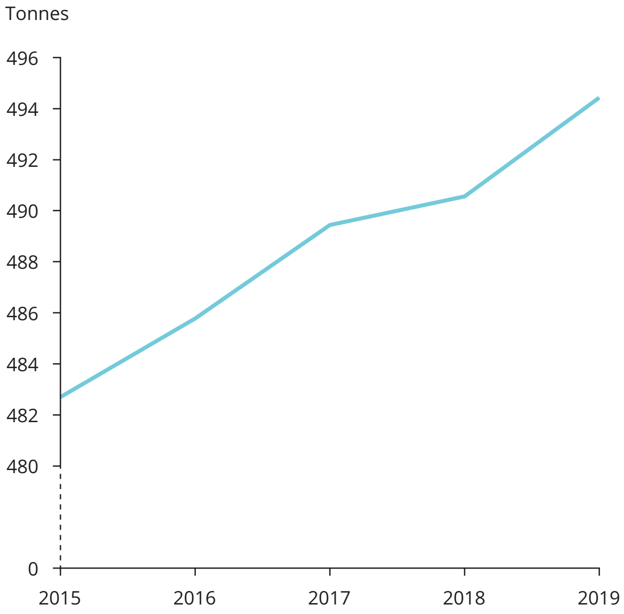
Source: STEAM (2021).

Figure 4.19 **Estimated nitrogen discharges in sewage by ship type, 2019**



Source: STEAM (2021).

Figure 4.20 **Estimated nitrogen discharges in sewage from Ro-pax ships, summer period 2015-2019**



Source: STEAM (2021).

Anti-fouling

Leaching from the anti-fouling paints used to prevent biofouling on ships' hulls represents another source of water pollution. The anti-fouling paints may contain biocides that are harmful to the marine environment. The pollution impact of the anti-fouling paints during the operation of a ship depends on the leaching rate of the biocide from the ship's hull to water and the area of the hull in contact with the water. The leaching rate depends on several factors: water characteristics, the biocide itself, the characteristics and age of the paint, and the speed of the ship. The area of the ship's hull in contact with water also depends on many factors: shipping trade patterns, size and volume of the hulls, idle time, cargo load, and weather and sailing conditions (van der Aa and van der Plassche, 2004).

One of the most effective anti-fouling paints, developed in the 1960s, contained tributyltin (TBT). However, it soon became clear that the use of TBT coatings had negative consequences for the wider marine habitat, including an adverse impact on numerous non-target organisms. It has been further proven to cause deformation in oysters and sex changes in whelks. It also has implications in terms of bioaccumulation in the human food chain. Moreover, TBT deposited in sediments and dredged material from affected areas (e.g. near ports, dockyards and marinas) became a serious concern. On account of such harmful effects, many countries eventually prohibited or restricted the use of TBT.

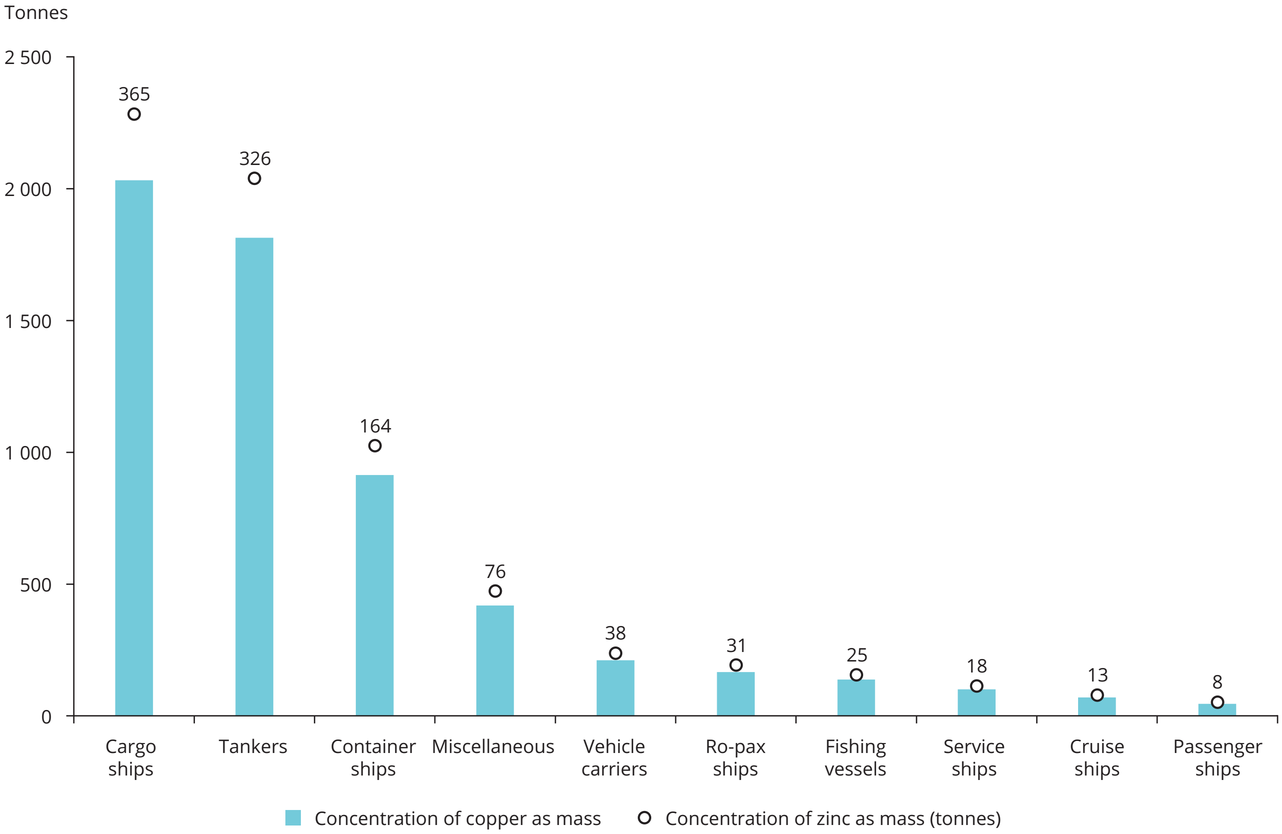
Monitoring data gathered by Helsinki Commission (HELCOM) countries (HELCOM, 2018a) show a decreasing trend in TBT levels in areas of heavy shipping traffic. An OSPAR Commission assessment of marine gastropods (OSPAR Commission, 2017) showed a marked improvement in the reproductive condition of marine snails. Nevertheless, historical contamination of sediments with TBT can lead to the long-term release of TBT into the water column.

Following the entry into force of the International Convention on the Control of Harmful Anti-Fouling Systems (AFS Convention) in 2008 and its transposition into EU rules banning the use of organotin compounds, copper-based compounds containing organic booster biocides started to be used. Copper exhibits anti-fouling properties against organisms such as barnacles and tube worms and against hard fouling. However, some species show some tolerance to copper, and therefore booster biocides are used in conjunction with copper (principal biocide) to develop a broad spectrum of anti-fouling paints (Part, 2008). Cybutryne is a booster biocide used as an additive in anti-fouling paints for protection against 'soft fouling' (e.g. due to algae). It inhibits the photosynthesis of marine algae, preventing fouling to the ship's hull. However scientific research shows that cybutryne has the potential to have adverse effects on non-target organisms, e.g. corals and other non-target organisms on which other species feed. It also persists in the environment (sea- and freshwater sediments) once released from painted surfaces (Sobey et al., 2011). In 2017, this adverse effect on the environment prompted an initial proposal by the EU Member States and the European Commission to include cybutryne in the AFS Convention and ban its use in ships' anti-fouling systems internationally.

Predictions of cybutryne concentrations have shown that these are expected to be higher in marinas and harbours than in the wider marine environment because of the high density of ships per unit area. In the case of shipping lanes and open seas, the concentration of cybutryne in water is low because of the dilution effect. Nevertheless, as cybutryne accumulates in the environment, higher concentrations in sediment would be expected in the long term because of the substance's continuous use. After the prohibition of the organotin compounds, copper oxide and zinc oxide have become frequently used biocides in anti-fouling paints. Looking at the calculated emissions of copper oxide and zinc oxide from anti-fouling systems (see Figure 4.21), the results show that cargo ships and tankers are among the ship types that emit higher quantities of pollutants to water. These substances can be highly toxic to marine organisms at elevated concentrations.

Cargo ships, container ships and tankers typically have a larger wet surface area, which could explain the high levels of emissions from these ship types. Nevertheless, as mentioned

Figure 4.21 Estimated releases of the main copper and zinc compounds from anti-fouling paints, 2019



Source: STEAM (2021).

above, other factors may contribute to the transfer of biocides from the paint on the ship's hull to the water.

The replacement of TBT by copper compounds has led to an increase in copper emissions in sediments in the Baltic Sea area (HELCOM, 2010). Although copper is less problematic in terms of its impact on the environment, as its complexation by dissolved and suspended organic materials may significantly reduce its bioavailability (Voulvoulis, 1990), it is an anthropogenic source of pollution, and the use of copper in anti-fouling paints is today the main source of diffuse copper input to the marine environment (HELCOM, 2018b).

Both chemical and non-chemical alternatives to the copper- and zinc-based products exist. Alternative technologies include hard coatings, ultrasonic systems, self-cleaning and repellent surfaces, and surfaces with spines that prevent organisms from attaching themselves to the ship. However, more independent information on the costs and effectiveness of the alternatives is needed (ECHA, 2019).

4.1.3 Marine litter

Marine litter refers to persistent, manufactured or processed solid materials that are discarded or abandoned in marine and coastal environments. Because of the transboundary nature of the problem, marine litter can be found in practically all of the world's oceans, seas, bays and estuaries and on shorelines even in remote areas far from contact with humans.

While the majority of marine litter originates from land-based sources, important contributions come from fishing and aquaculture activities, shipping (commercial and recreational), dredging operations, offshore mining and extraction, ships' sewage sludge and illegal dumping at sea of waste streams containing, for example, plastics and microplastics (Wang et al., 2016).

Despite some initiatives to monitor marine litter, there are large gaps in our knowledge on the amount of litter entering the ocean by source, its accumulation in the marine environment and reliable mapping of the sources, pathways, distribution and sink locations. More knowledge is needed to understand

(and thereafter try to mitigate) the impact of the maritime community on marine litter, evaluating the role of commercial and recreational shipping, fishery activities, lost cargoes and inappropriate or illegal discharges. To date, there is no traceable scientific literature evaluating how much marine litter comes from sea-based sources compared with those on land. One notable exception is an analysis of beach litter data from 2015 and 2016, indicating a higher proportion of sea-based litter on the Atlantic and North Sea coasts than on the Mediterranean Sea coasts (Hanke et al., 2019).

Macro-litter and micro-litter tend to accumulate on beaches and the sea floor (Figure 4.22). At a global scale, plastic concentrations by volume in beach, subtidal, deep sea and estuary sediments have been reported as being four to five orders of magnitude higher than they are in the water column (Worm et al., 2017).

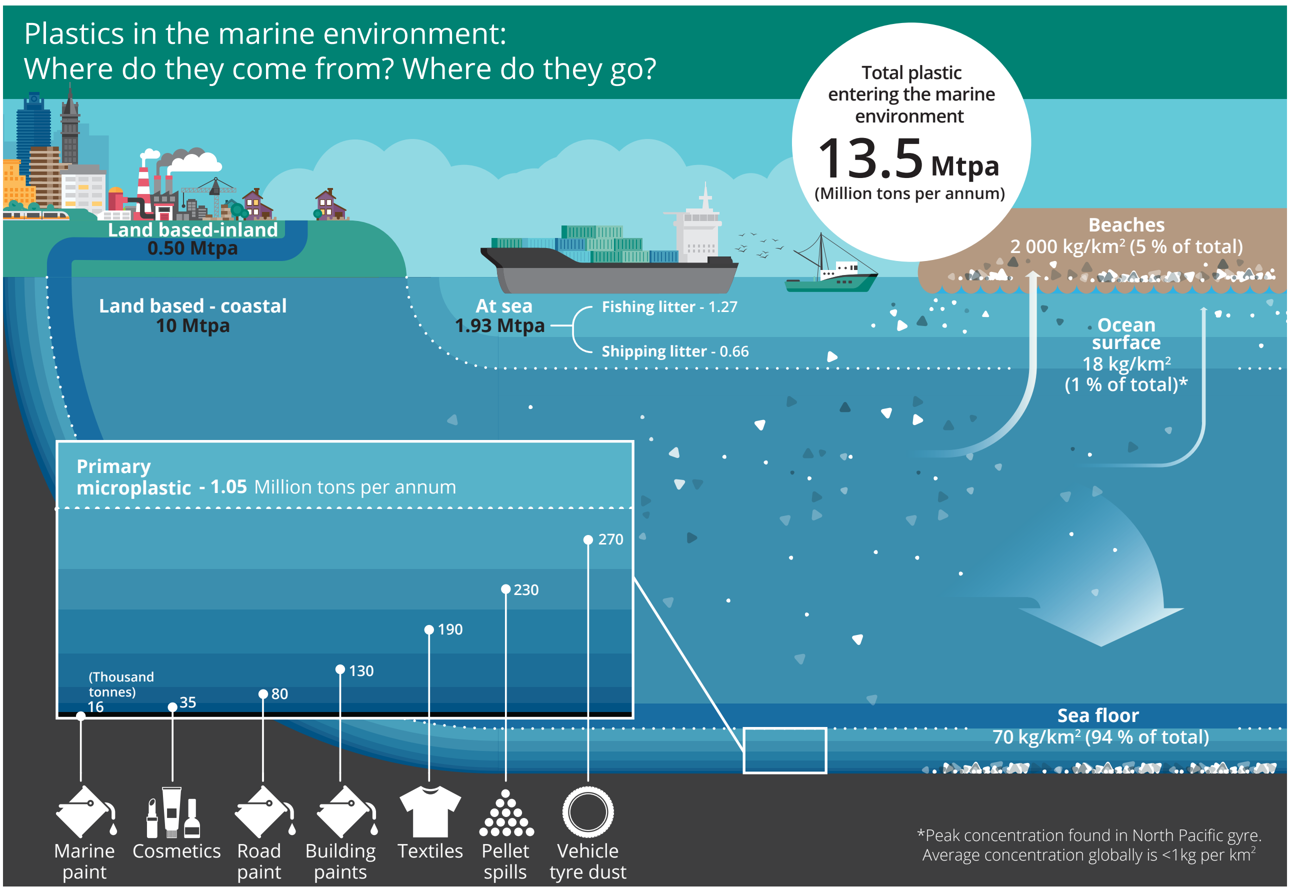
Floating litter can also interfere with navigational safety, as well as causing economic losses to fishing and maritime industries and degrading the quality of life in coastal communities. In this report, marine litter related to fisheries and fishing activities, and to offshore and other marine and maritime industrial platforms, is not considered.

Marine litter and the United Nations Sustainable Development Goals

Marine litter originates from a wide and diverse range of sources. It is generally agreed that the majority of litter entering the oceans originates from land-based sources, including sewage treatment, combined sewer overflows, storm-water run-off, and inappropriate and illegal dumping of recreational, domestic and industrial waste. When considering plastic waste alone, studies have estimated that in 2010 approximately 275 million tonnes of waste was discharged in the ocean from 192 coastal states (Jambeck et al., 2015). The United Nations 2030 Agenda for Sustainable Development includes a specific target (14.1) to significantly reduce the amount of marine debris in our ecosystem.

Sea-based activities also contribute to marine litter (Walker et al., 2019). Their estimated contribution is based on three separate studies (National Academy of Sciences, 1975; Macfadyen et al., 2009; Richardson, 2019), which, in the absence of real observational data, result in the commonly cited assertion that 80 % of the litter in the world's oceans comes from land, and subsequently 20 % comes from the sea (see also Gilardi, et al., 2020).

Figure 4.22 Pathways by which plastic is introduced into the marine environment



Note: Mtpa, million tonnes per annum.

Source: Sherrington (2016).

Ship-generated waste

There are different types of waste that can be generated on board a ship, including cargo residues, garbage (e.g. food waste, plastic, domestic waste), oily waste, sewage or ozone depleting substances.

For many of the of ship-generated waste types, there is a variety of waste flows and possible onboard treatment methods that can contribute to sustainable and sound management. The empirical evidence gathered through studies shows that ships use different treatment methods and often only treat part of a waste stream (CE Delft, 2017). Part of the waste may be legally discharged into the sea, outside special protected areas, and under certain conditions, such as at a minimum distance from the coast (Table 4.5). Waste that cannot be reused on board or legally discharged at sea under international MARPOL standards must be delivered to port reception facilities (PRFs), available in ports. These play an important role in the whole process of waste management by collecting and treating it, and often adding value to it.

Plastics and litter

Plastics are included under the litter category. Their relevance is evident, as it is estimated that more than 150 million tonnes of plastics have accumulated in the world's oceans, while 4.6-12.7 million tonnes are added every year. Although there are regional fluctuations in the distribution between the land- and sea-based origin of marine litter (i.e. in the North-East Atlantic, shipping and fishing are very important litter sources), estimates attribute one fifth of the source to be linked to maritime transport, industrial exploration and offshore oil platforms, fishing and aquaculture (UNEP, 2009).

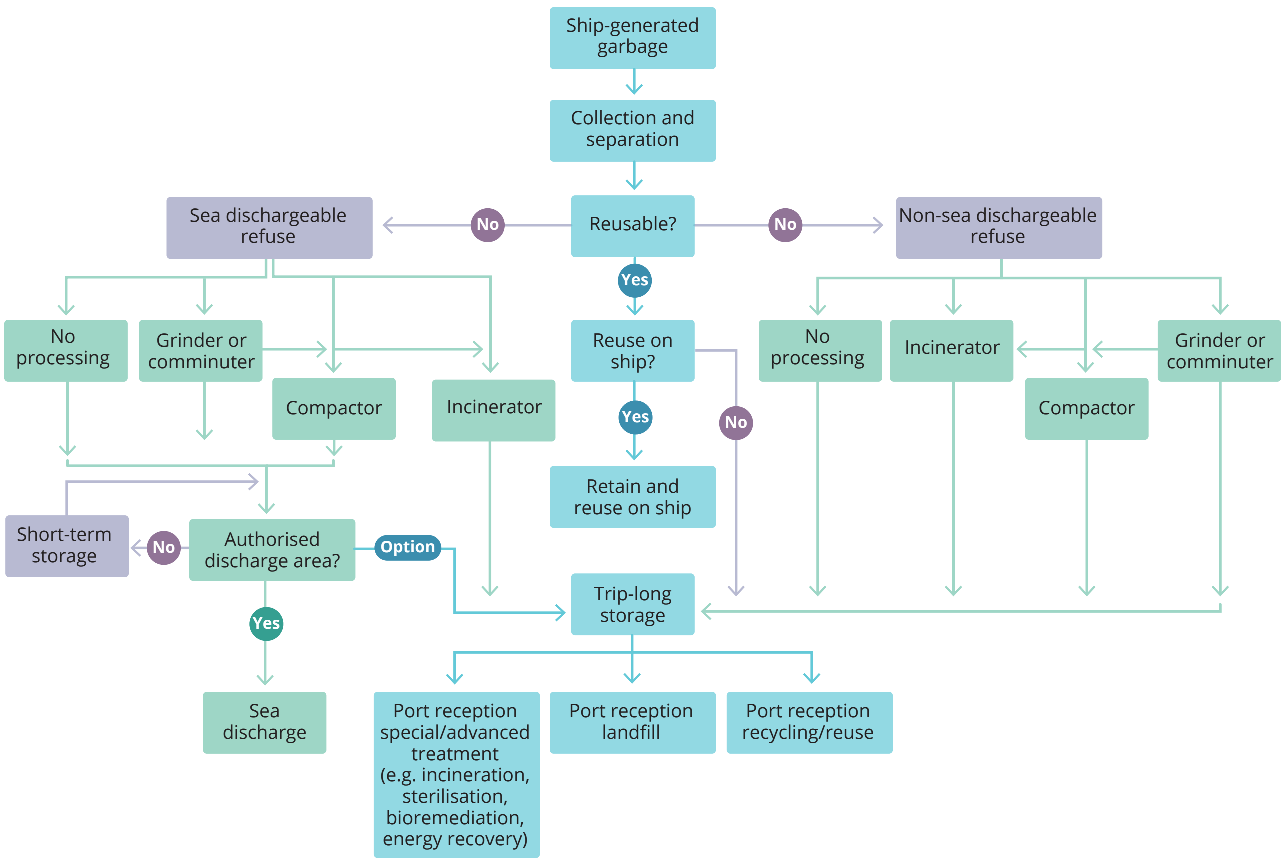
The amount of waste generated by ships can be reduced depending on the type of fuel used, onboard treatment practices and the availability of equipment such as incinerators, grinders and oil-water separators. However, not all types of waste can be properly or completely treated on board, and not all methods are suitable for all waste types. As an example, compacting paper can be done on board; however, compacting all types of plastics will make them impossible to treat further on shore, or necessitate sorting them out again, increasing the overall cost of the process. Any practice should therefore always keep in view the complete workflow, up to the point of delivery to an appropriate PRF, when necessary, and the final disposal. This will contribute to the circular economy targets of the European Green Deal, by promoting recycling and reuse or recovery of materials.

PRFs are particularly relevant when it comes to complex waste treatment chains that require high levels of investment, best dealt with by structures that can process large amounts, rather than by onboard solutions for smaller amounts that would also require space, decreasing loading capacity. Operational practices such as segregation can pave the way to efficient collection and treatment by a PRF. Training of crews also plays an important role in achieving these objectives.

Differences in onboard waste treatment practices explain the difference between the amounts of ship-generated wastes and the amounts that are eventually landed at PRFs (Figure 4.23).

Minimising the quantities of plastics brought on board in the first place makes an important contribution to the overall goal of improving the marine environment. This can be achieved by working with the suppliers of ships' stores and equipment and immediately returning packaging and dunnage to suppliers at the point of delivery to the ship.

Figure 4.23 Overview of options for onboard handling and discharge of garbage



Source: IMO (2017).

Data on the amounts of waste generated on board ships are not readily available and are kept in a number of (mostly paper) documents on board, such as 'oil record books', 'garbage record books' and 'waste receipts'. The recently amended EU legislation on PRFs aims to enforce waste delivery to ports and its subsequent appropriate recycling or disposal on land, and to provide for an increase in the exchange of information in electronic form on the amounts of waste produced by and disposed of from shipping (EU, 2019a). This will provide a clearer picture of ship-generated waste in the future. One important additional element of the new directive is the envisaged reduction in PRF fees on the basis of criteria that demonstrate that the ship produces less waste and manages its waste in a sustainable and environmentally sound manner. Recommendations for such criteria are being prepared by the European Sustainable Shipping Forum Waste from Ships sub-group.

The related impact assessment carried out to support the proposal for the new PRF Directive provided an estimate of how much ship-generated waste is potentially discharged at sea. A model (EC, 2017a) was used to compare the expected volumes of oily waste and sewage delivered at 29 ports (representing approximately 35 % of the throughput of all EU merchant ports) with waste delivery data obtained from the same ports. This was complemented with estimates derived from existing reports and the literature (Sherrington et al., 2016) to quantify the delivery waste gap for garbage from all types of ships, including fishing vessels and recreational craft. Table 4.4 shows the resulting 'waste gap' for ship-generated oily waste and sewage with the caveat that the estimated figures do not cover plastic waste (EC, 2018).

Figures available in the literature on the average amounts of waste expected from a ship are outdated and do not consider new onboard practices for the management of waste. Therefore, in 2017 EMSA commissioned the report *The management of ship-generated waste on-board ships*. This document aimed to estimate and update the expected waste arising from different types of ships and identify the waste pathways for the different types of waste on board these ships. The report does this successfully and provides more realistic figures. However, significant further research is needed, as the number of ships included in this study was small (CE Delft, 2017).

Table 4.4 Amount of waste generated by and delivered from ships annually and the resulting 'waste gap'

Parameter	Oily waste (MARPOL Annex I)	Sewage (MARPOL Annex IV)	Garbage (MARPOL Annex V)
Waste to be delivered (after treatment and legal discharge)	1 226 000 m^3	1 362 000 m^3	434 000 tonnes
Waste actually delivered	1 195 000 m^3	1 226 000 m^3	286 000-404 000 tonnes
Waste gap	**31 000 m^3 (2.5 %)**	**136 000 m^3 (10 %)**	**30 000-148 000 tonnes (7-34 %)**

Source: EC (2018).

Table 4.5 Simplified overview of garbage discharge provisions MARPOL Annex V ([a])

<table>
<tr><th rowspan="2">Garbage type</th><th colspan="2">All ships except platforms</th><th rowspan="2">Regulation 5
Offshore platforms located more than 12 nm from nearest land and ships when alongside or within 500 metres of such platforms</th></tr>
<tr><th>Regulation 4
Outside special areas and Artic waters
(Distances are from the nearest land)</th><th>Regulation 6
Within special areas and Artic waters
(Distances are from nearest land, nearest ice-shelf or nearest fast ice)</th></tr>
<tr><td>Food waste comminuted or ground</td><td>≥ 3 nm, en route and as far as praticable</td><td>≥ 12nm, en route as far as practicable</td><td>Discharge permitted</td></tr>
<tr><td>Food waste not comminuted or ground</td><td>≥ 12nm, en route and as far as practicable</td><td rowspan="2">Discharge prohibited</td><td rowspan="7">Discharge prohibited</td></tr>
<tr><td>Cargo residues not contained in washwater</td><td>≥ 12nm, en route and as far as practicable</td></tr>
<tr><td>Cargo residues contained in washwater</td><td></td><td rowspan="2">≥ 12 nm, en route and as far as practicable (subject to conditions in regulation 6.1.2 and paragraph 5.2.1.5 of part II-A of the Polar Code)</td></tr>
<tr><td>Cleaning agents and additives contained in cargo hold washwater</td><td rowspan="2">Discharge permitted</td></tr>
<tr><td>Cleaning agents and additives in deck and external surfaces washwater</td><td>Discharge permitted</td></tr>
<tr><td>Animal carcasses (should be slipt or otherwise treated to ensure the carcasses will sink immediatly)</td><td>Must be en route and as far from the nearest land as possible. Should be > 100 nm and maximum water depth</td><td rowspan="2">Discharge prohibited</td></tr>
<tr><td>All other garbage including plastics, synthetic ropes, fishing gear, plastic garbage, bags, incinerator ashes, clinkers, cooking oil, floating dunnage, lining and packing materials, paper, rags, glass, metal, bottles, crockery and similar refuse</td><td>Discharge prohibited</td></tr>
</table>

Note: ([a]) When garbage is mixed with or contaminated by other harmful substances prohibited from discharge or having different discharge requirements, the more stringent requirements apply. Comminuted or ground food wastes must be able to pass through a screen with mesh no larger than 25 mm.

nm, nautical mile.

Source: IMO (2018c).

To provide a realistic estimate of the amounts of waste collected in EU ports Table 4.6 presents data gathered by the members of Euroshore ([2]) in 2019 related to the quantities of waste collected in EU ports, by MARPOL annex classification. It is important to note that these values reflect only the activities of Euroshore members, and that the amounts reported refer only to waste delivered by ships to EU ports.

The total amount of waste (all MARPOL annexes) collected in 2019 by Euroshore members in European ports is equivalent to 1 905 544 tonnes.

Table 4.7 presents a summary of the results of the CE Delft (2017) report on the management of ship-generated waste on board ships.

([2]) Euroshore is an association of 36 members from 17 countries from Europe and Africa and the United Arab Emirates.

Table 4.6 Types of waste collected in EU ports and percentage of total, as reported by Euroshore members, 2019

Waste	Oil (Annex I)	Noxious liquid in bulk (Annex II)	Substances in packages (Annex III)	Sewage (Annex IV)	Garbage (Annex V)	Air pollution (Annex VI)
Amount (tonnes)	1 470 322	62 245	570	88 563	279 748	4 096
Percentage of total	77	3.20	0.30	4.60	14.70	0.20

Source: Euroshore (2021).

Table 4.7 Overview of the amounts of ship-generated waste, drivers and treatment methods

Type of waste	Generation rate	Driver	On-board treatment
Oily bilge water	0.01-13 m^3 per day; larger ships generate larger quantities	Condensation and leakages in the engine room; size of the ship	The amount can be reduced by 65-85 % by using an oil-water separator and discharging the water fraction into the sea
Oily residues (sludge)	0.01-0.03 m^3 of sludge per tonne of heavy fuel oil 0 and 0.01 m^3 per tonne of marine gas oil	Type of fuel; fuel consumption	Evaporation can reduce the amount of sludge by up to 75 %. Incineration can reduce the amount of sludge by 99 % or more
Tank washings (slops)	20 m^3 to hundreds of cubic metres	Number of tank cleanings; size of loading capacity	After settling, the water fraction may be discharged at sea.
Sewage	0.01-0.06 m^3 per person per day. Sewage is sometimes mixed with other waste water. The total amount ranges from 0.04 to 0.45 m^3 per day per person	Number of people on board; type of toilets; length of voyage	Effluent from treatment plants is often discharged at sea where permitted
Plastics	0.001-0.008 m^3 of plastics per person per day	Number of people on board	Often not incinerated. Dirty plastics (plastics that have been in contact with food) are often treated as a separate waste stream
Food wastes	0.001-0.003 m^3 per person per day	Number of people on board; provisions	Where permitted, food waste is often discharged at sea
Domestic wastes	0.001-0.02 m^3 per day per person	Number of people on board; type of products used	
Cooking oil	0.01-0.08 litres per person per day	Number of people on board; type of food prepared	Although not permitted, cooking oil is sometimes still added to the sludge tank
Incinerator ashes	0.004-0.06 m^3 per month	Use of incinerator; cost of using incinerator	The incinerator is not used for all types of waste, but mostly for paper and sometimes for sludge
Operational wastes	0.001-0.1 m^3 per person per day	Size of the ship; type of cargo	
Cargo residues	0.001-2 % of cargo load	Type of cargo; size of ship	

Source: CE Delft (2017).

Lost containers

Between 80 % and 90 % of the total goods (including raw materials and manufactured products) transported by sea are moved in containers.

Lost containers are a source of marine litter, as they contain metal, plastic, and toxic and dangerous material of various sizes and variety. Depending on sea conditions, containers may remain intact or release part or all of their contents. The loss of containers at sea may be the result of weather conditions, accidents, infrastructure failings, improper loading or operational losses connected with loading procedures or the dilapidated state of containers. Estimates of the number of lost containers vary enormously, and there are no consolidated official data published.

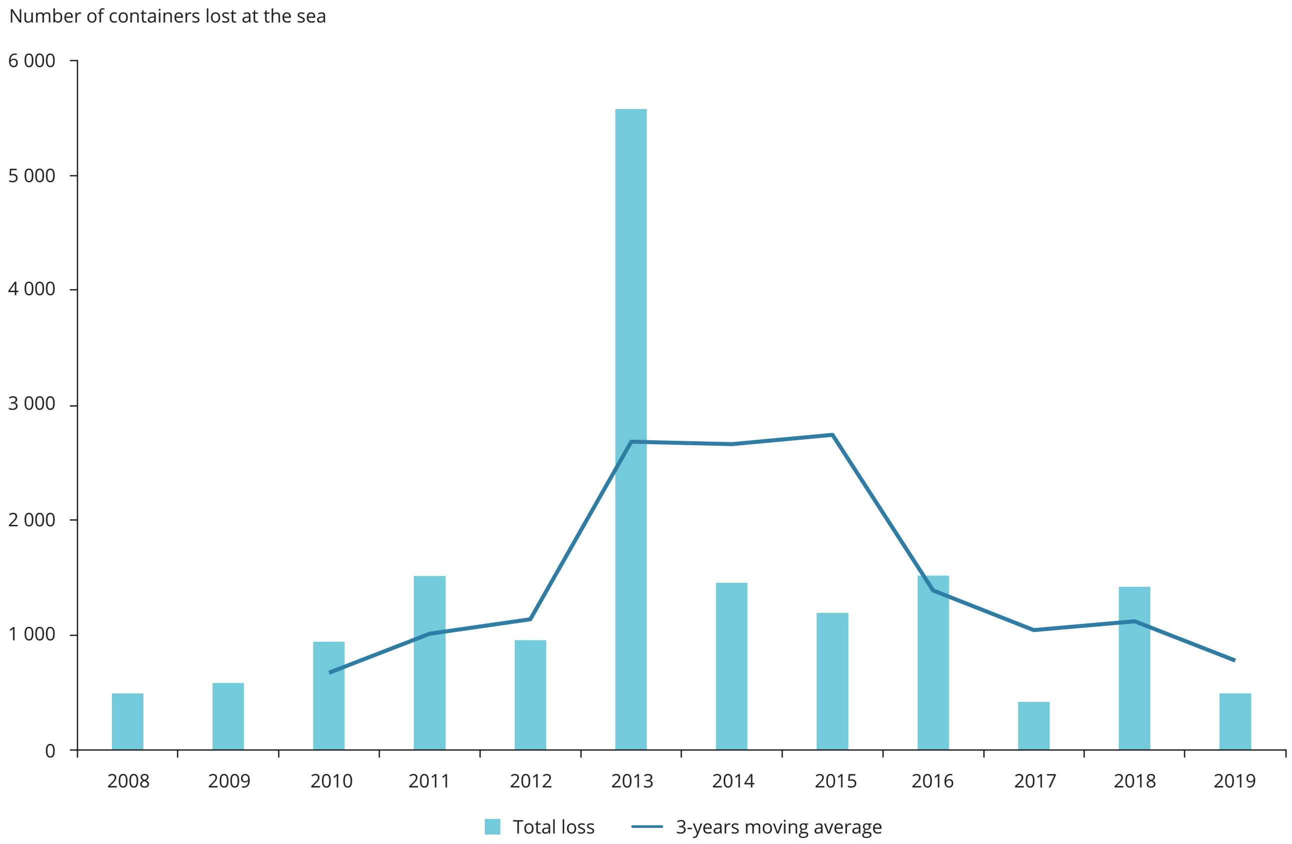
In the period 2008-2019 an average of 1 382 containers were reported lost every year (World Shipping Council, 2020). However, a previous World Shipping Council survey, conducted from 2008 to 2016 and differentiating between catastrophic losses (defined as incidents in which more than 50 containers are lost) and non-catastrophic losses, highlighted that 64 % of containers lost in this period were due to catastrophic events (World Shipping Council, 2017). Indeed, looking at the 3-year average trends in Figure 4.24 the peaks registered in the second (2011-2013) and third (2014-2016) periods are due to a significant container losses following the sinking of two vessels in 2013 and 2015. Despite that, in the last 6 years, the trend in lost containers has been decreasing (World Shipping Council, 2020).

International container traffic

Data from the United Nations Conference on Trade and Development Handbook of statistics 2019 (UNCTAD, 2019) shows that container traffic has risen from 487 million TEUs (20-foot equivalent units) in 2006 to 793 million TEUs in 2018. The yearly rate of increase is, however, falling, from 6 % between 2016 and 2017 (the highest rise in the last 5 years) to 4 % between 2017 and 2018.

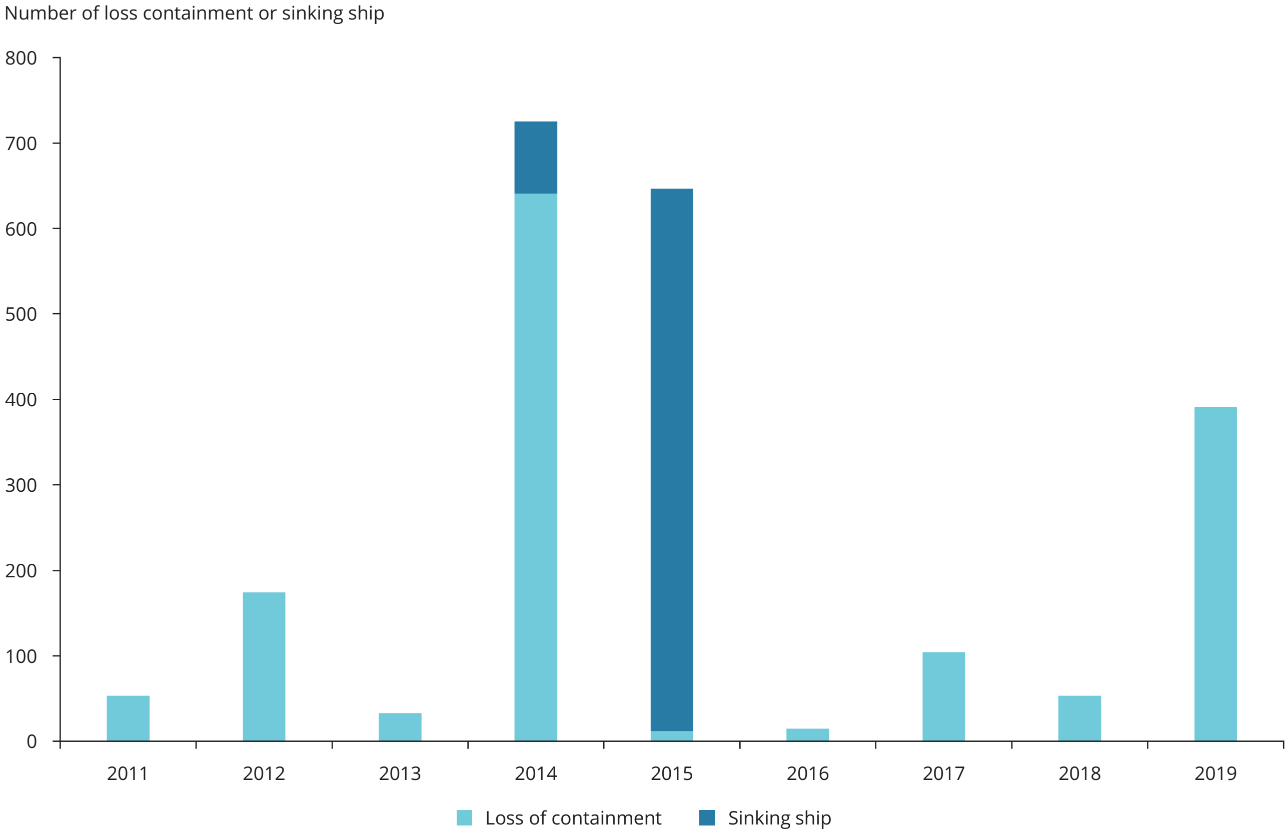
A recent example highlighting the particular challenges and complex operations of locating and recovering lost containers (and their contents) is the MSC Zoe incident, which resulted in the loss of 342 containers overboard in January 2019 in Dutch and German territorial waters (Dutch Safety Board and Bundesstelle für Seeunfalluntersuchung, 2019).

Figure 4.24 Total number of containers lost at sea per year and 3-year moving average



Source: World Shipping Council (2020).

Figure 4.25 Number and type of of containers lost at sea events in the EU



Source: EMCIP (2021).

Other studies commissioned by different entities provide additional data on the pattern of containers lost at sea. A study carried out in 2014 (Surfrider Foundation Europe, 2014) estimated that 13 441 containers were lost at sea between 1994 and 2013 worldwide (672 containers per year). Another survey conducted in 2019 (Surfrider Foundation Europe, 2019) identified and traced the loss of 2 563 more containers, due to incidents at sea during the period 2015-2018, resulting in a total in excess of 16 000 containers at the global level. The report also states that estimates suggest that only 2.6 % of lost containers are recovered each year. A 2020 report highlighted the impact of pollution events related to the loss and spillage of containers carrying plastic pellets (nurdles) at sea (Surfrider Foundation Europe, 2020).

As reported in Figure 4.25, data from the European Marine Casualty Information Platform (EMCIP) show that in the EU, for the period from 2012 until 2019, 57 occurrences were reported, resulting in a total of 2 195 containers lost overboard (i.e. an average of 268 containers per year).

Taking the World Shipping Council figure of an average number of 1 382 containers lost at sea per year, reducing this amount by a factor of 2.6 % (reflecting the share of containers recovered), and assuming an average weight of 26.5 tonnes per container, equates to the release of approximately 35 669 tonnes of litter into the sea every year. Although this analysis does not consider the contents of the lost containers, which may have a very variable impact, depending on whether they are biological resources or toxic and dangerous material, this value is rather small (i.e. less than 1 %) compared with the values estimated by Jambeck et al. (2015) of 4.8-12.7 million tonnes of plastic wastes released in the ocean by 192 coastal countries and even more minor compared with the total volumes of packed and empty containers shipped each year.

Other sources

Pleasure craft

The number of registered recreational craft in the EU is approximately 6 million (ICOMIA, 2019). Litter from pleasure craft is generated by the deliberate or accidental release of waste into the sea. This may contain plastic waste (e.g. bags, food packaging and containers, bottles) and other waste, such as aluminium cans, glass bottles and recreational fishing gear. While it is difficult to tell whether these materials are generated from land or sea (and furthermore from which sea-based activity), studies analysing data from beach monitoring surveys along the German North Sea coast show that 7 % of the overall litter retrieved could be attributed to pleasure craft (Schäfer et al., 2019). It should be noted that ports, marinas, moorings and slipways that facilitate the launching or overnight, temporary or permanent mooring of these vessels should provide PRFs under EU rules (EU, 2019a).

Ship recycling

Ship decomissioning or dismantling can potentially affect workers' health directly by contaminating the air they breathe (i.e. air pollution) and can potentially pollute the environment. The pollutant materials, which result in marine litter, include fibre products (e.g. glass and foam) and polyvinyl chloride (PVC) material (e.g. plastic coatings and floor coverings).

Data from one of the busiest ship dismantling yards in India has shown an average 81 mg of small plastic fragments per kg of sediment, resulting directly from ship-breaking activities at the facility (Reddy et al., 2006).

Out of the total of 41 ship dismantling facilities recognised up to January 2020 under EU rules on ship recycling, 34 are in the EU and Norway, six in Turkey and one in the United States. The volume and concentrations of pollutants from each site in the EU and in Norway are considered to be minimal and are covered by EU standards that control all waste from the site (EU, 2008c). It should be noted that the Waste Framework Directive also covers ship repair and maintenance yards, so the waste from operations at these sites has to be managed and disposed according to the waste management hierarchy: reuse, then recycling, then recovery and last of all disposal.

Ship recycling at international level

Approximately 10-15 million LDT (light displacement tonnage) of ships are recycled worlwide on a yearly basis, of which a very small percentage is recycled in the EU (Deshpande et al., 2012). Most of the ship recycling activity is concentrated in the Indian sub-continent (i.e. Bangladesh, India and Pakistan), China and Turkey. In these countries, various recycling practices can be observed, including tidal beaching, non-tidal beaching and ships alongside the beach or floating off shore.

Petroleum waxes and vegetable oils

As solid material derived from human activities, petroleum waxes (such as paraffin wax and microcrystalline wax) and vegetable oil (such as palm oils) are included in the current definition of marine litter, and are regularly retrieved along European beaches. For example, in the sea, palm oils form white or yellowish congealed lumps with a waxy texture, which float and are regularly washed up on the coastline.

It has been estimated that approximately 3 % of all beach litter retrieved in 2016 in the EU was paraffin waxes (Addamo et al., 2017). Paraffin wax is also included in the Joint list of litter categories endorsed by the Marine Strategy Framework Directive (MSFD) Marine Strategy Coordination Group for the unambiguous identification of macro-litter. While they can be found on beaches and thus are included in beach monitoring schemes, their identification requires specific methodologies, such as chemical analysis (Fleet et al., 2020). International MARPOL Convention standards classify petroleum waxes and some vegetable oils as 'high viscosity, solidifying, and persistent floating products', and their discharge with tank-washing residues into the marine environment is strictly regulated (MARPOL Annex II, 2006). MARPOL Annex II was also updated at the 74th session of the Marine Environment Protection Committee (IMO, 2019a) to include a definition of a 'persistent floater' and the requirement to prewash tanks after the delivery of cargoes that may cause persistent floaters when the tank is subsequently washed out to remove cargo residues. The resulting prewash then has to be landed to PRFs. This applies to cargoes that are designated as 'noxious liquid substances which are deemed to present a hazard to either marine resources or human health in waters'. These regulations specifically target ships operating in north-west Europe, the Baltic Sea, western European waters and the Norwegian Sea.

To avoid mixing a new cargo with residues of the previous one, cargo tanks on ships are washed before new cargoes are loaded. The first round of washing is done with seawater, and freshwater is then used for rinsing and for steaming the tanks to remove residues if required. About 15-20 tonnes of freshwater will be used for washing each tank. The washing of the cargo tanks to remove these residues (also known as 'stripping') produces a mixture of water and cargo. For petroleum waxes and vegetable oils, discharge into the sea is deemed legal if they are discharged en route at a minimum speed of 7 knots and at least 12 nautical miles from the nearest land in depths of water exceeding 25 m. These legal discharges, together with their accidental release (KIMO, 2017), is a major source of pollution affecting birds and marine species over hundreds of kilometres of coastline (UEG, 2014) and have obvious detrimental consequences for the local communities that have to manage the clean-up and disposal of these substances.

Data on marine litter within the EU

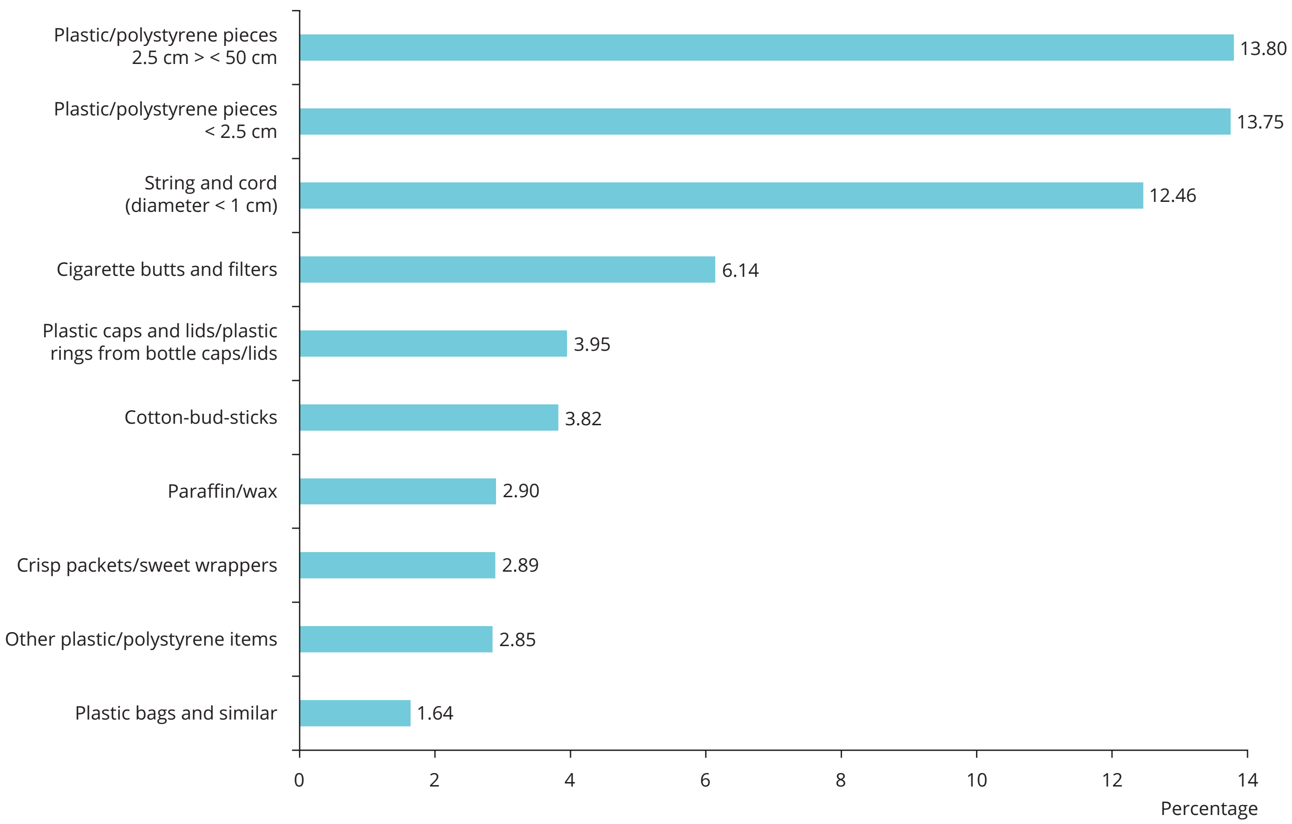
The Technical Group on Marine Litter (TG Litter), set up under the auspices of the MSFD Common Implementation Strategy (CIS), provides guidance and acts as an interface between science and policy stakeholders on matters related to litter baselines, thresholds and monitoring requirements. The work of TG Litter is therefore key to coordinating the assessment of marine litter in EU waters (EC, 2020e).

Data analysis undertaken by the European Commission Joint Research Centre within the scope of the work of TG Litter ranked litter items found on European shores at different spatio-temporal scales (Addamo et al., 2017). This led to the quantification of items based on their abundance. Data are based on 1 year's sampling (2016) and include the outcome from monitoring programmes, clean-up campaigns and research projects.

The analysis shows that the top 10 litter items found on beaches in 2016 represent approximately 64 % of the total items (Figure 4.26). Plastic items are predominant and represent a total of 84 % of the material. The collection of beach litter data from 2012 to 2016 across the EU resulted in the identification of marine litter baselines on EU coasts at different levels of spatial aggregation (Hanke et al., 2019). The identification of litter abundance baselines for other environmental compartments, such as the water surface and the sea floor, including micro-litter and litter impacts on biota, are ongoing. The further harmonisation of monitoring methodologies is crucial in deriving comparable data for that purpose. The availability of comparable data, with identified litter categories, attributable to their origin, will enable the establishment of links to the sources and thus enable the implementation of effective measures at EU level and in Regional Action Plans.

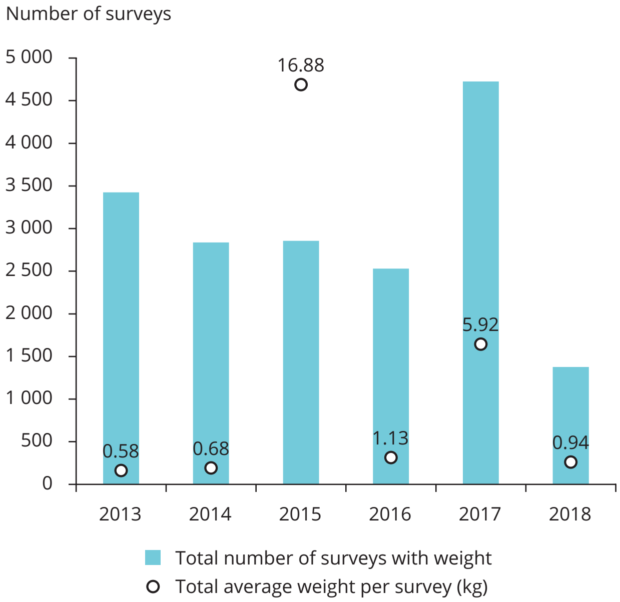
These types of studies are feasible through the implementation of the MSFD, providing monitoring data based on agreed guidance (EC, 2013) and research projects that improve the availability of monitoring methods, as well as the efforts of the Regional Sea Conventions. TG Litter acts as forum and advisory body for all stakeholders, including Member States, the Regional Sea Conventions and relevant research projects. Data collection and management are enabled through close collaboration with the European Marine Observation and Data Network (EMODnet), whose Chemistry portal provides data on the temporal and spatial distribution of marine litter in European seas.

Figure 4.26 Top 10 marine litter items — representing a total of 64.21 % of all marine litter found on European beaches, 2016



Source: Addamo et al. (2017).

Figure 4.27 **Number of surveys with marine litter per year and average weight per survey retrieved from EU sea floors**



Source: EMODnet (2020a).

Figure 4.27 shows the data for marine litter retrieved from European sea floors by bottom trawling surveys, available from the EMODnet Chemistry portal. Except for 2015, the average weight per survey is rather constant. While the number of surveys returning with litter is also constant, 2017 saw a rise and a subsequent drop. While the data currently available on sea floor macro-litter are mainly from bottom trawling surveys, there is also a need to consider areas that are not accessible by such surveys, but rather employ remotely operated vehicles (ROVs) and other non-destructive platforms for sea floor litter monitoring (Canals et al., 2021).

From the perspective of the Regional Sea Convention action plans to reduce marine litter, qualitative data show that, for the OSPAR Convention, half of the actions identified in the plan for ship-generated waste and PRFs have been completed, while the remaining half are being implemented (OSPAR Commission, 2015). For HELCOM, the guidelines relating to the four regional actions addressing sea-based litter have been drafted and their implementation is ongoing (HELCOM, 2020). For the Mediterranean Sea, the development of the Marine Litter Node in 2019 establishes the cooperation mechanisms at regional level for the implementation of the regional action plan, including for the better management of marine litter from sea-based sources in ports and marinas (MedNode, 2019). The Regional Action Plan on Marine Litter Management in the Black Sea was only adopted in 2018, and hence no data are yet available on its implementation.

4.1.4 Underwater radiated noise

Underwater noise from shipping is increasingly recognised as a significant and pervasive pollutant, affecting marine ecosystems on a global scale. Measurements in the last 50 years have shown that noise in the oceans is rapidly increasing (Southall et al., 2017). There is also documented scientific evidence linking noise exposure to a range of harmful effects on marine mammals, sea turtles, fish and invertebrates (Williams et al., 2015). The impact affects species that are at serious risk of extinction, those that are commercially important and those that are critical for supporting ecosystems. There has been some progress on underwater noise, in particular due to the work linked to the implementation of the MSFD. In spite of this, many knowledge gaps remain, making it difficult to quantify the link between ship traffic, underwater noise and its effects on the overall marine habitats. The policy and operational measures to limit underwater noise pollution are still in development.

Marine Strategy Framework Directive (MSFD) and underwater noise

EU rules (EU, 2017a) define good environmental status of marine waters and set out how to assess the extent to which good environmental status is achieved for underwater impulsive and continuous noise.

EU Member States are to establish threshold values for these underwater levels through cooperation at the European level, considering regional and sub-regional specificities. To steer this work and advise EU Member States on the operational implementation of this descriptor, a Technical Group on Underwater Noise (TG Noise) was set up in 2011. This group is a sub-group of a European Commission Expert Group on the Implementation of the MSFD.

So far, the work implemented at EU and regional levels through TG Noise has focused on monitoring aspects and has been closely related to activities undertaken in the European Regional Sea Conventions. Such work includes the publication of monitoring guidance for underwater noise in European seas (Dekeling, et al., 2013), currently under review. It also comprises the setting up of a register of loud impulsive noise and the development of a joint monitoring programme for continuous noise. Consequently, significant progress was made in this field during the first cycle of the implementation of the MSFD. TG Noise is now focusing on the assessment of the impacts of noise and the development of thresholds for the indicators developed in the framework of the MSFD.

Anthropogenic underwater noise emissions are mainly caused by commercial shipping and by the offshore oil and gas exploration industry. While the seismic testing and pile driving used in the offshore industry create high-intensity impulsive noise that can injure marine species, commercial ships emit lower to medium levels of continuous noise that can also affect marine species, especially mammals. Ships are reported to be the predominant source of anthropogenic low-frequency noise in the oceans. An increase in the noise levels in the ocean attributable to an intensification of shipping activity has been reported in areas such as the North Pacific Ocean (McDonald et al., 2006; Miksis-Olds and Nichols, 2016) and in areas of the Indian Ocean (Miksis-Olds et al., 2013).

Sources from ships

The main sources of underwater noise from ships are caused by the propeller (both cavitating and non-cavitating propeller), machinery (i.e. main and auxiliary engines) and the movement of the hull through the water. The relative importance of these three categories depends on many factors related to the ship type and operation profile and the sea conditions (Table 4.8).

The main underwater noise emitted by ships comes from the propeller when operating under cavitation. Several research projects and studies have been launched to further understand the propeller's cavitation mechanism and noise generated and to find technical solutions to mitigate its negative consequences (AQUO project, 2012-2015; SONIC project, 2012-2015; LIFE-PIAQUO project, 2019-2022; Vard Marine Inc., 2019).

Some studies have provided an example of the radiated underwater noise produced by a bulk carrier operating under conditions producing maximum noise levels of 182 dB at 50 Hz (dB re μPa at 1 m) (Arveson and Vendittis, 2000). The study showed how the same propeller operating with no cavitation, produces a noise level of 162 dB at 50 Hz at 1 m, and therefore reduces the resulting radiated underwater noise by 20 dB. This is an example of how the underwater noise generated relates to the ship's speed and the cavitation of the propeller.

With regard to ships with controllable pitch propellers (CPPs), there is still the need to determine the differences in the resulting underwater noise under different operating conditions. For example, the EU FP7 Silenv project focused on developing an optimisation procedure that would allow identification of the design parameters and the functioning operational points, aiming to characterise the propeller behaviour and the radiated underwater noise for CPPs (Bertetta et al., 2012).

Further studies have shown a need for improving the empirical models predicting underwater noise, as these are not very accurate in situations where a ship's propeller could operate outside its design range or in cases where the propeller is experiencing different hydrodynamic loads in the radial direction, which is usually the case for CPPs, supporting the adverse effect of the hydrodynamic loading parameters of CPPs (Gaggero et al.,, 2014).

Underwater noise at the International Maritime Organization (IMO)

At international level, the IMO has been working on the adverse effects caused by underwater noise generated by merchant vessels on the marine environment since 2008. Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life were published in 2014. These non-binding guidelines recognise two areas of mitigation: routeing and operations, as well as ship design and maintenance. However, their voluntary nature and the lack of measurement specification and data demonstrating the impacts of underwater noise have limited the uptake of these guidelines. To this extent the IMO Member States, supported by the EU Member States and the Commission, are now pursuing more stringent mitigation measures and are proposing a new guideline specifically aimed at reducing continuous underwater noise from ships (IMO, 2014).

Table 4.8 Sources of underwater radiated noise from ships

Source	Frequency range	Impact on marine environment	Impact on ship environment	Type of noise
		Ship's propeller		
Non-cavitating propeller tonal components	Blade passage frequencies (BPFs)	Low/medium	Depends on ship type (draught, length, operational speed) and propeller type	Propeller hydrodynamic noise
Non-cavitating propeller broadband	1 Hz-20 kHz	Low	Low	
Singing propeller	100 Hz-2 kHz	Medium/high	Medium/high	
Cavitating propeller tonal components	BPFs	High	High	
Cavitating propeller broadband	10 Hz-20 kHz	High	High	
		Fluid-hull interaction		
Propeller-hull interaction	BPFs and hull structure natural frequencies	Low	High	Fluid-structure interaction noise
Cavitation from hull appendages	100 Hz-20 kHz	Medium	Medium	
Slamming	1 Hz-100 Hz	Low	Low	
Wave breaking	100 Hz-10 kHz	Low	Low	
		Ship's machinery		
Main engines	1 Hz-500 Hz	Medium	High	Machinery noise
Cooling system	100 Hz-10 kHz	Medium	Medium	
Driving system	10 Hz-1 kHz	Low	Medium	
Auxiliary engine and other systems	10 Hz-10 kHz	Low	Medium	

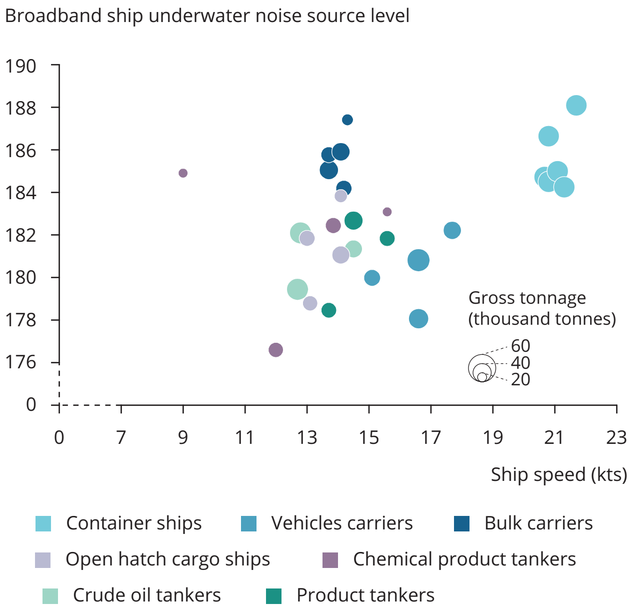
Source: AQUO project and SONIC project (2015).

As well as speed, other design parameters are also relevant for radiation of underwater noise. A study evaluated the acoustic footprint of seven ship types in various operational conditions (Figure 4.28). The findings demonstrated that container and tanker ships radiate the highest noise levels at frequencies below 40 Hz, while bulk carriers radiate the highest noise levels at a frequency near 100 Hz (dB re μPa at 1 m) (McKenna et al., 2012).

A 2020 report (MacGillivray et al., 2020) showed that vessel size was the design characteristic most strongly related to underwater radiated noise. The two main operational characteristics investigated, speed through water and actual draught, had the strongest correlation with underwater radiated noise in all vessel categories.

Noise level maps for different sea areas based on real-time information on ship movements, together with the average radiated noise levels for different ship types, would provide the ideal observational data to estimate ship-generated underwater noise. However, this task is currently not possible, as several ship operational conditions would need to be known for the specific time period and sea area of interest. To overcome this, a number of parametric models have been developed to produce noise source maps, together with alternative methods for filling in the missing information (Wittekind, 2014; STEAM, 2021). Figures 4.29 to 4.32 show the energy noise power emissions calculated using STEAM (Karasalo et al., 2017) in this way for a period between 2014 and 2019 and for the frequency of 125 Hz of one-third octave band per year, per ship type and for both the whole of EU waters and different European sea basins.

Figure 4.28 Broadband radiated underwater noise levels for different ship types and speeds



Source: McKenna et al. (2012).

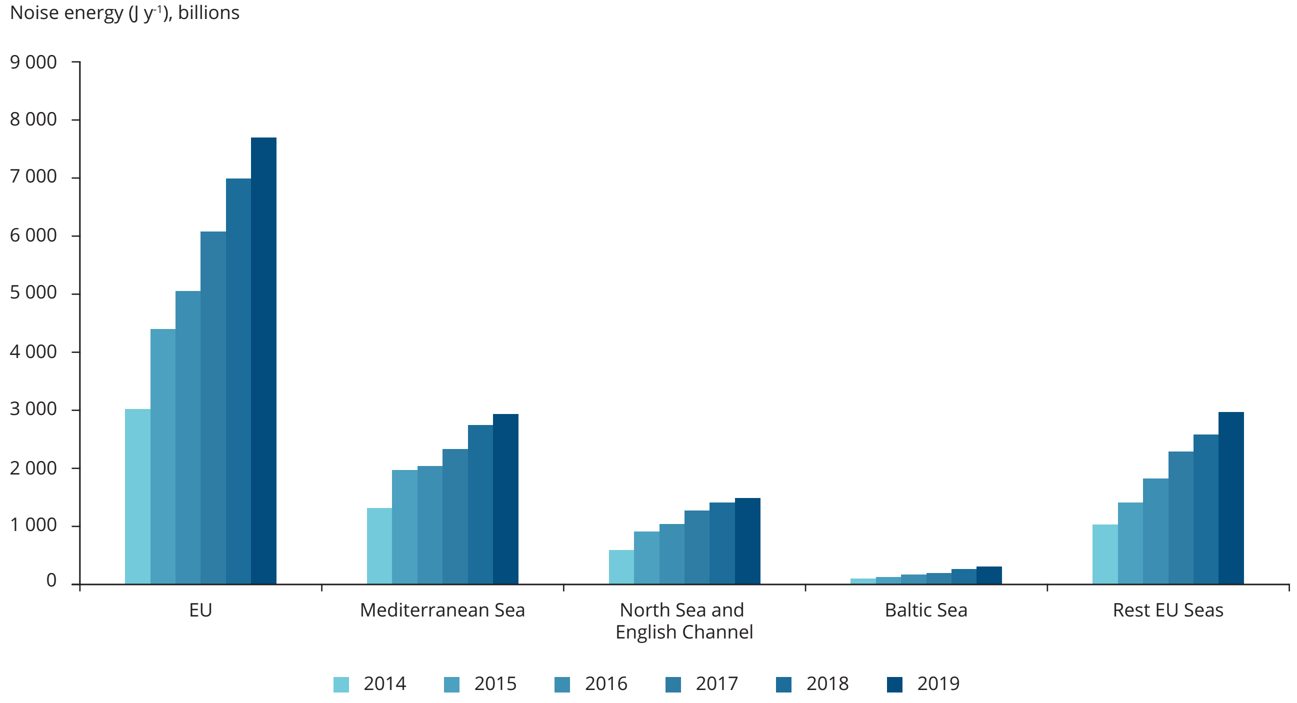
It should be noted that the noise power illustrated in Figures 4.29 to 4.32 does not include ships idling, although their auxiliary engines might be also running when at berth or anchorage. Furthermore, the model does not consider underwater noise propagation in the ocean. Figures 4.29 to 4.32 display results based on the specific noise energy (in joules) emitted by ships, facilitating its summation over a specific period. Figures 4.29 to 4.32 are therefore energy noise maps, as opposed to noise maps, and offer a visual aid that may be further used as a direct input for a potential noise propagation model. However, presenting the noise energy distributed over a wide geographical area helps visualise noisy areas, thus identifying areas of interest for further calculation, or even direct measurement, of their underwater noise distribution.

Notwithstanding the assumptions made, the outcome of the modelling supports the conclusion that underwater noise has increased in EU waters since 2014. In particular, total noise energy emissions have more than doubled between 2014 and 2019 in EU waters (Figure 4.29). From the noise energy figures (Figure 4.30), for all the EU sea areas it can be seen that container ships, followed by cargo ships and tankers, are responsible for the highest noise energy emissions in the 125 Hz one-third octave band. This may be related to the cavitation inception speed, which is estimated and included in this model, and the fact that ships operating at low speeds do not reach the cavitation inception speed. However, this is not the case for container ships which most of the time operate close to the cavitation inception speed.

The modelled underwater noise energy data show the same overall increasing trend for all European seas. For the Mediterranean Sea and the North Sea and English Channel, the modelled underwater noise energy emissions from containers and cargo ships seem to stabilise in 2019, while the emisisons from tankers show a slight increase (Figure 4.31). For the Baltic Sea the modelled underwater noise energy data shows that the contribution to the total noise energy emissions from all ship types has increased also in 2019 (Figure 4.32).

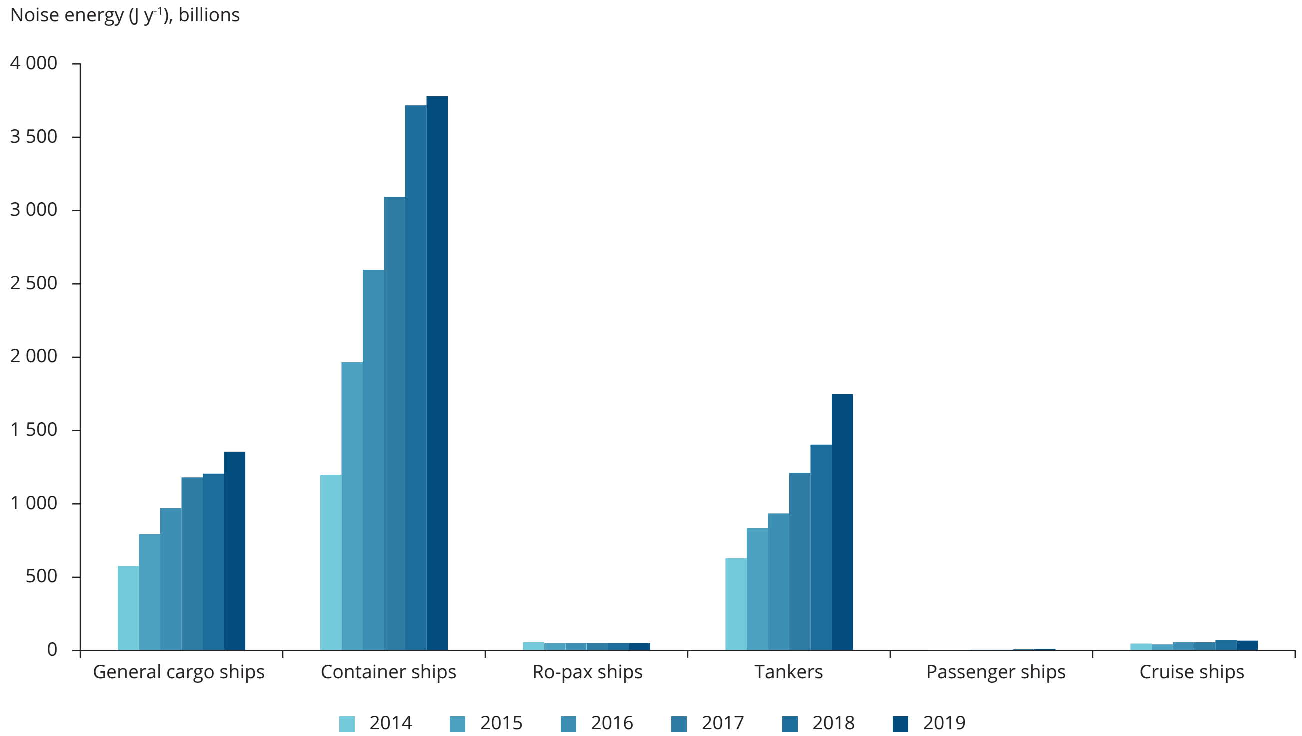
Nevertheless, it is important to reiterate that further studies need to be performed to ascertain the relationship between faster seagoing ships and the cavitation inception speed and to advance frameworks modelling ship characteristics, speed and movement to underwater radiated noise. There is a need to improve the monitoring and modelling of the cavitation inception speed of vessels to determine the underwater noise in sea basins, as errors in current models can lead to systematic over- or underestimation of the associated underwater noise generated.

Figure 4.29 **Overall EU underwater noise energy (J) at 125 Hz one-third octave band centre frequency by sea, 2014-2019**



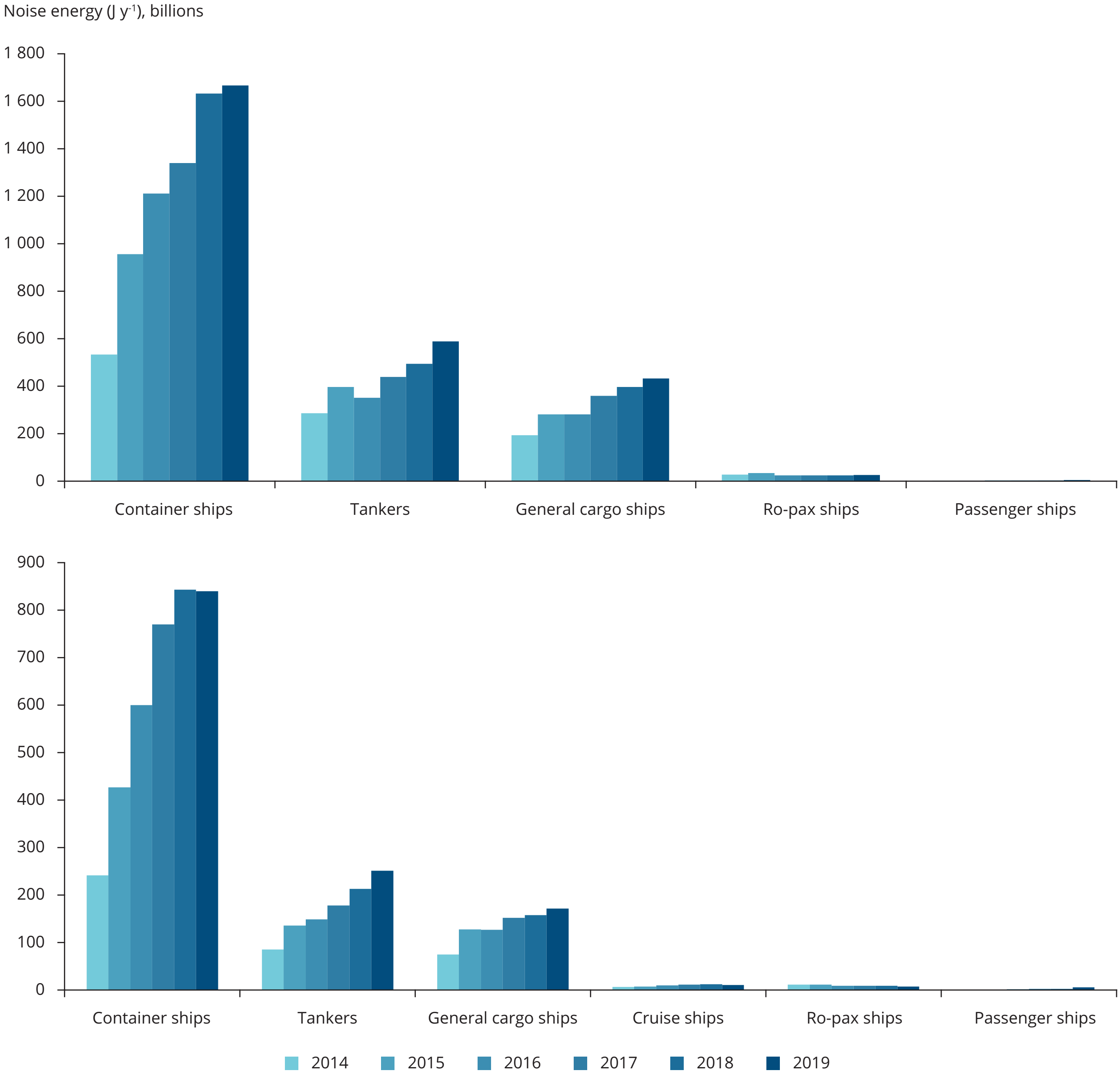
Source: STEAM (2021).

Figure 4.30 **EU underwater noise energy (J) at 125 Hz one-third octave band centre frequency by ship type, 2014-2019**



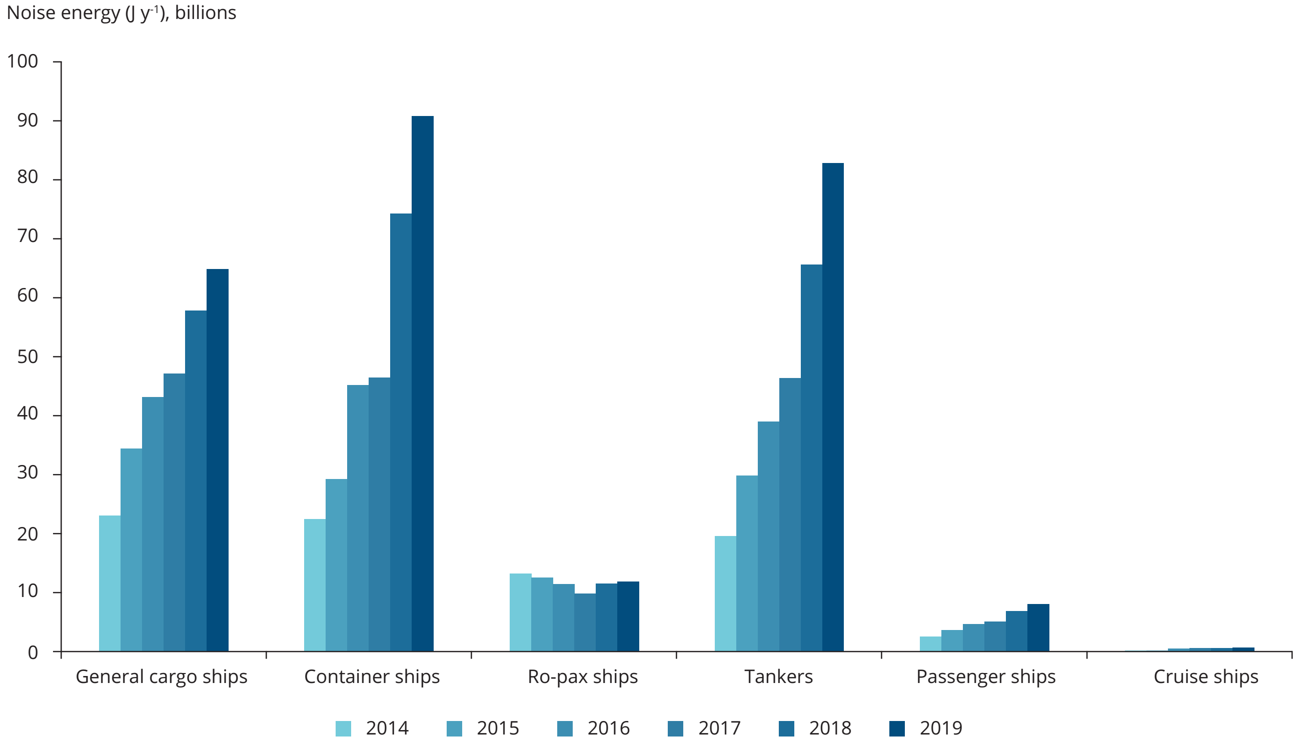
Source: STEAM (2021).

Figure 4.31 Mediterranean Sea (above) and North Sea and English Channel (below) underwater noise energy (J) at 125 Hz one-third octave band centre frequency by ship type, 2014-2019



Source: STEAM (2021).

Figure 4.32 **Baltic Sea underwater noise energy (J) at 125 Hz one-third octave band centre frequency by ship type, 2014-2019**



Source: STEAM (2021).

Vulnerability of marine species

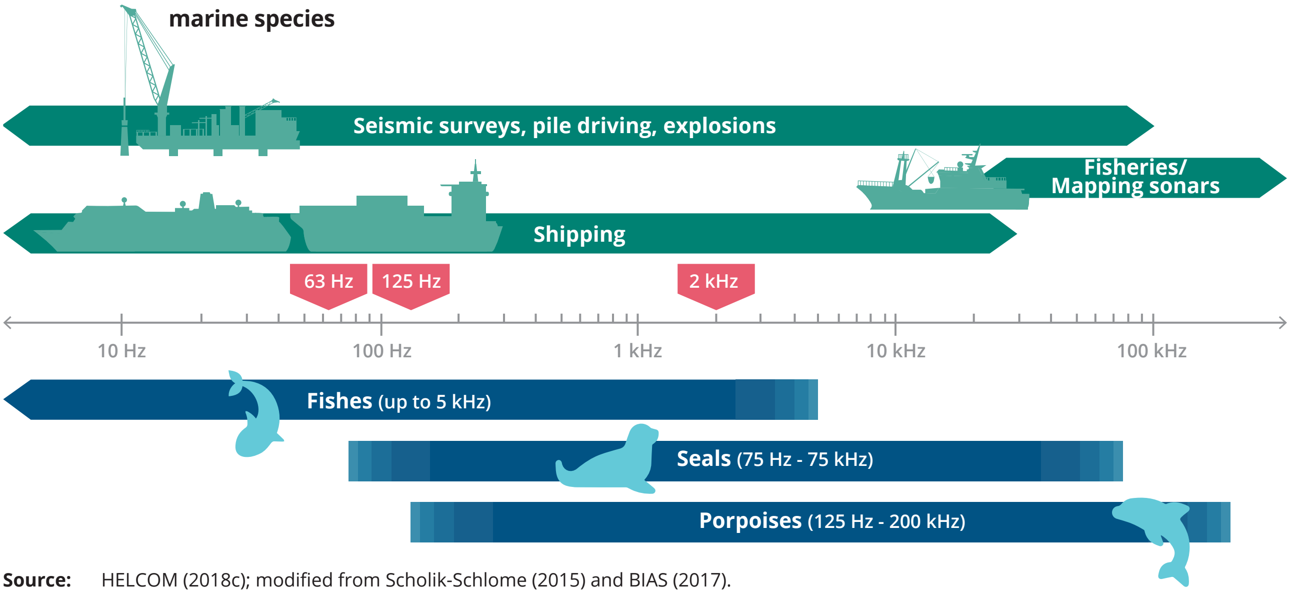
The range of noise frequencies emitted by commercial ships interacts with the frequency that is critical for various marine species, potentially masking the sounds made by these animals and having undesirable consequences (Figure 4.33). This is particularly the case with cetaceans, which are highly vocal and use sound for communication, food-finding, reproduction, detection of predators and navigation.

Within the context of the MSFD (EU, 2008b), and specifically for the determination of good environmental status, the monitoring and mapping of underwater sound pollution due to anthropogenic activities was declared a priority in EU waters (EU, 2010a, 2017a) ([3]). The EU-funded BIAS project used 40-point measurements and shipping density information to generate noise maps (Map 4.5). A further study looked at the spatial and temporal variability of ambient underwater sound in the Baltic by monitoring 36 different locations during 2014 (Mustonen et al., 2019). It concluded that an increase in observed ambient underwater noise can be attributed to maritime traffic in a number of areas of the Baltic Sea.

Following this approach, and after applying the hearing capabilities of some marine species, maps of hearing loss factors have been generated that can help estimate the geographical distribution of the decrease in the hearing capabilities of marine species (Map 4.6).

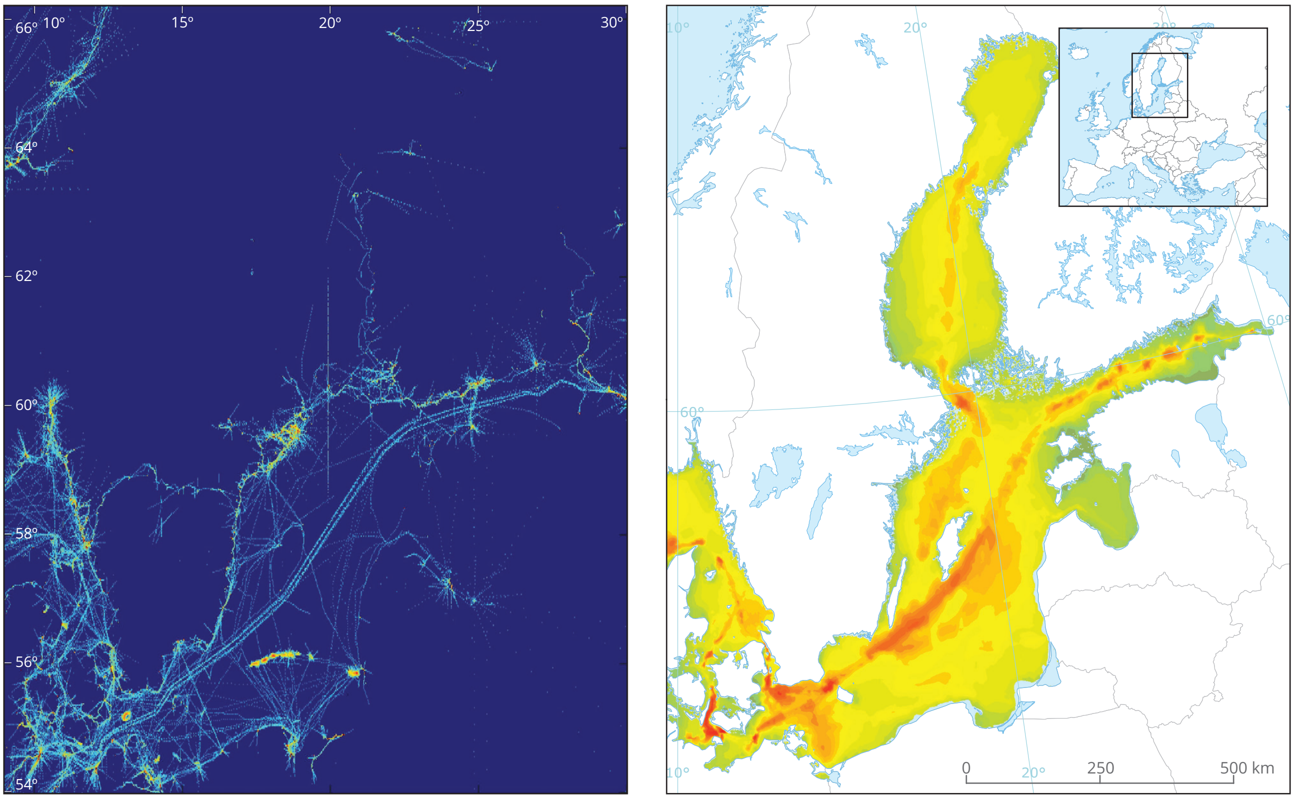
([3]) AQUO (Achieve Quieter Oceans by shipping noise footprint reduction), SONIC (Suppression of underwater Noise Induced by Cavitation), and BIAS (Baltic Sea Information on the Acoustic Soundscape).

Figure 4.33 **Sound frequencies from anthropogenic activities compared with the auditory range of some marine species**



Source: HELCOM (2018c); modified from Scholik-Schlome (2015) and BIAS (2017).

Map 4.5 **Left: shipping density map for the Baltic Sea region. Right: map of ambient underwater noise, including both natural and anthropogenic components type**



Reference data: GISCO

Shipping Density map in the Baltic region (left) and ambient noise including both natural and anthropogenic components of underwater noise (right)

Ship density per km²

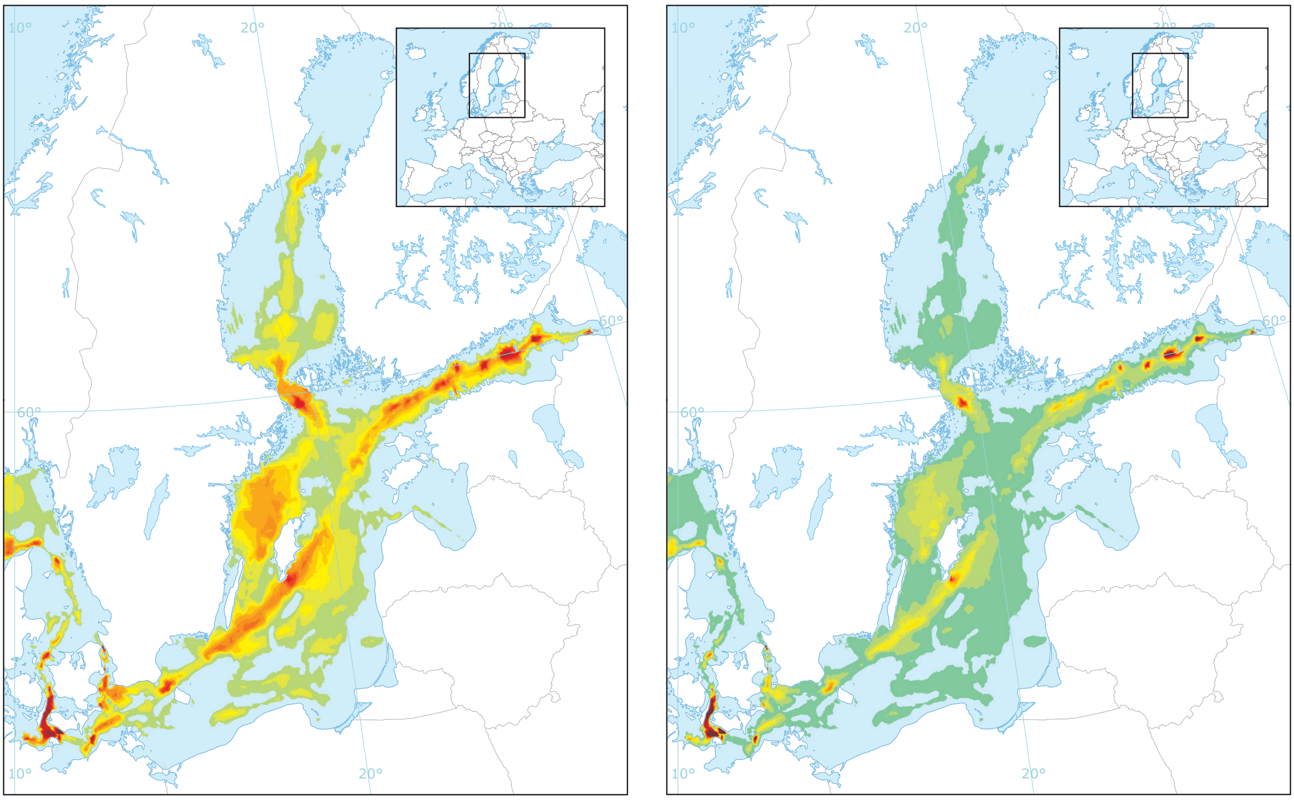
-5.0 -4.5 -4.0 -3.5 -3.0 -2.5 -2.0 -1.5 -1.0

Received Level Third Octave 125 Hz (dB ref 1μPa²)

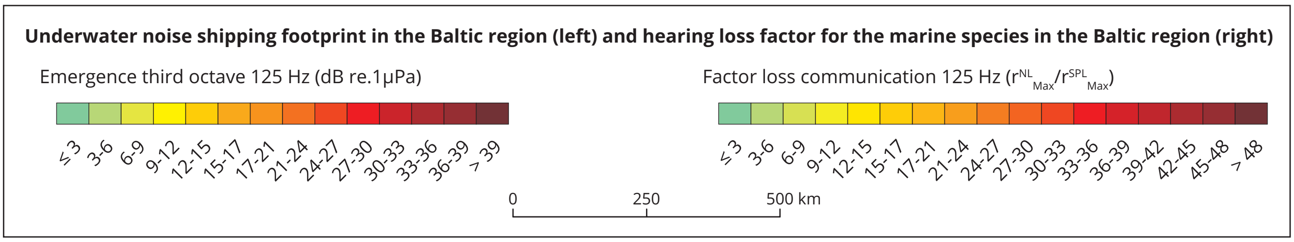
60 66 72 78 84 90 96 102 108 114 120

Source: BIAS project (2012-2016).

Map 4.6 **Left: map of underwater noise shipping footprint in the Baltic Sea region. Right: map showing hearing loss factor for marine species in the Baltic Sea region**



Reference data: GISCO



Note: Maps produced by Quiet-Oceans for the EU LIFE BIAS project.

Source: BIAS project (2012-2016).

By identifying the spatial distribution, this type of map can also help in identifying where continuous noise may have the greatest impacts, and where measures could therefore be implemented to mitigate its impact. It does not measure the overall increase in radiated energy at the EU level, elements which existing and future EU-funded projects, such as Jomopans (Jomopans project, 2018-2020) JONAS (JONAS project, 2019-2022) and Saturn (Saturn project, 2021-2025), might be able to address.

Studies have also recognised underwater noise as a dominant stress factor in the Mediterranean Sea, linking the increase in anthropogenic noise levels to behavioural disturbance in cetaceans (Maglio et al., 2015).

In addition to mammals, there is a large quantity of published research showing the impact of continuous underwater noise on fish and invertebrates. Analysis of human-produced underwater noise sources on 66 species of fish and 36 species of invertebrates has shown that noise can affect behaviour (e.g. reproduction, anti-predator behaviour, foraging and feeding, attention, schooling behaviour), auditory masking, abundance and distribution (Weilgart, 2018). Similar effects of masking, behavioural change and physiological stress have been documented in other studies (Popper, 2003; Cox et al., 2018; Di Franco et al., 2020).

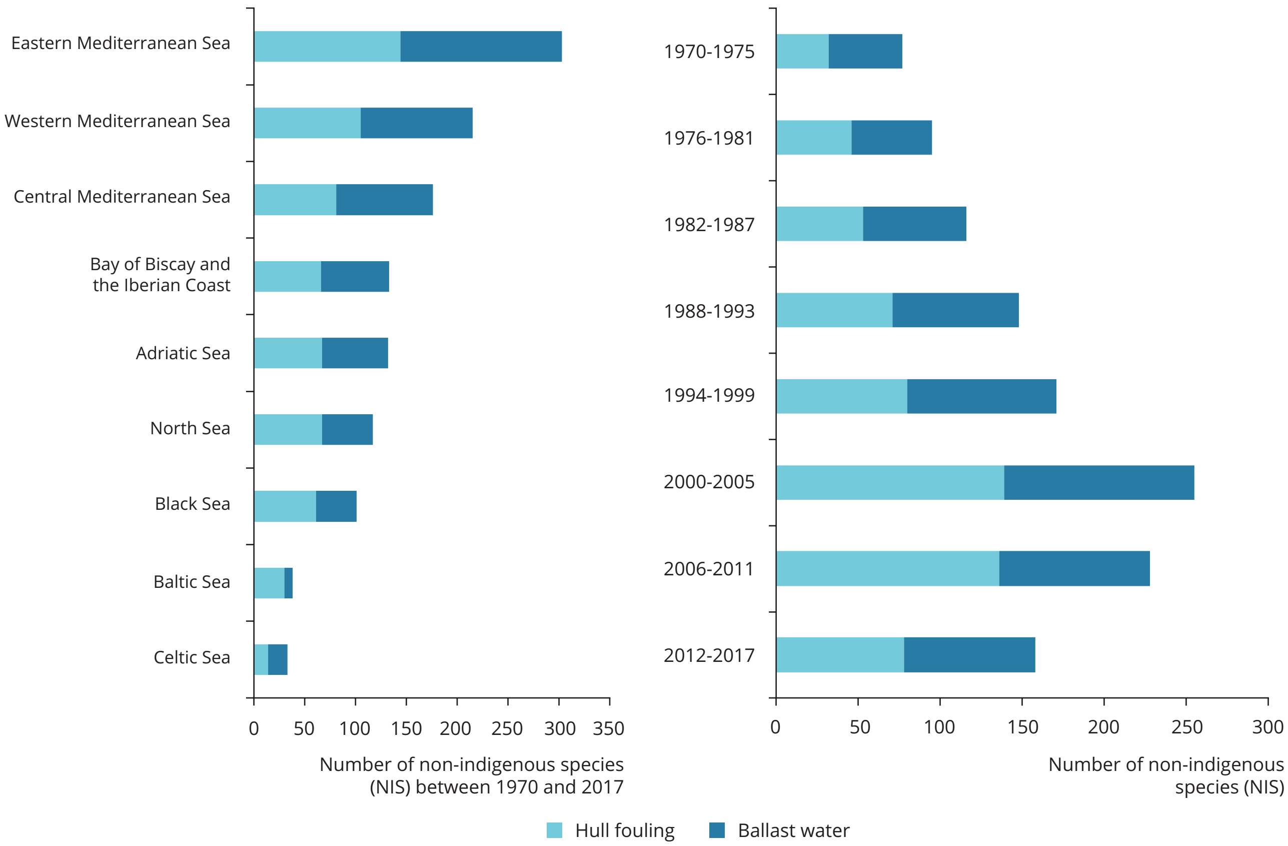
4.1.5 Non-indigenous species

According to the Convention on Biological Diversity, non-indigenous species (NIS) are those species introduced outside their natural past or present distribution. Once introduced in a new area they can become 'invasive' and have impacts on local ecosystems. Such species may arrive in new areas through natural migration, but they are often introduced by human activities, such as maritime transport, aquaculture and canals.

Maritime transport accounts for the largest proportion — up to 49 % — of NIS (including invasive species) introductions in the seas around the EU since records began in 1949. Organisms are transported mainly through ballast water (up to 25.5 %) and hull fouling (up to 21.2 %), while other sources, such as dredging, angling or fishing equipment, account for a minor percentage of introductions (2.3 %) (EEA, 2019b). However, maritime transport-related infrastructure, such as the Suez Canal, has also contributed to the introduction of a great number of species in seas around the EU (i.e. 33.1 %).

The Mediterranean Sea is the European sea basin with the highest number of NIS introduced by maritime transport, especially in eastern Mediterranean, while the Celtic Sea (Atlantic subregion) and the Baltic Sea are those with the lowest introductions (Figure 4.34, left). Although the number of introduced NIS has increased overall at the European level over the past century, it seems that the rate of new introductions has slowed down since 2005 (Figure 4.34, right). There are several reasons for this, ranging from increased awareness of the problem, effective policies and new legislation to other reasons such as a decreasing pool of potential new NIS.

Figure 4.34 Left: NIS introductions associated with hull fouling and ballast water in EU seas from 1970 to 2017. Right: trend in NIS introductions associated with hull fouling and ballast water in EU seas from 1970 to 2017



Source: EEA (2019b).

Once settled, NIS are very difficult to fight and eradicate, because of their rapid proliferation. This is why individual Member States' measures to stop the proliferation of NIS focus on the pathways that spread the organism so that new introductions are prevented.

In order to define a baseline for the determination of good environmental status in the context of the MSFD, EU Member States were asked to submit a list of the NIS present in their national marine waters (EU, 2008b). However, an analysis of the reported information revealed significant inconsistencies between EU Member States' monitoring approaches (Palialexis et al., 2014). Moreover, these lists, such as the list of invasive alien species (IAS) of Union concern (EU, 2016c), have a generic nature and do not discriminate between environments or vector of introduction. Therefore, specific research focusing on the vectors of NIS introductions is needed.

Example of a non-indigenous species (NIS) pathway

Corridors such as the Suez Canal and inland canals are the second main pathway of NIS introduction in EU waters (Katsanevakis et al., 2013). For instance, since the opening of the Suez Canal in 1869, the Mediterranean Sea has been subject to a massive migration — called Lessepsian migration — of NIS from the Red Sea. However, as species can be introduced through vectors such as ships or floating marine debris into new environments, it becomes very difficult to understand the true role played by ships in the introduction of NIS through the Suez Canal.

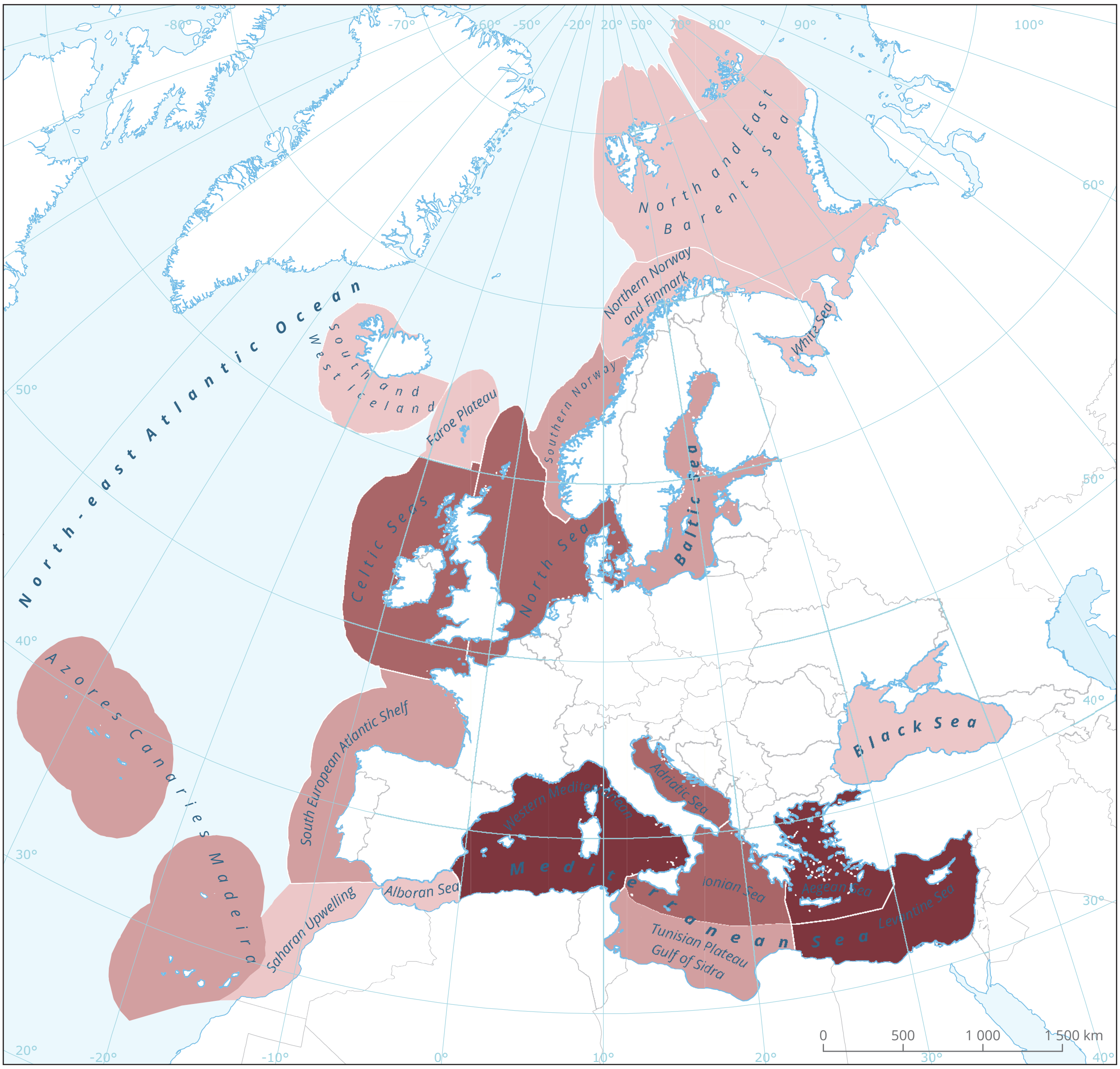
In this section data from different information systems have been combined in order to present comprehensive information. Two main databases have been consulted: EASIN and AquaNIS. The European Alien Species Information Network (EASIN), which is an initiative of the Joint Research Centre of the European Commission, enables access to data and information on alien species occurring in Europe, including pathways, distribution and level of impact. EASIN contains 1 521 marine NIS. AquaNIS (the online information system on aquatic NIS) stores and disseminates information on NIS introduction histories, recipient regions, taxonomy, biological traits and impacts in marine and coastal freshwater in Europe and neighbouring regions. AquaNIS is constantly updated; however, the data available online for the Mediterranean area covers only some countries, and therefore caution is needed when looking at figures for this area (AquaNIS, 2015).

Selecting the species recorded in EASIN as having been introduced through maritime transport (through ships' ballast water or hull fouling) and that have a high impact on ecosystems, and excluding both cryptogenic species (those without definitive evidence for their native or alien status) and questionable species (new entries not verified by experts or species with unresolved taxonomic status), the database provides a list of 64 marine NIS that have been introduced to EU waters. Taking that list and excluding species with no distribution maps and no reliable information on their vector of introduction reduces the number to 51 NIS. EASIN has information on the geographical distribution for 46 of these introduced species. Map 4.7 shows the number of those species for each marine ecoregion.

While the Mediterranean Sea is the area with the highest number of NIS, the Baltic and the Black Seas are those with the lowest numbers. Among the 13 taxonomic groups represented by those 51 species introduced by maritime transport that can have impacts on the environment, macroscopic algae account for the highest number of species, followed by crustaceans, molluscs and filter feeder invertebrates (Table 4.9) (EASIN, 2021).

It should be noted that not all introduced species cause damage in their receiving environments. Some can form viable communities within the environment that do not affect the balance of the ecosystem. However, the same organism in another location could proliferate to reach large numbers, resulting in environmental damage to ecosystems and subsequent economic impacts if ecological resources or habitats are affected. In addition, if environmental conditions change, then an NIS that has been introduced into a new habitat without any impact can suddenly increase its population density with associated ecological and environmental impact.

Map 4.7 **NIS of high impact introduced by maritime transport (as a primary or secondary pathway) by marine ecoregion**



Reference data: ©ESRI

Non-indigenous species (NIS) of high impact introduced by shipping (as a primary or secondary pathway)

Number of NIS

≤7
8-19
20-32
> 33

Source: EASIN Hulme framework (EASIN, 2021).

Table 4.9 **Estimates of the number of NIS of high impact introduced in EU seas by maritime transport**

Description	Baltic Sea area	Black Sea area	Mediterranean Sea area	North Sea area
Unicellular algae	0	1	1	3
Macroscopic algae	3	1	10	6
Plants with a vascular system	0	0	1	0
Anellid worms	0	1	3	1
Crustaceans such as crabs, lobsters, shrimps or barnacles	3	1	8	6
Insects	0	0	0	1
Molluscs such as snails, squids, octopus, clams and oysters	2	2	8	4
Filter feeder invertebrates	0	0	4	4
Jellyfish or sea anemones	1	0	3	1
Comb jellies	1	1	1	1
Starfish, sea urchins, brittle stars, crinoids and sea cucumbers	0	0	1	0
Total	**10**	**7**	**40**	**27**

Source: EASIN (2021).

Ballast water

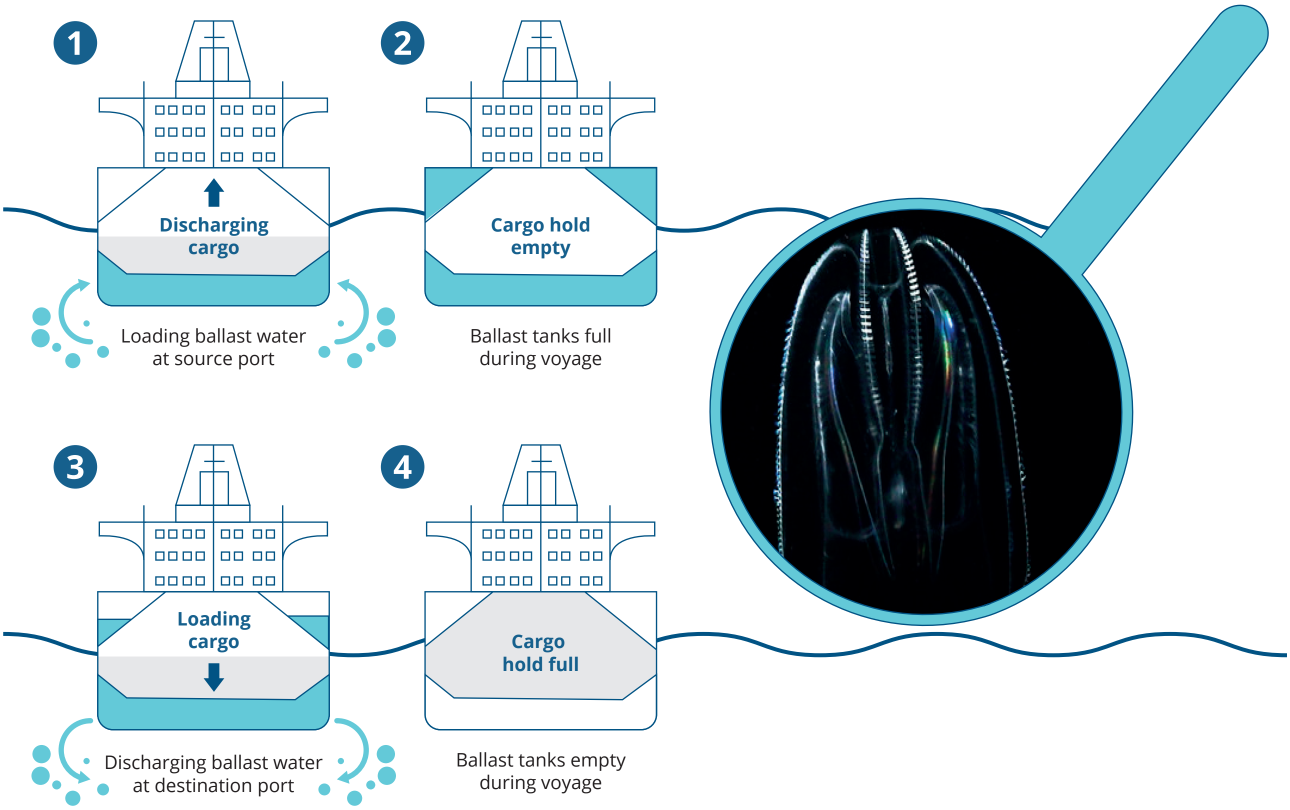
On ships, ballast is needed to maintain their stability during loading and unloading operations and while the ship operates with partial or no cargo or in rough weather. In the past, solid materials, such as stones and rocks, were used as ballast, but it was a time-consuming task to load and unload this ballast and one that needed a significant labour force (Christopher and Richard, 2002; Kholdebarin et al., 2020). As ships became larger, they were built to be stable when laden; therefore, ballast water is essential for the safe operation and transit of the ship when unladen. The introduction of steel hulls allowed ships to use water instead of solid materials as ballast. Ships fill their ballast tanks near the port of departure where various species with a free or floating life stage can be pumped into tanks (e.g. eggs, larvae, spore cysts, adults) and then be discharged with the ballast water in the destination port (Figure 4.35, left) (Tamelander et al., 2010; Kholdebarin et al., 2020). This allows organisms to travel long distances and be released in areas far from their native range, thereby becoming an NIS and, if suitable conditions exist, turning into an invasive species. According to the 'tens rule', approximately 10 % of all introduced species will become established and 10 % of these will become invasive (Mannino et al., 2017). The problem has exacerbated as trade and traffic volumes have expanded over the last few decades.

The effects of the introduction of new species in many parts of the world have been devastating. A good example of this is the well-documented invasion of the Black Sea by a voracious comb jellyfish (*Mnemiopsis leidyi*) originating from North America (Figure 4.35, right). The comb jellyfish arrived in the Black Sea on ships from the American Atlantic coast in 1982. This invasive species eats both zooplankton, the food of commercially important fish in the Black Sea, and the eggs and larvae of the same fish species. With no natural enemies in their new home, the jellyfish propagated easily and were found everywhere in the Black Sea by the end of 1988; by the mid-1990s, they accounted for 90 % of the total biomass in the Black Sea.

The species had quickly spread into the neighbouring Azov Sea by 1989. The invasion contributed to the near collapse of Black Sea commercial fisheries within a few years. The once quite prosperous seafood industry suffered dramatic economic consequences as a result. Anchovy fisheries in the Azov Sea, already under stress from pollution and overfishing, completely collapsed. Dolphin numbers in the Black and Azov Seas also dropped dramatically, as the fish they used to feed on disappeared. The entire ecosystem was also disrupted as the jellyfish also reduced the amount of oxygen in the Black Sea (GEF-UNDP-IMO, 2021). By 1989-1990 the jellyfish had spread to the Sea of Marmara, by 1996 to the Aegean Sea, by 2005 to the Gulf of Trieste and by 2006 to Kiel Bay in the Baltic Sea and to the North Sea.

At present there are no direct EU standards on ballast water. However, EU rules on the prevention and management of the introduction and spread of invasive alien species recognises the Convention for the Control and Management of Ships' Ballast Water as one of the possible management measures for invasive species of concern

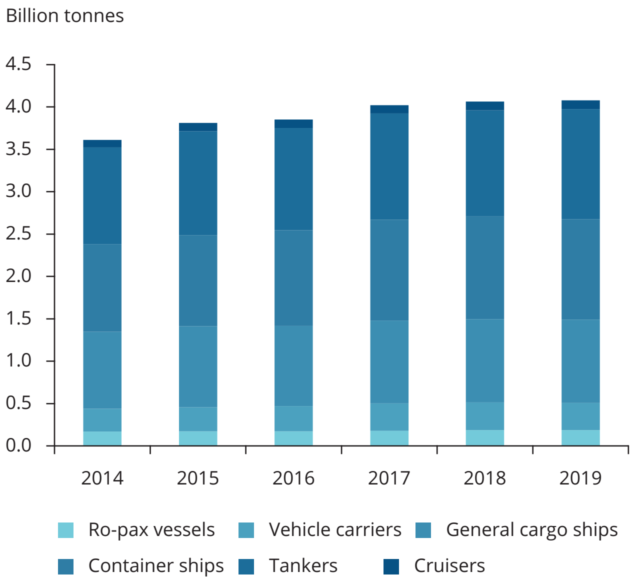
Figure 4.35 **Left: the ballast water cycle. Right: Warty comb jelly *(Mnemiopsis leidyi)*: invasive species introduced by ballast water from the Atlantic Ocean to the Black Sea**



Source: Left: SEOS (2021); adapted from GEF-UNDP-IMO GloBallast Partnership Programme (2021). Right: © Erickson Smith (CC BY-NC 2.0).

(EU, 2014d). An analysis of maritime traffic in Europe sea areas shows that the volume of ballast water discharges from 2014 to 2019 remained relatively stable (Figure 4.36). Among the different categories of ships, container ships and tankers are responsible for most ballast water discharges in EU waters because of the large amounts of ballast water these ship types need to trim the ship. Therefore, container ships and tankers could play an important role in introducing non-indigenous species in ballast waters (Figure 4.36). It is important to note that the model used for the analysis considers the standard practice in the Baltic Sea, whereby ballast water is discharged only when the ship is not in transit. Therefore, caution is needed when interpreting the results for other seas. Moreover, the model assumes that ships discharge all of their ballast water during a port visit, which could overestimate the total amount of discharges, as partial discharges are also possible en route. However, studies confirmed that 92.4 % by volume of ballast water is normally discharged in the destination port, with 98.2 % discharged in the port or the neighbouring ecoregion, confirming the reliability of the model used. Moreover, it has been estimated that 78.4 % of ballast water discharged originates from the last port of call, and 85 % originates from the last port of call or neighbouring ecosystem (Cope et al., 2015). It should also be noted that many ships have to discharge ballast water to enable them to enter certain estuarine ports, tidal ports and ports with shallow water, and that ships may need to take on or discharge ballast water en route to ensure stability during storms and bad weather.

Figure 4.36 Estimations of ballast water discharges in EU waters by ship type

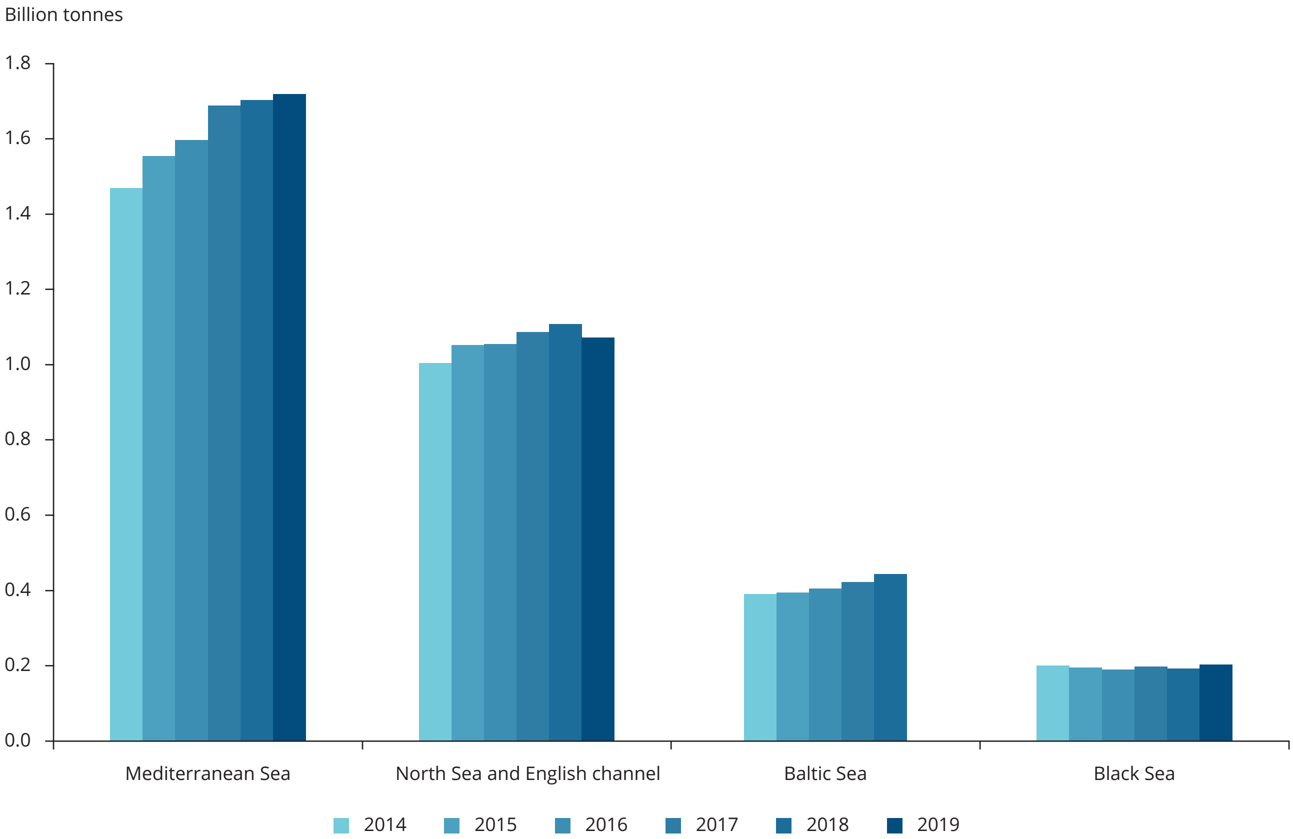


Source: STEAM (2021).

Among the different EU seas (Baltic Sea, Black Sea, Mediterranean Sea and North Sea), the highest volume of ballast water is discharged in the Mediterranean Sea area (Figure 4.37). The Mediterranean Sea is also the one with the highest number of NIS; therefore, the release of large quantities of ballast waters, characterised by the presence of potential invasive species, could exacerbate an already existing problem.

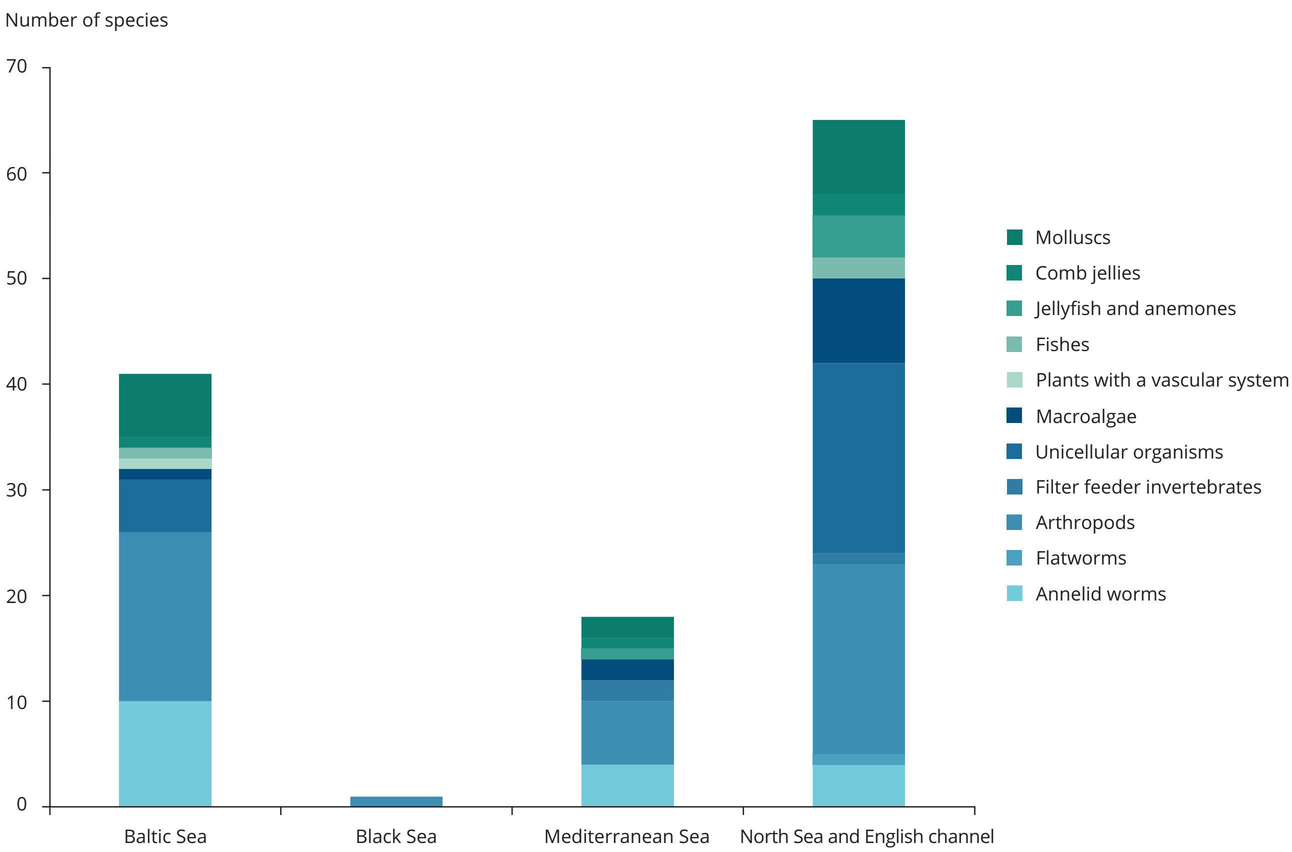
Considering the lack of studies on the role of the different vectors in NIS introductions, it is difficult to provide a precise evaluation of the number of NIS introduced only by ballast waters in EU marine seas. However, AquaNIS allows estimation of both numbers and pathways (vectors) of species introduced into EU waters. Therefore, through the AquaNIS database (AquaNIS, 2015), by selecting NIS with various population status in the recipient marine area, it is possible to extrapolate the number of NIS introduced by ballast water in the Baltic, North and Mediterranean Seas. As shown in Figure 4.38, in all sea areas, selected arthropods, unicellular organisms and anellid worms are the most susceptible to introduction through this particular vector. Among the four sea areas, the Black Sea is the least affected by species introductions through ballast water. Indeed, the Black Sea is the area with the lowest number of species introduced by ships (Figure 4.38) while the North Sea appears to be the most susceptible. However, even if the figures extrapolated from the AquaNIS database are a qualitative example to describe the scale of NIS introductions, it is important to highlight that it remains an estimation. For instance, AquaNIS's data for the Mediterranean area covers only some countries; therefore, the number of NIS introduced through ballast waters in this area is likely to have been underestimated.

Figure 4.37 **Estimations of the total volume of ballast water discharged by EU sea**



Source: STEAM (2021).

Figure 4.38 **Estimations of the number of NIS introduced by ships' ballast waters by EU sea**



Source: AquaNIS (2015).

Hull fouling

Sea life such as algae, molluscs and other sessile organisms can travel from one place to another by attaching themselves to a ship's hull, hereafter referred to as hull fouling, slowing down the ship, increasing fuel consumption and thereby facilitating the movement and dissemination of NIS. Considering that, at global level, in excess of 50 % of NIS may have been transported through biofouling, their impacts are likely to be significant; however, there have been very few assessments of NIS introduced by hull fouling alone, as numerous species can be introduced by both ballast water and hull fouling (GloFouling, 2019).

Biofouling develops slowly on vessels, and its speed of growth is dictated by the anti-fouling coating the vessel has, the frequency of hull cleaning and the exposure to water. Certain areas of a ship, such as the anchor locker, pipework and other sheltered parts, are more likely to be fouled quickly and have a large range of organisms in the fouling that develops. This is because they are in contact with still water for a greater period of time. Laid up or moored vessels can also develop heavy fouling, which can reach on average 5 kg/m^2 (Walters, 1996).

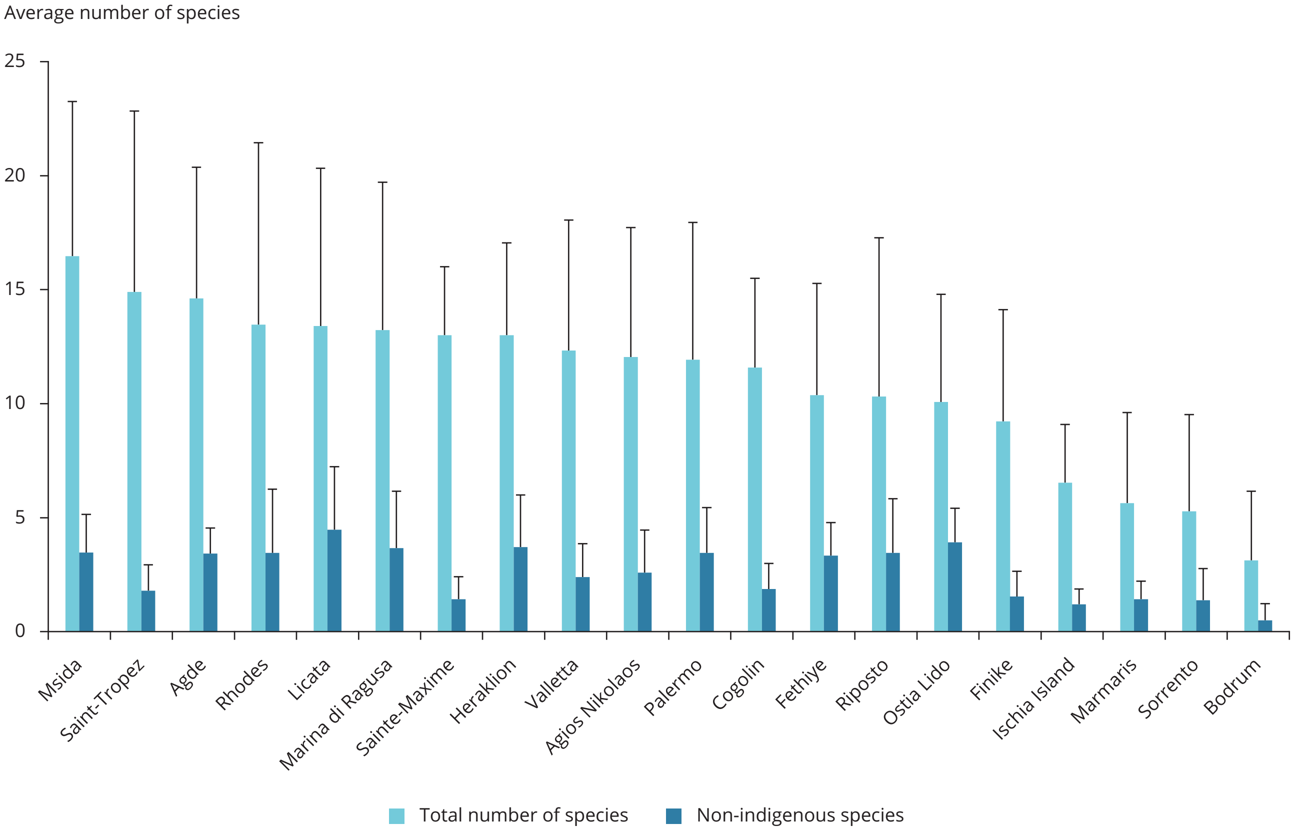
When the organisms on a ship's hull reach maturity, they will, in most cases, release larval stages into the water column, and therefore introduce the species into the local environment. Other introductions can occur when living species drop off the hull, either through the action of the anti-fouling coating or during in-water hull cleaning operations, which are prevalent in certain ports and estuaries.

An interesting example of an invasive species introduced from Europe to all over the globe is the case of the European green crab, *Carcinus maenas* (Linnaeus 1758). *C. meanas* is listed as one of the 100 of the world's worst invasive alien species (Lowe et al., 2000). This species, native to Europe and North Africa, has been introduced in several areas, such as the Atlantic and Pacific coasts of North America, South Africa, Australia, South America and Asia (Carlton and Cohen, 2003; Klassen and Locke, 2007). Its present dispersion can be attributed mainly to hull fouling as the main vector of *C. maenas*'s global introductions in the 19th century (Carlton and Cohen, 2003). *C. maenas* can also be considered a model invader, which, once introduced into a new area, can adversely impact ecosystems and native species through predation, competition and habitat modification.

Image 4.1 European green crab *(Carcinus maenas)*: invasive species introduced from Europe to all over the globe by ship's hull fouling

Source: © John Haslam (CC BY-NC 2.0).

Figure 4.39 **Average number (± standard deviation) of total species and NIS recorded in 20 Mediterranean Sea marinas**



Note: Numerical values indicate the number of boats sampled per marina.

Source: Ferrario et al. (2019).

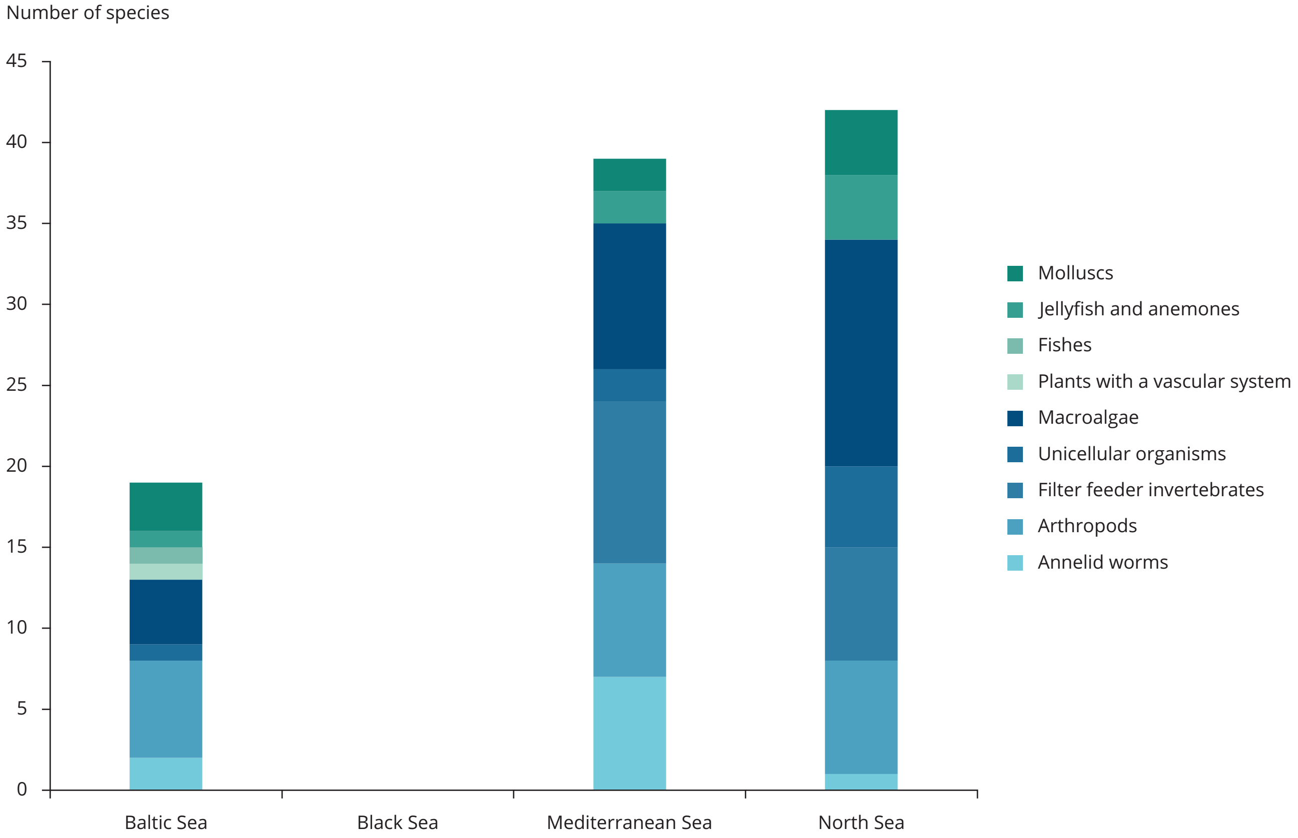
The spread of NIS in domestic waters has also been exacerbated following introductions by recreational craft. Small vessels can often distribute new NIS from port areas, which serve as central 'hubs' for their invasion of broader coastal and estuarine ecosystems. There is now an understanding that, in some cases, ship biofouling may have contributed to more introductions of NIS in many parts of the world than ballast water and other dispersal mechanisms.

Concern over the spread of NIS by biofouling of recreational boats is also highlighted in a study conducted in 20 different Mediterranean Sea marinas where over 367 boats were inspected. A total of 154 species was recorded on boats' hulls and 33 species were identified as NIS (Figure 4.39). Over half of the inspected boats (67 %) were fouled by an average of one to three NIS, with three boats carrying over 10 NIS (Ferrario et al., 2019). In a similar study conducted in 25 different Mediterranean Sea marinas, in general recreational vessels were characterised by macrofouling communities different from those of the hosting marinas, highlighting that the longer a ship stays in a new area, the more the two different communities become aligned and the greater the risk of NIS transferring between the two habitats (Ulman et al., 2019).

The Mediterranean Sea, characterised by intensive interregional recreational boating traffic, is the European sea region most affected by NIS introductions by hull fouling. Preventing fouling on hulls, and addressing the issue of negleted boats, should be prioritised to prevent potential NIS dispersal (Ulman et al., 2019).

The AquaNIS database allows estimation of the number of NIS and taxonomic groups introduced into EU waters by ship hull fouling. As shown in Figure 4.40 the most frequently represented taxonomic group of NIS is the macroscopic algae, followed by arthropods (crabs, shrimps, barnacles) and filter feeder invertebrates. The Black Sea is the region least affected by NIS introductions through hull fouling, followed by the Baltic, the Mediterranean and the North Seas. Although the figures for the Mediterranean Sea need to be interpreted with caution, comparing the numbers of NIS introduced in the Mediterranean Sea through hull fouling with those introduced through ship ballast water (Figure 4.40 and Figure 4.38), the Mediterranean seems to be more susceptible to the introduction of species through hull fouling. This may suggest a possible connection with the high maritime traffic density in this area.

Figure 4.40 Estimations of NIS introduced by ship hull fouling by EU sea



Source: AquaNIS (2015).

4.1.6 Physical disturbance of the seabed

Impacts on the seabed from navigation are mainly related to anchoring and the wakes produced by ships, as well as the dredging operations carried out for navigation purposes and the subsequent disposal of the dredged sludge in the sea.

Dumping

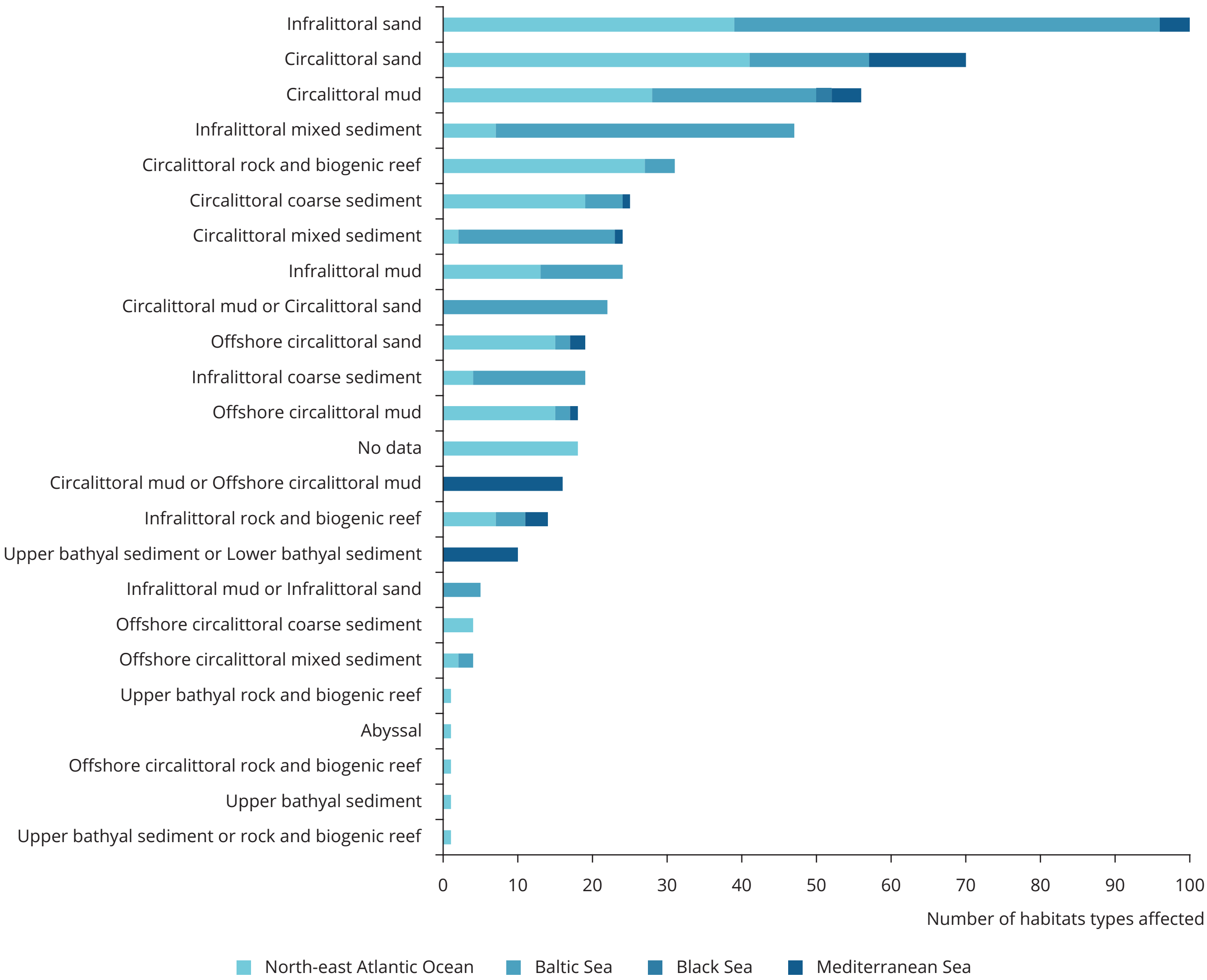
Under the auspices of the United Nations Convention on the Law of the Sea (UNCLOS, 1982) dumping is defined as any deliberate disposal at sea of wastes or other matter from vessels, aircraft, platforms or other artificial structures at sea, and any deliberate disposal at sea of vessels, aircraft, platforms 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 as follows:

- dredged material;
- sewage sludge;
- fish waste, or material resulting from industrial fish processing operations;
- vessels and platforms or other artificial structures at sea;
- inert, inorganic geological material;
- organic material of natural origin;
- bulky items primarily comprising iron, steel, concrete and similarly harmless materials, for which the concern is their physical impact, and limited to those circumstances in which such wastes are generated in locations, such as small islands with isolated communities, having no practicable access to disposal options other than dumping; and
- CO_2 streams from carbon capture and sequestration processes.

The largest reported volumes of material being dumped at sea are dredged sediments. These originate from estuaries, ports and other coastal sites. While a large proportion of dredged material is considered to be clean, some may be contaminated with heavy metals or garbage, providing an often temporary and localised pathway for these substances to enter the marine environment. The dumping of dredged material can, depending on the dump site, also lead to the loss of benthic habitats as a result of the burial of organisms. In addition, it may also tempoarily increase the suspended matter in the water, which in turn increases the turbidity.

An analysis was carried out in which a layer showing the locations of dumping sites at the European level was overlaid with a layer showing benthic broad habitats. As dumping generally takes place in shallow areas, the most affected habitats are local infralittoral and circalittoral habitats with sedimentary bottoms, such as sand or mud, which in general are the more diverse and productive (Figure 4.41). Dumping therefore is a localised impact, controlled by the London Convention and Protocol, that produces local impacts that are less intense than other sources of pollution from shipping.

Figure 4.41 Benthic broad habitat types affected by the dumping of dredged material by sea



Source: EMODnet (2017b, 2019b).

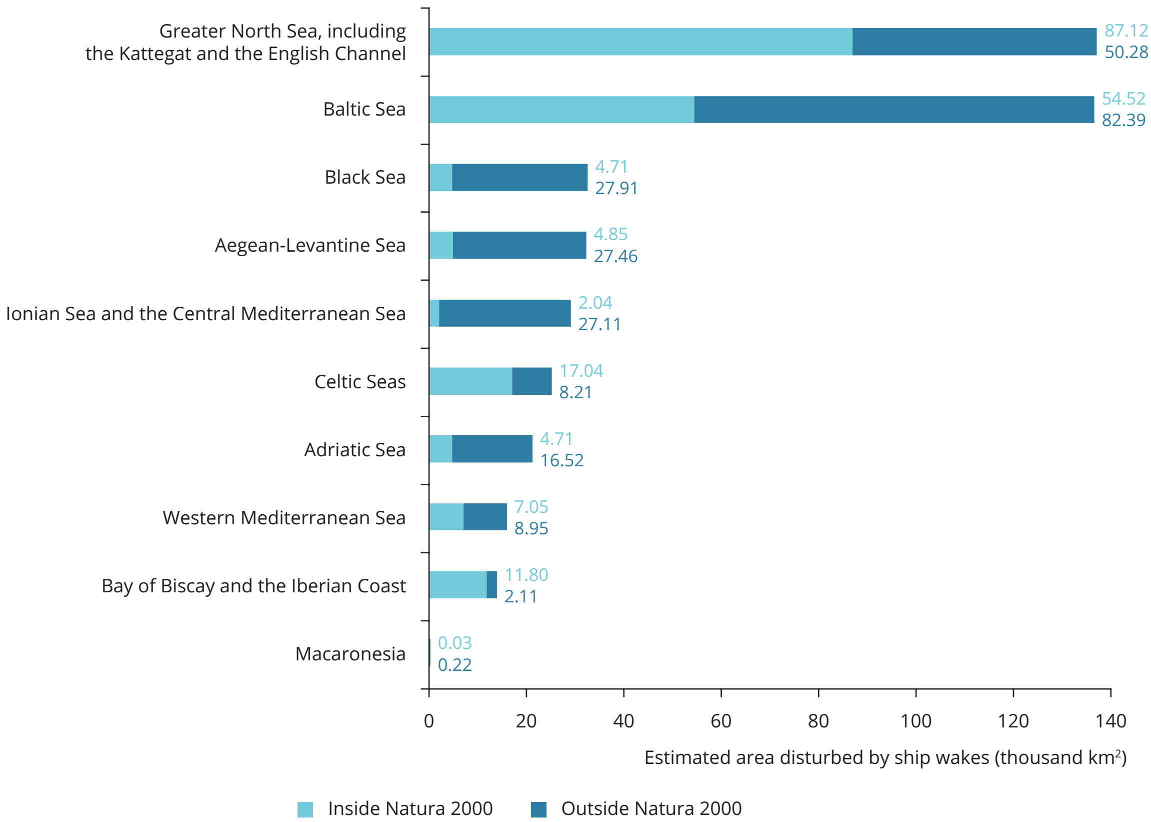
Wake induced turbulence

Wakes produced by ships can cause turbulent mixing and sediment re-suspension of soft bottoms in shallow areas. This induced turbulence can be felt down to 30 m depth (Nylund et al., 2020). The suspended sediment increases the turbidity and temporarily affects those seabed organisms that are directly dependent on light (such as aquatic plants), as it hinders photosynthesis. If this happens repeatedly, the productivity of the affected habitat can result in knock-on effects on the local ecosystem. If not managed, this can have a significant impact on rivers and small estuaries near harbours with large numbers of ships calling at them, or along shipping lanes with regular traffic.

In order to estimate the potential area affected by this pressure in Europe's seas and to understand to what extent it can affect the Natura 2000 network ([4]) of marine protected areas (MPAs), a map of soft bottom habitat types (sand, mud, and coarse or mixed sediment substrates) down to 30 m depth was overlaid with traffic density maps, for which the density values were rescaled according to the depth. The resulting layer was then overlapped with the Natura 2000 sites layer.

The results show that the marine regions with the largest estimated area potentially disturbed by ship wakes are the North and the Baltic Seas, where 63 % and 40 %, respectively, of the regions fall within Natura 2000 sites (Figure 4.42). The results indicate that the physical disturbance produced by the ship wakes may affect some of the species and habitats protected within the Natura 2000 network, which are listed under the Habitats Directive. However, there is currently no information available at European level demonstrating this impact, as the Habitats Directive lists only the conservation status of species and habitats, which cannot be directly linked to this pressure.

Figure 4.42 Estimated area disturbed by ship wakes inside and outside Natura 2000 network by marine subregion



Source: EEA (2019c, 2020d).

([4]) Natura 2000 is the largest coordinated network of protected areas in the world. Natura 2000 in the marine environment is a subset of the main network with designated areas in the marine waters of the 23 EU coastal countries. Find more information online: https://www.eea.europa.eu/themes/water/europes-seas-and-coasts/assessments/marine-protected-areas.

Anchoring

In the same way that the dumping of dredged material and ship wakes disturb the seabed, anchors can also increase suspended matter near the bottom, thus disturbing the seabed life. In addition, and most importantly, anchors may also physically abrade the sea floor, causing permanent damage from which recovery is impossible. Many studies have focused on assessing the localised impact of recreational boat anchoring, as it is rarely regulated and can have significant effects on the seabed, especially in the summer season. Anchoring is classified as the largest impact that Marine Protected Areas (MPAs) in the Mediterraen Sea suffer from recreational boating (Milazzo et al., 2002; Lloret et al., 2008).

Studies show that sensitive habitat-forming slow-growing sessile species, such as seagrasses, maerl or corals, are more vulnerable than others to this pressure (Table 4.10). The EU funded project Pharos4MPAs (Pharos4MPAs project, 2014-2020) investigates the impact of maritime transport, including pressures due to anchoring, in MPAs and promotes recommendations and policy tools to contribute to the conservation of marine biodiversity and natural ecosystems (Carreño et al., 2019).

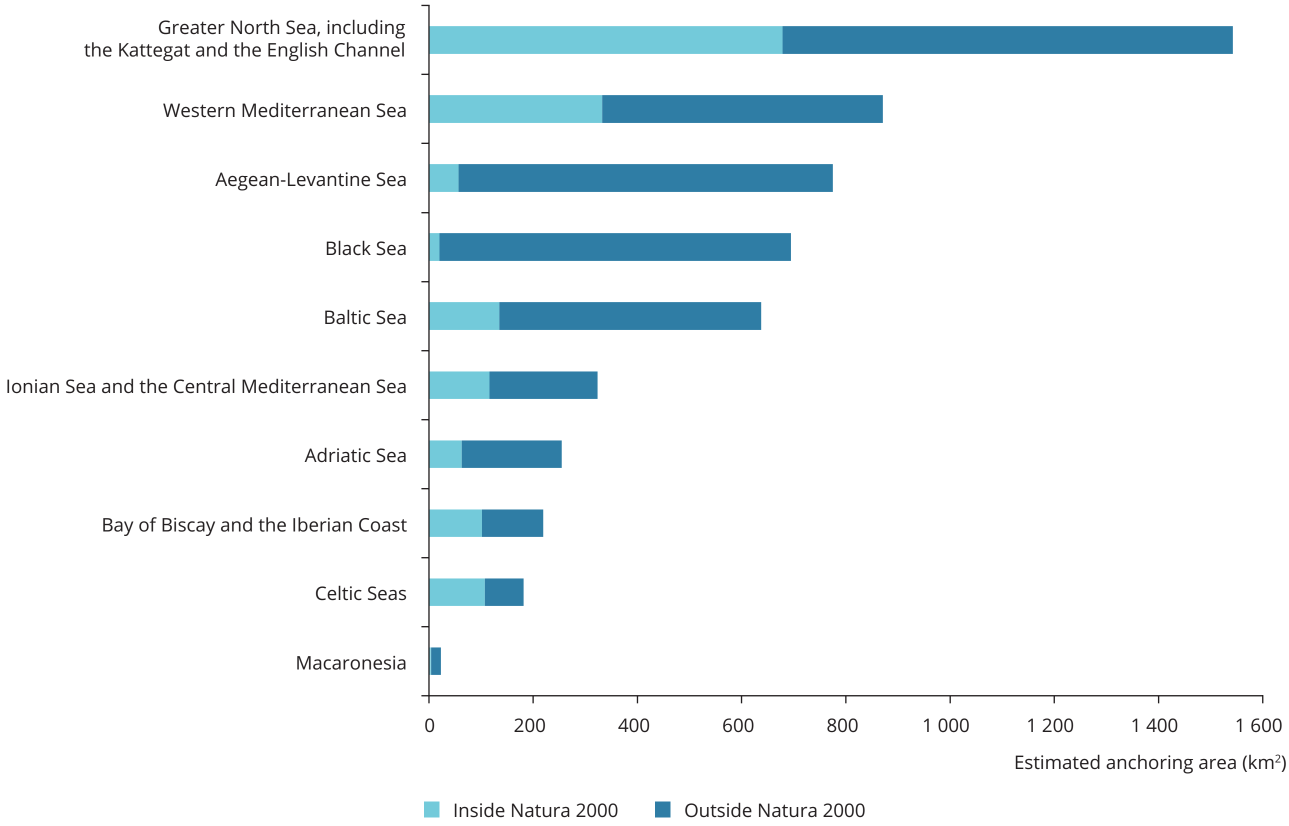
While there are no studies at the European level assessing the impact of commercial shipping on the effects of anchoring, in order to estimate the potential area of Europe's seas affected by this pressure, as well as to understand to what extent it affects the Natura 2000 network of MPAs, areas less than 100 m in depth and subject to high maritime traffic density were mapped, excluding those within 500 m of ports (to avoid areas likely being used for docking and other harbour activities). The resulting layer was overlaid with the Natura 2000 sites. The results showed that an area of only 5.522 km^2 is potentially affected by the pressure of anchoring. However, if this pressure takes place within protected areas, it can negatively affect their environment. The marine region with the largest estimated anchoring area is the North Sea, of which 44 % falls within Natura 2000 sites (Figure 4.43).

Table 4.10 Key Mediterranean species and habitats that are susceptible to disturbance by anchoring

Key species	Key habitat
Posidonia oceanica	*Posidonia oceanica* beds
Cymodocea nodosa	*Cymodocea nodosa* beds
Cystoseira spp.	Infralittoral algae
Cladocora caespitosa	Infralittoral algae
Eunicella spp.	Coral
Lophogorgia ceratophyta	Coral
Paramuricaea clavata	Coral
Pentapora fascialis	Coral
Lithothamnion corallioides	Maerl beds
Phymatolithon calcareum	Maerl beds

Source: Abdulla and Linden (2008).

Figure 4.43 Estimated anchoring area inside and outside the Natura 2000 network by marine subregion



Source: EEA (2019c, 2020e).

Permanent alteration of hydrographical conditions

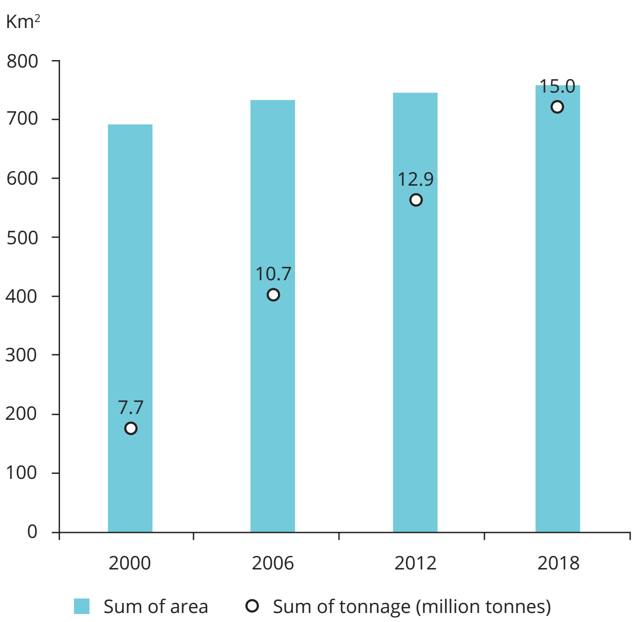
Port development has been very intense in the last two decades, contributing to a great increase in the volumes of cargo that can be handled by ports (Figure 4.44). Similarly, increasing demand for recreational craft has led to the development of more marinas.

The development of port infrastructure produces changes in the coastal morphology, with a corresponding alteration in the local hydrographical conditions and the loss of seabed habitats. It can also produce relevant changes in local currents and wave energy, which in turn affect the overall coastal ecosystems.

4.1.7 *Risk of collision of vessels with marine species*

Marine species can be directly affected by ship strikes (i.e. animals colliding with vessels; Vanderlaan et al., 2009), as well as other pressures arising from navigation that can interfere in their daily lives (e.g. underwater noise). The species most vulnerable to collisions are marine mammals and sea turtles, due to their size and their need to surface to breathe. In addition, their migration routes can overlap with shipping lanes.

Figure 4.44 Area of port development and cargo tonnage

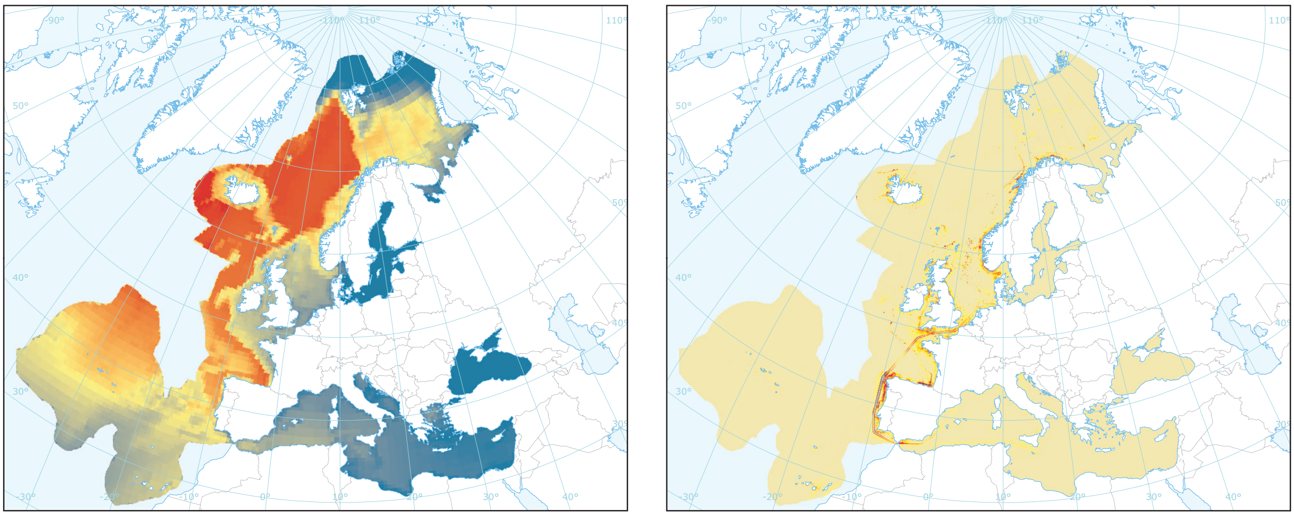


Source: EEA (unpublished data); compiled from Corine Land Cover and Eurostat data.

Ship strikes can result in the death or injury of the animals and may not even be noticed by vessel operators, as these animals are not always clearly visible from the sea surface. For this reason, information on vessel strike events is scarce, leaving considerable room for improvement in how these data are collected. In particular, data on marine mammal stranding could be an efficient way to estimate the number of collisions. However, this information is not collected in a harmonised way at the EU level.

Currently and because of the lack of relevant information, the best approach to estimating the potential impact of collisions is by calculating the risk of collision with vessels. This has been done for waters surrounding the EU using the probability of the occurrence of large cetaceans (i.e. blue whale, sei whale, humpback whale, sperm whale, fin whale and northern right whale ([5])) (AquaMaps, 2019) and by comparing this with maritime traffic density data (EMODnet, 2020b) (Map 4.8).

Map 4.8 Probability of whale occurrence (left) and collision risk index (right) in Europe's seas



Reference data: ©ESRI

Probability of whale occurrence (left) and collision risk index (right) in Europe's seas

Occurrence index
High: 5.28
Low: 0

Risk of collision index
High: 20.68
Low: 0

0 500 1 000 1 500 km

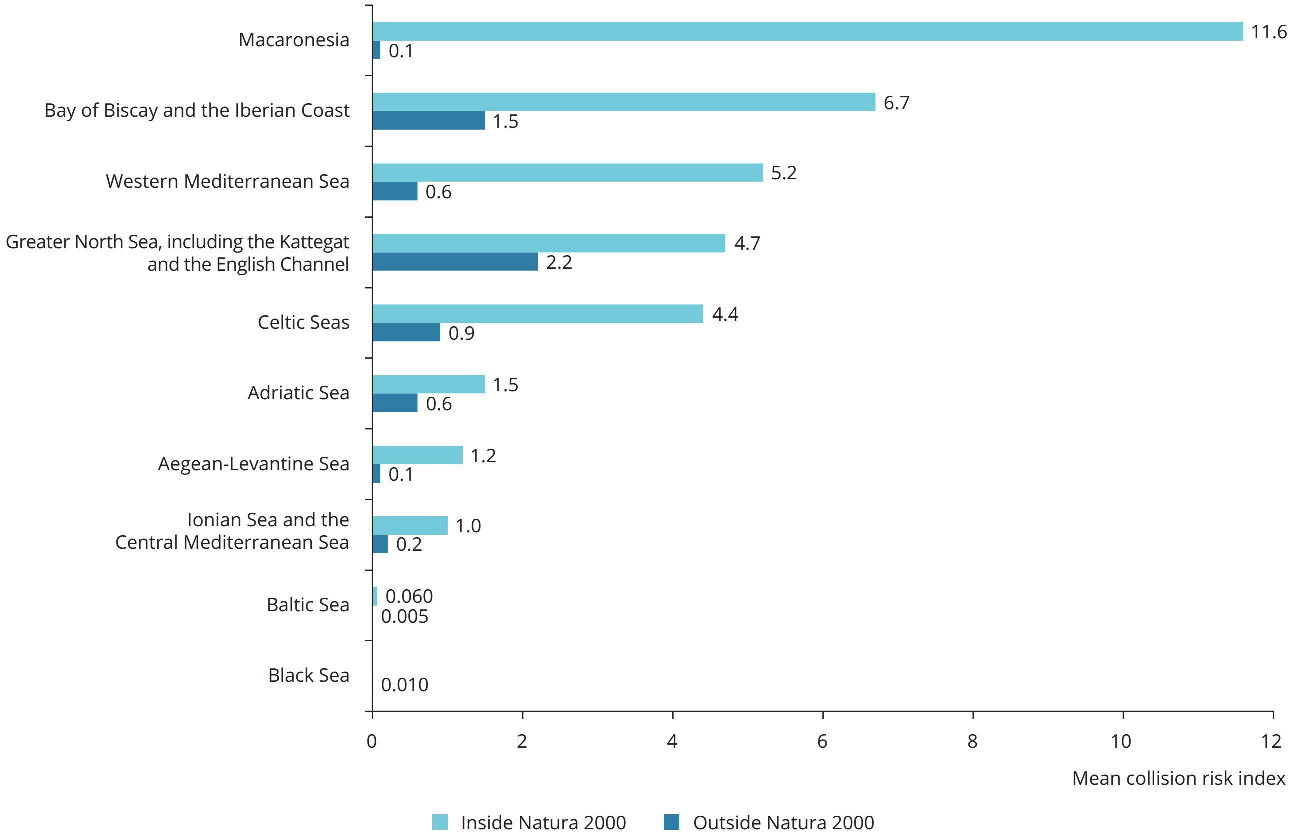
Source: Left: EEA (2020f). Right: EEA (2020g).

A mean collision risk index has been calculated for each marine region inside and outside the Natura 2000 network (EEA, 2019d). Inside Natura 2000 sites the index is calculated considering all the sites in the sea region, while outside Natura 2000 sites the index is calculated as the mean for the whole sea region. Marine Natura 2000 sites have often been designated because of the presence of marine mammals; hence, the probability of whale occurrence in the sites is generally high. Whenever there is intense marine traffic in areas with a high probability of whale occurrence, the index values are high.

The collision risk index shows that marine transport can be a risk for large cetaceans in Natura 2000 sites of the four archipelagos in the North Atlantic Ocean off the coast of the continents of Europe and Africa (i.e. Macaronesia), the Bay of Biscay and the Iberian coast, the western Mediterranean, the Greater North Sea and the Celtic Seas (Figure 4.45).

([5]) The northern right whale model only describes the range of the western population of this species, as the eastern population is probably almost extinct.

Figure 4.45 Mean collision risk index by marine subregion



Source: EEA (2020g).

4.1.8 Port activity-related pressures

Ports are at the heart of the maritime shipping industry, as they are the departure, entry and transfer points for all goods, services and people transported by ships. This section aims to provide an overview of the main activities carried out in ports, as they can affect the environment with very heterogeneous pressures and impacts. Nevertheless, the related pressures can also be categorised under air emissions or permanent alteration of the hydrographical conditions. The various related port activities can be divided into industrial or commercial and recreational or touristic.

Industrial or commercial activities may include:

- shipyards;
- use of non-road machinery and cranes;
- handling of cargoes (sand and gravel, seeds, etc.), including loading/unloading;
- shipbuilding operations;
- ships sailing into port and at berth/anchor;
- industrial activities under the Industrial Emissions Directive (e.g. refining of oil mineral and gas, gasification or liquefaction of coal and other fuels, and chemical industry);
- loading and unloading of gas and liquid bulk products and bunkering activities;
- other combustion processes;
- road traffic of heavy-duty vehicles to and from the port;
- rail traffic to and from the port area;
- river traffic to and from the port;
- dredging operations causing impacts on sediments;
- port development and use of land.

Recreational or touristic activities may include:

- fuels used by vessels and cruise liners at berth;
- passenger road traffic to and from the port;
- arrivals of a lot of passengers from a cruise ship;
- recreational vessels sailing into and out of port and road traffic to bring these people to their vessels.

All of these activities can cause local and global environmental impacts such as air pollution, GHG emissions, waste generation, noise, ship waste, local community impacts, sediment impacts, dust, water pollution, and use of land because of port development.

Monitoring and reporting of environmental performance are now well-established procedures for a number of proactive port authorities. There is a considerable amount of data that is reported on a monthly and annual basis, and monitoring means that there is an awareness of the environmental impacts that these activities have. As the port sector is very diverse, environmental control is often beyond the remit of the port authorities. To compensate for this, port authorities often incorporate monitoring tools into their environmental control systems that enable them to determine the extent to which the companies that operate in the ports are behaving appropriately from an environmental point of view.

4.2 Impacts caused by maritime transport-related pressures

Impacts on the environment are generally difficult to assess, because of the spatial and temporal observational challenges and the cost of monitoring programmes. Moreover, pressures on the environment can be cumulative and produce synergetic effects. Impacts are caused by changes in the state of the environment, which at the same time are induced by pressures arising from human activities taking place in the ecosystems. In the case of shipping, Table 4.11 reflects the main changes in the environment, that is, the state of the environment, that can be produced by maritime transport.

Table 4.11 Main changes in the environment produced by pressures related to shipping

<table>
<tr><th>Pressures</th><th>Changes in state due to pressures</th></tr>
<tr><td rowspan="3">Emission of air pollutants</td><td>Increased levels of NO_x, SO_x and PM in the air</td></tr>
<tr><td>Decreased pH of waters and soils due to sulphuric or nitric acid rain from NO_x and SO_x</td></tr>
<tr><td>Increased level of ground-level ozone</td></tr>
<tr><td>Emission of air pollutants (atmospheric deposition)</td><td>Increased levels of nitrogen in the marine environment</td></tr>
<tr><td>Emission of air pollutants (atmospheric deposition)</td><td rowspan="3">Increased levels of contaminants in the marine environment</td></tr>
<tr><td>Dumping of material dredged in ports or navigation canals</td></tr>
<tr><td>Inputs of water pollutants</td></tr>
<tr><td>Inputs of marine litter</td><td>Increased amount of litter in the marine environment</td></tr>
<tr><td>Dumping of material dredged in ports or navigation canals</td><td rowspan="2">Increased suspended matter</td></tr>
<tr><td>Wake-induced turbulence</td></tr>
<tr><td>Inputs of anthropogenic underwater noise</td><td>Masking of marine species' acoustic communication of</td></tr>
<tr><td>Pressure due to port development</td><td>Increased level of noise</td></tr>
<tr><td>Input or spread of NIS</td><td>Establishment and spread of NIS</td></tr>
<tr><td>Disturbance of species</td><td>Ship strikes (collisions with animals)</td></tr>
<tr><td>Anchoring</td><td>Abrasion</td></tr>
<tr><td>Pressures due to port development</td><td>Change seabed substrate and morphology by artificial infrastructure</td></tr>
<tr><td>Dumping of material dredged in ports or navigation canals</td><td>Burial of benthic organisms</td></tr>
<tr><td>Pressures due to port development</td><td>Permanent alteration of hydrographical conditions</td></tr>
</table>

On top of this, the emission of GHGs by the maritime transport sector contributes to climate change, representing a further threat to the marine environment and human health, producing changes in temperature, increasing CO_2 levels, decreasing the pH of waters and soils, changing the levels of nutrients and dissolved oxygen due to changes in circulation and stratification, as well as contributing to extreme weather events and sea level rise.

The changes in the state of the environment may have adverse effects on living organisms and their habitats. Table 4.12 provides an overview of the main impacts caused by the changes in the state of the environment listed in Table 4.11.

Additional information on the relationship between the pressures, state and impacts on the ecosystems caused by shipping can be found in Annex 2.

Table 4.12 Main impacts caused by changes in ecosystems induced by maritime transport

Change in state of environment	Impacts
Increased levels of NO_x, SO_x and PM in the air	Health problems in citizens living in port cities and coastal areas (diseases such as asthma, bronchitis, emphysema and cancer)
Increasing level of ground-level ozone	Direct effects on human health
	Damage to forests and crops with secondary effects on human nutrition
Increased levels of nitrogen in the marine environment	Eutrophication, proliferation of harmful algae, depletion of fish species and death of benthic organisms due to hypoxia
Decreasing pH	Adverse effects on organisms that build calcium carbonate shells or skeletons due to acidification
	Indirect effects on populations due to damage to forests, crops and aquaculture
Increased levels of pollutants in the marine environment	Changes in distribution of individuals in a population, effective population size, mutation rate and migration rate. Changes in community composition and in both taxonomic and ecological diversity. Change in ecosystem services provided
Ship strikes (collisions with animals)	Death or injury of animals
Increased suspended matter	Decrease in the abundance of organisms and number of species
Establishment and spread of NIS	Changes in the trophic chain (e.g. new predators)
	Decrease in indigenous species populations due to competition with NIS for space or food or other factors
	Introduction of new pathogens and parasites dangerous for marine organisms and human health
	Replacement of indigenous species by NIS in the area
	Introduction of new diseases to the local systems, to which indigenous species are not resistant
Increased levels of contaminants in the marine environment	Ecotoxic lethal effects: death of exposed organisms
	Ecotoxic sublethal effects: problems related to development and behaviour, as well the reproductive, nervous and cardiovascular systems of exposed organisms
	Indirect effects: marine organisms and people affected by the loss of food
Increased amount of litter in the marine environment	Entanglement of animals, which may lead to injury, illness, suffocation, starvation and death
	Litter ingested, which may lead to loss of nutrition, internal injury, intestinal blockage, starvation and death

Table 4.12 Main impacts caused by changes in ecosystems induced by maritime transport

Change in state of environment	Impacts
Masking of marine species' acoustic communication	Loss of hearing, reduction in communication, increase in stress levels corresponding to behavioural changes (e.g. changes in surfacing and breathing patterns, cessation of or change in the frequency and duration of vocalisations, change in navigation patterns, avoidance of noisy areas, change in feeding behaviour)
Abrasion	Loss of seabed habitat
Burial of benthic organisms	Decrease in the abundance of organisms and number of specie
Permanent alteration of hydrographical conditions	Impact on population leaving near the coasts due to extremes weather events

4.2.1 Impact on marine and coastal ecosystems

EU rules providing the framework for achieving good status of the marine environment (EU, 2000a, 2008b, 2014b) require EU Member States to assess the 'status' of different elements of the ecosystems (species, habitats, water bodies, etc.) and whether this 'status' is good or not (when the status is not good, it means that the particular feature assessed has been mpacted). Within these assessments, the main pressures or threats to the ecosystems must be identified. However, only the Habitats Directive requires information to be collected on the activities producing those pressures, which can therefore help identify the impacts caused by maritime transport (EU, 2014b). In addition, the MSFD provides the tools to assess the status of the marine environment and the main pressures affecting it, and the WFD assessments can be used to evaluate water quality in ports.

Impacts on marine species

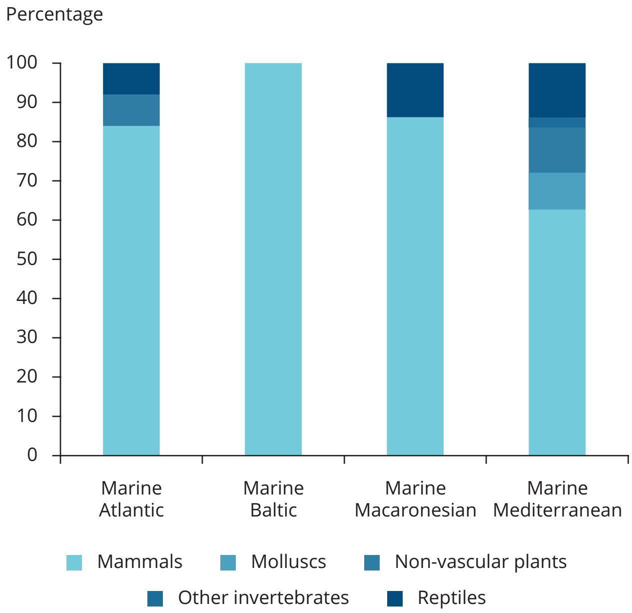
Climate change-induced modifications in the marine ecosystem produce numerous adverse effects. These include changes in organisms that build calcium carbonate shells or skeletons due to acidification; changes in the distribution, metabolism, life cycle and behaviour of species due to changes in water temperature; death of organisms due to the unavailability of nutrients and reduced levels of dissolved oxygen; changes in habitats because of changes in depth zones due to sea level rise; and damage to coastal ecosystems due to extreme weather events.

Similarly, contaminants released into the environment can also have various effects on the marine fauna, which at the individual level can range from sublethal effects (problems related to development and behaviour and to the reproductive, nervous and cardiovascular systems of exposed organisms) to lethal effects (death of exposed organisms). At the population level, contaminants can cause changes in type distribution, effective population size, mutations and migration rate. For instance, marine litter can entangle animals (especially marine vertebrates, such as fish, seabirds, turtles and mammals), possibly leading to injury, reduced mobility, strangulation, and death. The ingestion of litter can damage the intestine, affecting nutrition, which can lead to starvation and death. On the other hand, floating litter itself provides a habitat for some marine organisms, which may facilitate the spread of NIS.

Regarding the protection of species, under the Habitats Directive shipping lanes and related infrastructure have been reported as pressures or threats that can affect the conservation status of these areas. The species protected under the Habitats Directive (listed in Annexes II, IV and V) are 'species of community interest which are endangered, vulnerable, rare, endemic and requiring particular attention' (EU, 2014b).The pressures and threats related to maritime transport reported by EU Member States (2019 reporting exercise ([6])) mostly affect marine mammals (Figure 4.46).

([6]) Pressures corresponding to codes E02 (Shipping lanes and ferry lanes transport operations) and E03 (Shipping lanes, ferry lanes and anchorage infrastructure).

Figure 4.46 Percentage of reported maritime transport-related pressures and threats affecting non-bird marine species groups (excluding anadromous fish) by bioregion



Source: EEA (2019d, Article 17).

The number of pressures or threats reported per species depend on the distribution of the species and on the number of countries reporting within each region. Table 4.13 lists the species that have been reported by at least four EU countries affected by maritime transport in the Baltic Sea or Mediterranean Sea or the Atlantic Ocean or, in the case of Macaronesia, reported at least by two countries ([7]).

As presented in Table 4.13, the species most affected by shipping vary from whales to deep-diving toothed cetaceans, small toothed cetaceans (Image 4.2) and reptiles (turtles). These are all species that need to surface to breathe, and therefore they may be more exposed to ships strikes (see Section 4.1.7). Cetaceans' communication can also be masked by the underwater noise emitted by ships (see Section 4.1.3). The effects that the noise can have on marine species range from loss of hearing to a reduction in communication between individuals and a potential increase in stress levels. This can lead to behavioural changes, such as changes in surfacing and breathing patterns, cessation of or change in the frequency and duration of vocalisations, changes in navigation patterns, avoidance of noisy areas, and changes in feeding behaviour (see Annex 2).

Table 4.13 Main species affected by shipping in Europe's waters and countries that have reported maritime transport-related pressures for those species by bioregion

Species name	Atlantic	Macaronesia	Mediterranean	Baltic
Fin whale (*Balaenoptera physalus)*	ES, FR, IE, PT,	ES, PT	ES, FR, IT	
Sperm whale (*Physeter macrocephalus*)	ES, FR, IE, PT	ES, PT	EL, ES, FR, IT	
Harbour porpoise (*Phocoena phocoena*)	DE, DK, ES, PT, SE			DE, DK, PL, SE
Loggerhead turtle (*Caretta caretta*)	ES, PT	ES	ES, HR, IT	
Curvier's beaked whale (*Ziphius cavirostris*)	ES, FR, IE	ES, PT	ES, FR	
Striped dolphin (*Stenella coeruleoalba*)	ES, PT	ES		ES, IT, MT
Minke whale (*Balaenoptera acutorostrata*)	DK, FR, IE	PT		
Bottlenose dolphin (*Tursiops truncatus*)	PT			HR, IT, MT
Gervais's beaked whale (*Mesoplodon europaeus*)		ES, P		
Blainville's beaked whale (*Mesoplodon densirostris)*		ES, PT		
Bryde's whale (*Balaenoptera edeni*)		ES, PT		

Note: DE, Germany; DK, Denmark; EL, Greece; HR, Croatia; IE, Ireland; IT, Italy; MT, Malta; PL, Poland; PT, Portugal; SE, Sweden.

Source: EEA (2019d, Article 17).

([7]) Macaronesia is a collection of four archipelagos in the North Atlantic Ocean off the coast of the continents of Europe and Africa. The Macaronesian islands belong to three countries: Cabo Verde, Portugal, Spain. The three European archipelagos (i.e. not including Cabo Verde) constitute a unique biogeographic realm: the Macaronesian region.

Image 4.2 Examples of species affected by shipping in Europe's waters: harbour porpoise (left); sperm whale (right)

Source: Left: © Colin Knowles (CC BY-NC 2.0). Right: © Chelsea Leven (CC BY-NC 2.0).

Impacts on habitats

Shipping lanes and related maritime infrastructure are considered under the Habitats Directive as pressures or threats that can affect the conservation status of marine habitats. The habitat types listed in the Habitats Directive (Annex I) are 'natural habitat types of community interest whose conservation requires the designation of special areas of conservation'.

EU Member states have reported that habitats that are facing the greatest number of pressures or threats due to maritime transport (2019 reporting exercise ([8])) are estuaries, large shallow inlets and bays and sandbanks that are always partly covered by seawater (Figure 4.47). This is the case partly because estuaries, bays and shallow areas are sheltered from waves and wind, which makes them good locations for ports. Maritime transport activities that are frequent in those areas could therefore contribute to further degradation of the listed habitats. It should be noted that the number of pressures reported per habitat depends on the distribution of the habitat and the number of countries reporting within each region.

One of the MSFD's objectives is to ensure that the permanent alteration of hydrographical conditions does not adversely affect marine ecosystems. EU Member States have to assess and monitor the spatial extent and distribution of permanent alterations of hydrographical conditions (e.g. changes in wave action, currents, salinity, temperature), as well as the spatial extent of each benthic habitat type that may be adversely affected (physical and hydrographical characteristics and associated biological communities) by these alterations.

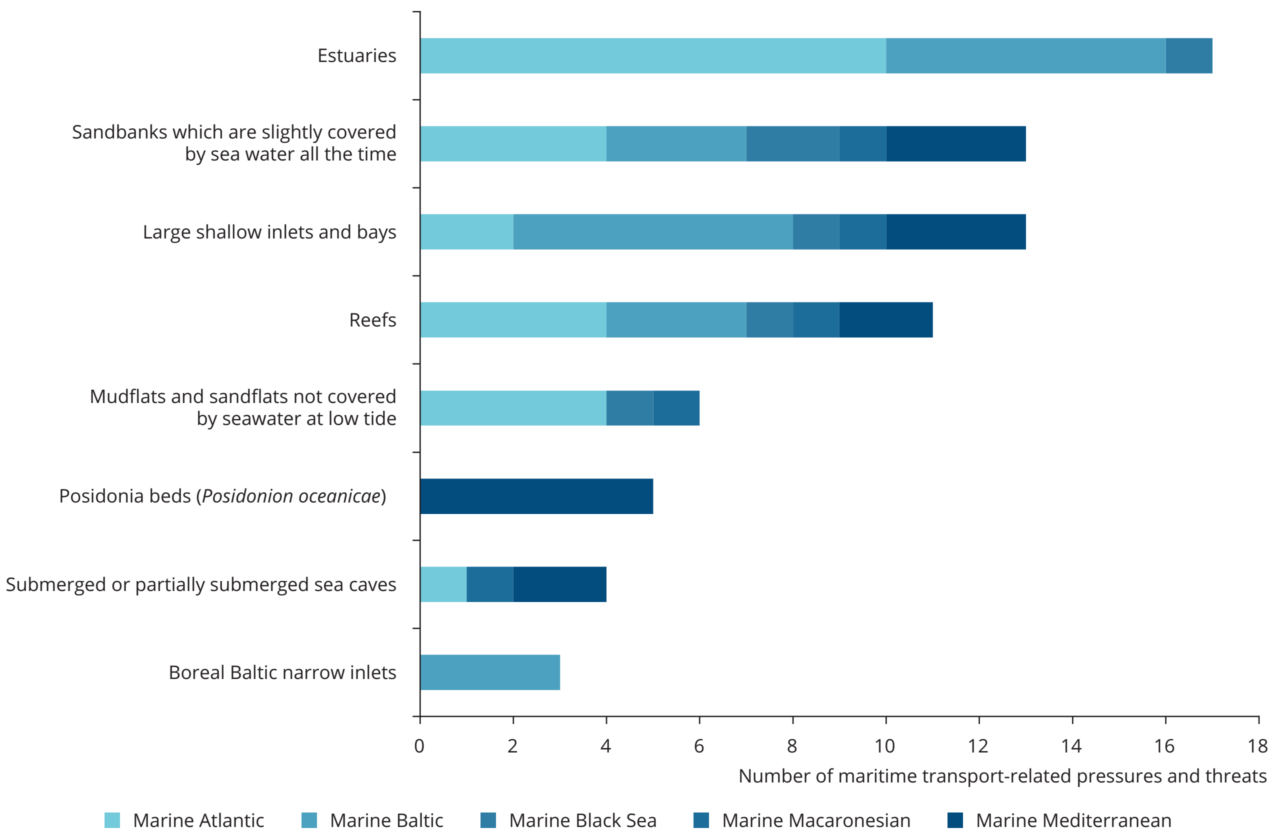
([8]) Pressures corresponding to codes E02 (Shipping lanes and ferry lanes transport operations) and E03 (Shipping lanes, ferry lanes and anchorage infrastructure).

As a result of the changes in coastal marine currents, port infrastructure can alter sediment dynamics and transport along the coast and cause erosion and accretion processes along the shoreline. Frequently, sand tends to accumulate on the upstream side of the harbour and stops accumulating downstream. For those beaches affected by a decrease in sediment accumulation, beach nourishment projects are needed to compensate for the resulting impact, for example by moving the accumulated upstream sand to the beach downstream through mechanical means.

By analysing coastal behaviour data (EMODnet, 2019a) within 10 km from the trans-European transport network (TEN-T) ports, changes in shorelines predominantly caused by port developments are found in different countries. Figure 4.48 shows that, while in countries such as Spain, Romania and Ireland the changes in shorelines reflect mainly accretion processes, in countries such as Latvia and Cyprus erosion is predominant.

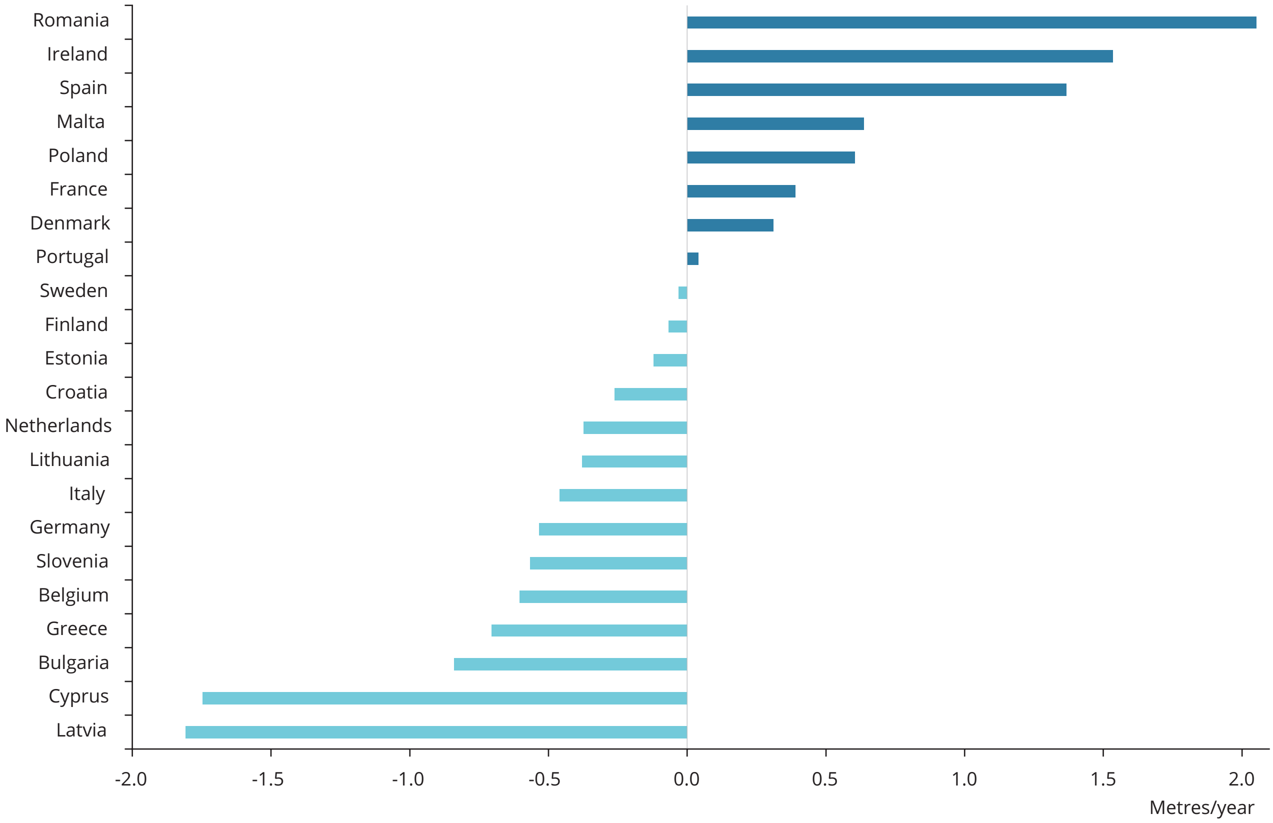
Coastal habitats, which may be affected by port developments, are also among the most productive and vulnerable ecosystems, as they are the interface between freshwater and marine waters. Overall the development of new ports, or the enlargement of existing ones, does not lead to large-scale impacts, but rather to small and localised effects, which are subject to rules on environmental impact assessment (under the Strategic Environmental Assessment Directive (EU, 2001) and Environmental Impact Assessment Directive (EU, 2011).

Figure 4.47 Number of maritime transport-related pressures and threats reported by habitat



Source: EEA (2019d, Article 17).

Figure 4.48 **Rate of change in shoreline within 10 km distance from the TEN-T ports**



Source: EMODnet (2019a); EEA (2020h).

Impacts on water bodies

Water quality monitoring is generally conducted by national, regional or municipal environmental agencies; nevertheless, in ports it can also be performed by port authorities. Monitoring usually consists of measurements of contaminants and other physical-chemical parameters in water and sediments but may also include the monitoring of biological elements such as phytoplankton and benthic macroinvertebrates. The main water quality issues are those caused by semi-closed water flow regimes in ports. One of the main reasons for the accumulation of pollutants in port environments is the fact that the water in port areas may receive different types of discharges, and that the residence time of this water is often high (the water circulates slowly until it gets out of the port).

Ports are connectivity nodes for ships and other supply chain operators and are therefore subject to high pressures with regard to water pollution from maritime transport. In many cases ports also function as industrial clusters and may therefore have high levels of industrial discharge. However, these discharges fall within the scope of the WFD and consequently the water quality in ports is subject to the environmental objectives defined under this law. The main objective of the WFD is to have all water bodies in Europe with a good ecological and chemical status by 2027 (EU, 2000a).

Trans-European transport network (TEN-T)

TEN-T consists of a network of railways, roads, airports and water infrastructures that aims to harmonise the EU's social, territorial and economic cohesion (EU, 2013b). The TEN-T is built on a twolayer system. The basal layer, the comprehensive network, includes the existing transport infrastructure in all European regions, while the overlapping layer, the core network, is a subset of the basal layer and represents the main strategic nodes of the TEN-T from a traffic perspective. Core network infrastructure should meet some specific requirements, for instance core maritime infrastructure should ensure the availability of alternative clean fuels (EU, 2013b). At present 286 European ports meet the requirements defined by the guidelines for the TEN-T's development (EU, 2013b), and the core ports layer is defined by 89 ports (EC, 2014).

According to the WFD, and based on the river basin management plans that have been adopted or updated, EU Member States have to report the assessment of the ecological and chemical status of their water bodies every 6 years to the European Commission. The data reported by EU Member States on water bodies surrounding the TEN-T ports show little improvement in terms of their ecological and chemical status between 2010 and 2016 (next reporting exercise will be in 2022). While in the core network only around 15 % of water bodies meet the good ecological status criteria, in the comprehensive network more than 30 % of water bodies achieve the criteria. Regarding the chemical status, approximately 50 % of the core ports meet good chemical status criteria. The data reported also show that most of the comprehensive ports achieve good chemical status. Further to this, the proportion of water bodies with an unknown status has decreased, and therefore confidence in status assessments has grown (see Figures 4.49 and 4.50).

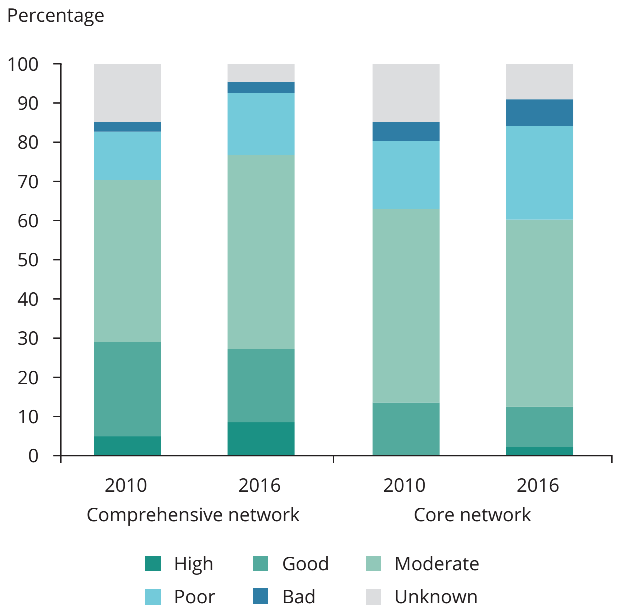
This is in line with the overall conclusion for all water bodies assessed under the Directive, where only around 40 % of surface waters (rivers, lakes and transitional and coastal waters) meet good ecological status criteria, and 38 % meet good chemical status criteria (EEA, 2018).

4.2.2 Impact on human health

The main air pollutants associated with health impacts on the population are SO_x, NO_x, PM (including black carbon) and ozone. Air pollutants can have several cumulative effects on human health. SO_x and NO_x have direct impacts on health and furthermore undergo different chemical reactions in the atmosphere that lead to the formation of fine particles known as sulphur and nitrogen aerosols. These fines particles, along with PM, can enter the lungs and then pass into the blood system causing damage to various organs and eventually lead to premature death (WHO, 2018a). The effect of air pollutants on human health have been investigated in many studies (Andersson et al., 2009; Barregard et al., 2019; Nunes et al., 2020).

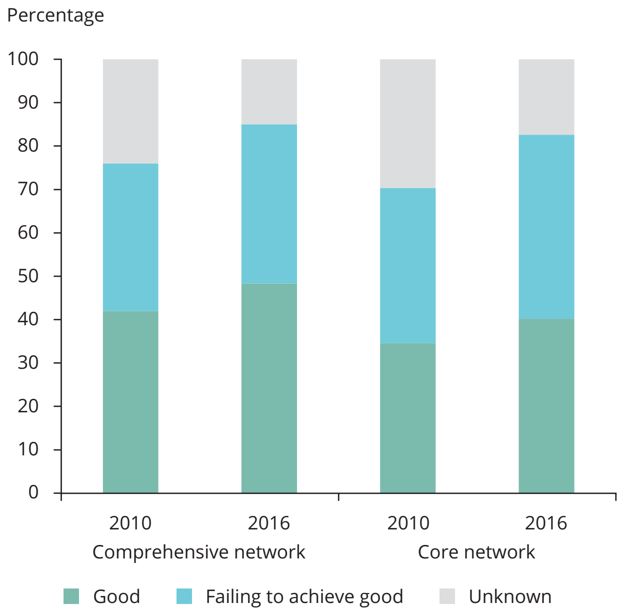
NO_x chemical interactions with volatile organic compounds (VOCs) are also responsible for the formation of ground-level ozone. This natural gas plays a fundamental and positive role in human health, acting as barrier against harmful ultraviolet radiation. However, when ozone forms just above the Earth's surface, it is associated with several respiratory conditions. Table 4.14 presents an overview on the effect of air pollutants on human health.

Figure 4.49 Ecological status or potential of water bodies where ports from the TEN-T core and comprehensive networks are located (2010 and 2016 river basin management plans)



Source: Compiled from EEA Services data.

Figure 4.50 Chemical status of water bodies where ports from the TEN-T core and comprehensive networks are located (2010 and 2016 river basin management plans)



Source: Compiled from EEA Services data.

An EEA air quality report estimates that in 2018, the exposure to $PM_{2.5}$, NO_2 and ozone from all sources caused up to 450 000 premature deaths per year in the EU-27 and UK population (379 000 deaths due to $PM_{2.5}$, 54 000 deaths due to NO_2 and 19 400 deaths due to ozone) (EEA, 2020i).

At global level, low air quality due to international maritime transport contributes to approximately 60 000 deaths annually. The highest mortality rates, associated with high concentrations of shipping-related PM, are seen in Asia and Europe (Corbett et al., 2007). Indeed, considering that almost 40 % of the European population lives within 50 km of the sea, ship emissions have the potential to reach the shoreline and adversely affect a large percentage of people living near the coast.

The introduction of SO_x and NO_x ECAs, if implemented in all EU seas, have been estimated to prevent 15 000 premature deaths caused by emissions from maritime transport in Europe by 2050, with one third of those prevented deaths being in EU Member States (Cofala et al., 2018). The largest improvements in air quality resulting in health benefits would be seen before 2030, particularly by the population around the Mediterranean Sea (Cofala et al., 2018). The 'designation of the Mediterranean Sea as an ECA would reduce SO_2 and NO_x emissions from international shipping by 80 % and 20 % respectively', preventing up to 4 100 and 10 000 additional premature deaths in 2030 and 2050 respectively (Cofala et al., 2018).

Noise from ships' activities in ports also has a negative impact on health and well-being. Although the levels of noise generated by transport sources are generally too low to cause biological damage to the ear, it is well established that noise can lead to non-auditory health effects if exposure is long term and exceeds certain levels. This can manifest itself in annoyance, sleep disturbance, negative effects on the cardiovascular and metabolic system, and cognitive impairment in children (WHO, 2018b).

The Noise exploration program to understand noise emitted by seagoing ships (Neptunes, 2019) identified that the areas of a ship that produce the most noise include the exhaust funnel outlet of the auxiliary engines; ventilation openings such as air conditioning for state rooms and the engine room; pumps on deck; public address systems; horns; compressors; generators; and ramps. Most nuisance perceived by residents living near ports is caused by low-frequency noise caused by the funnel exhaust from the auxiliary engines unless they are fitted with effective silencers (Neptunes, 2019). However, ship-generated noise and its perception is complex and depends on numerous factors (Neptunes, 2019), such as the size of the port, number of ships calling, type of ship, equipment on board the ship, meteorological conditions and topography, and distance of residents from the port/berth side.

Table 4.14 Air pollutant effects on human health

Air pollutant	Description	Effect on human health
Carbon monoxide	A toxic gas caused by incomplete combustion	Behavioural effects
SO_x	SO_x are produced as result of the combustion of marine fuel containing sulphur	Effects on the respiratory system and the functions of the lungs Irritation of the eyes Inflammation of the respiratory tract Aggravation of asthma and chronic bronchitis
NO_x	NO_x are various compounds formed during the combustion process in the ship's main engines from nitrogen and oxygen precursors. They can form the secondary products ground-level ozone and PM	Respiratory illness such us emphysema, asthma and bronchitis; reduced lung function
PM	Inhalable particles, produced as a result of various combustion processes on board	Respiratory infections, cardiovascular disease, chronic obstructive pulmonary disease, lung cancer
Ground-level ozone	Ozone is a secondary colourless gas produced from the reaction between NO_x and non-methane volatile organic compounds (NMVOCs)	Breathing problems, asthma, reduced lung function, lung diseases

Source: WHO (2018a).

5 Navigating towards sustainability

Starting in the second half of the 20th century, measures have been put in place to mitigate the various pressures from maritime transport on the marine environment in order to reduce their impact. These efforts have been driven by the adoption of more stringent standards at international and EU levels. Looking ahead, the maritime transport sector continues to evolve, becoming more sustainable and responding to current environmental challenges such as air pollution or carbon emissions. This chapter presents an overview of current and long-term efforts to improve the sustainability of maritime transport.

5.1 Emission abatement methods

Maritime transport has traditionally relied on the use of conventional fossil fuels. However, regulatory developments aiming to reduce air emissions, including air pollutants, and the need to contribute to greenhouse gas (GHG) reductions have led to exploring the use of low-sulphur or emission technologies, alternative or low-carbon fuels and other sustainable fuel and energy-efficient technologies.

The use of emission abatement methods (EAMs) as an alternative to conventional marine fossil fuels is referred to in EU law (EU, 2016b), where they are defined as any fitting, material, appliance or apparatus to be fitted to a ship or another procedure, alternative fuel or compliance method, used as an alternative to low-sulphur marine fuels. EAMs are also regulated at international level (MARPOL Annex VI, 2006).

However, when considering the various EAMs, a life cycle assessment (LCA) is needed to assess their environmental sustainability and carbon footprint performance. Life cycle assessments allow the evaluation of the environmental performance of a product throughout its whole life cycle from raw material extraction, through production and use to end-of-life treatment and final disposal.

This chapter provides an insight on some currently available alternative fuels and technologies as well as insights into the further development of some novel fuels in maritime and energy solutions aiming to decarbonise the shipping sector and leading to zero emissions.

The table in Annex 3 provides a summary of some of the advantages and disadvantages identified for different EAMs (i.e. alternative fuels, technologies, exhaust gas cleaning systems and energy solutions). However, it needs to be noted that the advantages and disadvantages listed might not be comprehensive or applicable in all scenarios and that it will depend on the particular ship, operation and route.

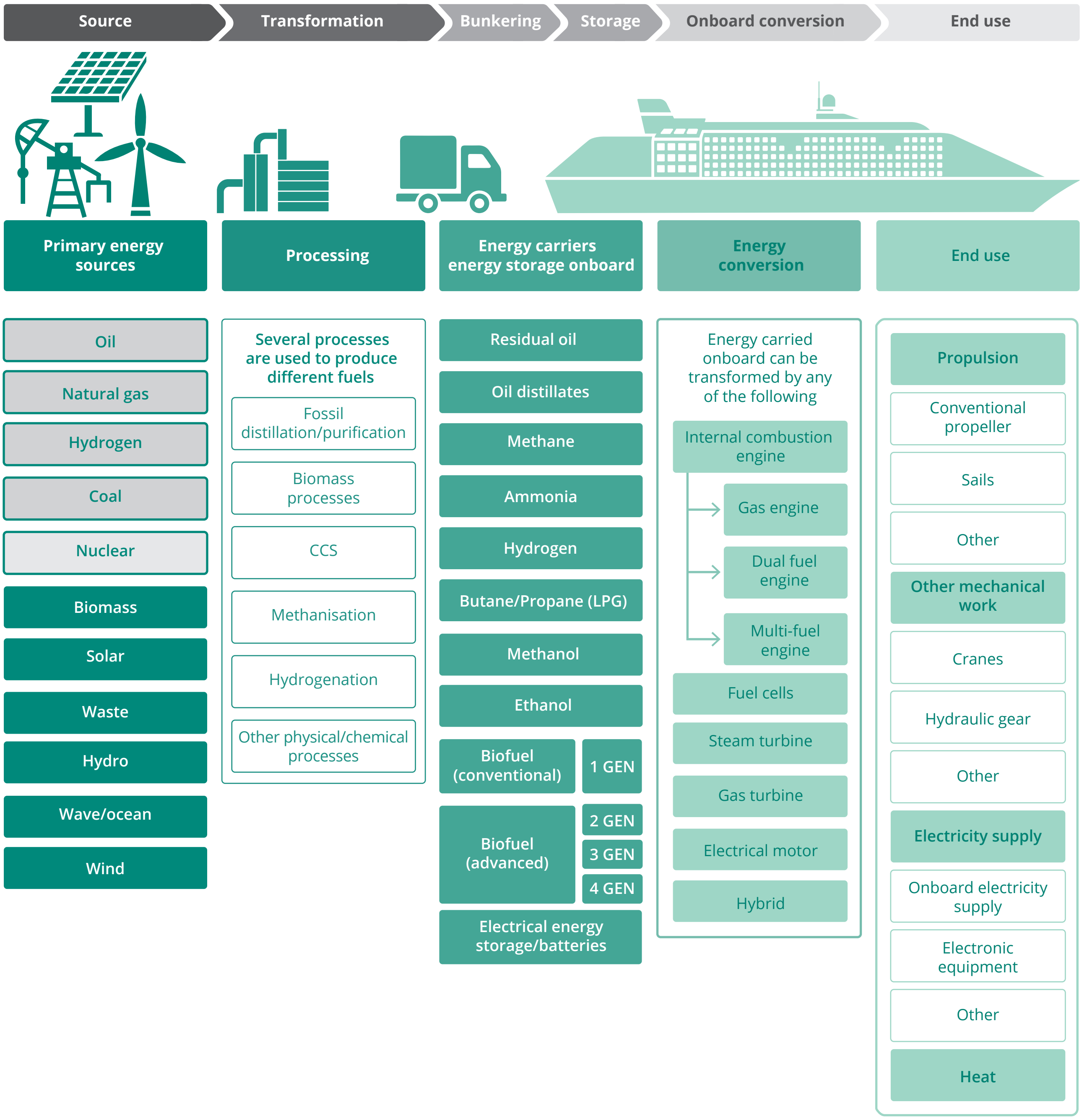
Life cycle assessments (LCAs)

An LCA of the greenhouse gas (GHG) emissions related to fuels could be developed for the following: tank-to-wake (TTW) related to the total emissions from combustion on board a ship and potential leakage; well-to-tank (WTT) related to the total emissions of extracting raw materials and producing and transporting the fuel; and well-to-wake (WTW) related to the total carbon footprint of a fuel as a sum of TTW and WTT. As part of the International Maritime Organization GHG strategy, work is under way to develop a methodology for LCA and calculating the WTW GHG emissions of different fuels used on board ships and the criteria to assess their sustainability. An LCA also considers the emissions involved in the production of the energy carrier as opposed to a WTW analysis.

5.1.1 Alternative fuels and energy technologies

Several existing alternative fuels and energy technologies today have the potential to decarbonise shipping and lead to zero emissions. There are, however, different pathways for fuel production, with different sustainability impacts. The same molecule may have different sustainability impacts depending on its source (fossil, biological, renewable, synthetic). For example, performing a well-to-wake (WTW) analysis on carbon dioxide equivalent (CO_2e) emissions may result in significantly different environmental impacts, depending on ship and fuel type. Provided that the safety aspects are duly addressed, ships are capable of using a wide variety of fuels, individually, blended or in combination (dual fuel) depending on the engine or the energy converter on board (IMO, 2010). In 2018, over 95 % of the fuel mix used by maritime transport corresponded to high- and low-sulphur conventional fuels (EC, 2019b).

Figure 5.1 Different possible paths for alternative fuels or power for ships, from primary source to end use



Note: CCS, carbon capture and storage; GEN, generation; LPG, liquefied petroleum gas.

Source: EMSA (2021).

Liquefied natural gas

For more than 40 years, liquefied natural gas (LNG) carriers have been using the natural gas cargo vapours as fuel to propel the ship. This translated into the recognition of LNG as an alternative fuel for this type of ship, initially while at berth and under certain conditions during navigation. In 2018, the use of LNG by ships in the EU represented only 3 % of the total amount of fuel consumed (EC, 2019b).

Current technologies that make use of LNG as fuel include gas-only engines and dual-fuel four-stroke and two-stroke diesel engines (BMVI, 2011; IMO, 2020a).

Natural gas in tanks

Natural gas is stored as a cryogenic liquid (i.e. liquified natural gas, LNG) to achieve greater volume reductions as opposed to compressed natural gas (CNG). The temperature required to condense the natural gas represents a challenge for its storage on board. It depends on the precise composition of the gas, but it is typically between -120 °C and -170 °C.

The use of natural gas as fuel substantially reduces the air pollutants sulphur oxides (SO_x), particulate matter (PM; up to 90 % reduction) and nitrogen oxides (NO_x; up to 80 %) compared with traditional fossil fuels. As a fraction of PM, the use of LNG would also imply reductions in black carbon (BC) emissions (IMO, 2015a). Regarding the potential contribution to GHG reductions, on a WTW analysis, LNG has been reported to reduce GHG emissions by up to 9-15 % compared with low-sulphur fuels if used in high-pressure dual-fuel diesel engines preventing methane slips (i.e. marine gas oil, MGO) (Lindstad, 2020).

A challenge in the use of LNG as fuel relates to the methane slip, which is the unburnt gas that leaks from the engines in addition to that leaked during production and distribution. Methane has a much bigger GHG effect than CO_2 (global warming potential over 100 years (GWP100) 30 times higher and global warming potential over 20 years (GWP20) 85 times higher). Levels of methane slip vary with engine type and operating mode and have not been systematically measured in service. In high-pressure dual-fuel engines, the combustion is nearly complete with nearly zero methane slip. However, this might not be the case in low-pressure engines where LNG is injected under low pressure, which has been reported to result in an increase in GHG emissions of between 15 % and 40 % compared with using low-sulphur fuels (i.e. MGO) (Lindstad, 2020).

Global warming potential (GWP)

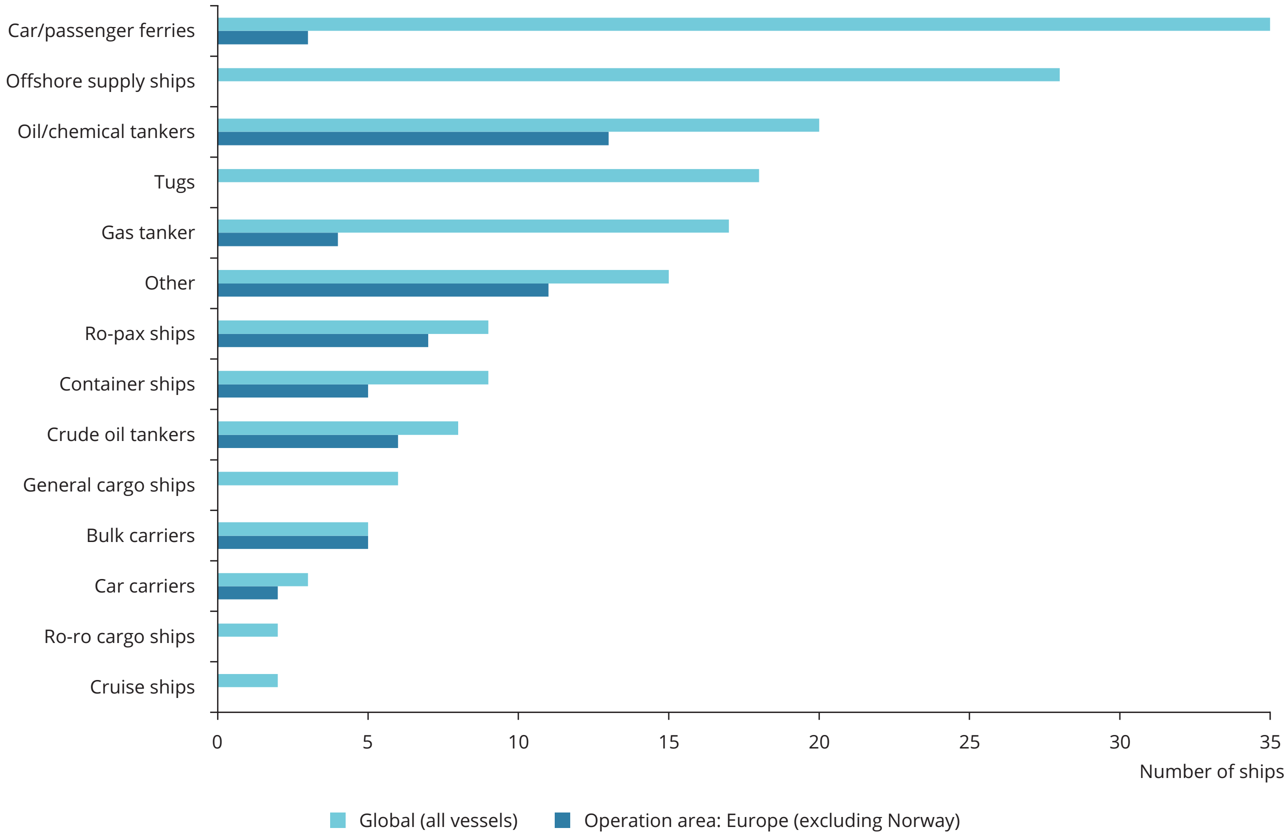
GWP metrics are used to assess contributions to climate change. GWP metrics allocate negative weights to exhaust gases and particles that have a cooling effect and positive weights to those that have a warming effect. GWP usually refer to periods over 20 or over 100 years. GWP20 measures the effect over 20 years and gives a relatively high weight on short-lived greenhouse gases such as methane. In contrast, GWP100 gives a larger weight to CO_2, which resides much longer in the atmosphere (Shine, 2009).

Conversely, other studies point to low-pressure LNG fuelled engines achieving WTW GHG reductions of up to 21 % compared with low-sulphur fuels (Bell, 2019; Sphera, 2020).

The use of LNG as a fuel could represent a transitional alternative, particularly in short-sea shipping and ship types such as LNG carriers. For container ships, LNG could be viable as an option in dual-fuel engines for specific routes in combination with creating the related LNG bunkering infrastructure (Clarkson Research Services Limited, 2021). LNG ready ships can also use liquefied biogas (LBG) or liquefied synthetic gas (LSG) as fuels. LBG and LSG can also be mixed with LNG, and these alternatives would have the advantage that the technology and infrastructure is already available. Dual-fuel engines can be further retrofitted to use other types of fuels (Tan, 2021).

Figure 5.2 provides an overview of the ships in service worldwide, and the share of ships under an EU flag, using or ready to use LNG as a fuel.

Figure 5.2 Number of LNG-fuelled ships operating globally and in the EU up to May 2020



Note: Ro-ro, roll-on, roll-off; Ro-pax, roll-on, roll-off passenger (ships).

Source: EAFO (2019a).

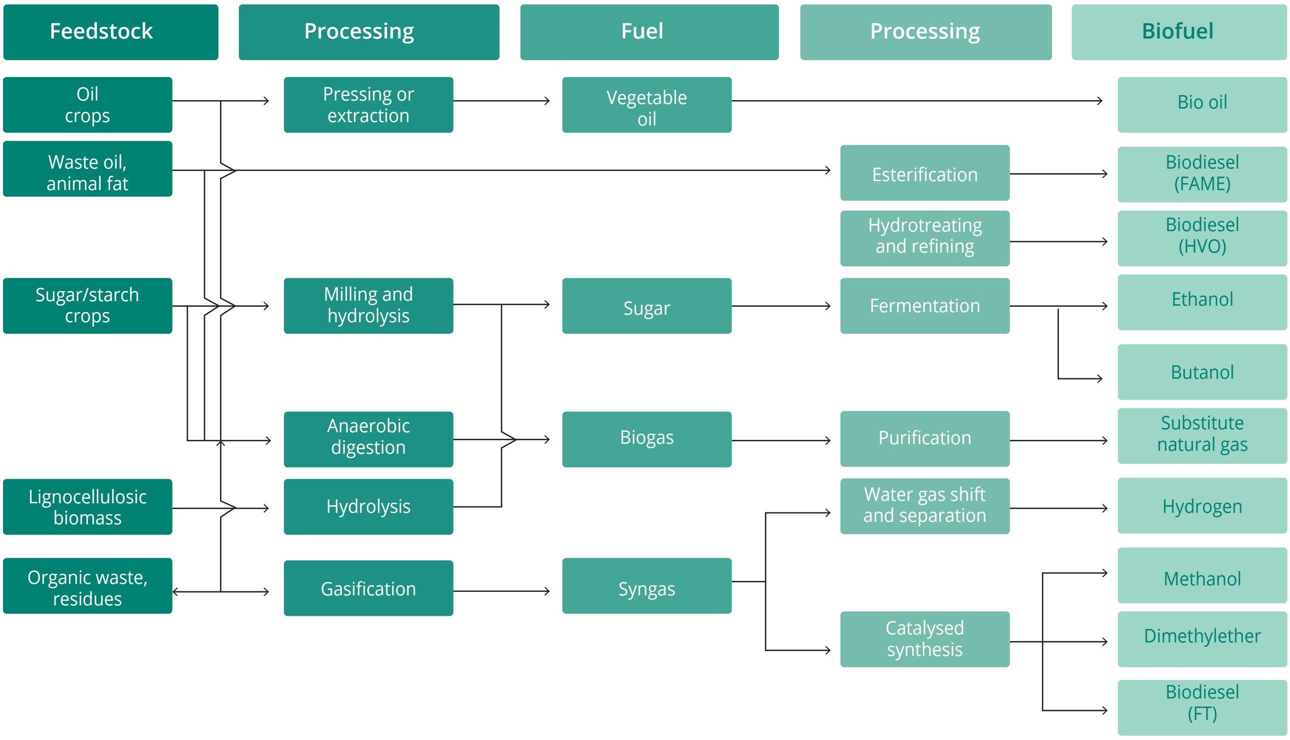
Biofuels

Biofuels are fuels that are derived from feedstock resources such as oil and sugar crops, forest or agricultural residues or algae (i.e. biomass) (EU, 2018). These feedstocks undergo several processes before being converted into a biofuel. Of the various biofuels, biodiesel can be used as a substitute for MGOs, marine diesel oils and other marine fuel oils in low- to medium-speed diesel engines, which are normally installed on tugboats, small carriers or cargo ships. However, they are currently more commonly used as a fuel additive and are poured directly (drop-in) into blended fuels. The use of biodiesels (i.e. fatty acid methyl ester or FAME) in automotive diesel engines has been shown to reduce SO_x, carbon monoxide and unburned PM emissions. Second-generation biofuels, such as hydrotreated vegetable oils (HVOs), are growing in importance in the maritime fuel mix.

Different generations of biofuels

Despite the differences involved in the various processes for production of biofuels, a key factor to assess the sustainability of biofuels is the feedstock resource to be used. The first-generation volumes of biofuels have been mostly from food and sugar crop-based resources whereas the second generation was produced from biomass resources such as wood and organic waste. Third generation biofuels could be produced from sustainably cultivated organic materials such as algae, though to date there is no commercial algae plant for biofuel production in use. Future fourth generation biofuels could involve a combination of biomass with carbon dioxide capture and storage techniques.

Figure 5.3 Different biofuels and their process pathways



Source: Florentinus et al. (2012).

As biomass is a renewable fuel source, biofuels produced from it could in theory be considered carbon neutral. This line of reasoning derives from the fact that CO_2 is considered to have been first absorbed during plant growth, resulting in no net change in atmospheric carbon. However, on a WTW analysis, biofuel's actual GHG contribution depends very much on the type of plant or waste from which it is made. There are also several sustainability criteria set out at EU level that must be fulfilled to ensure that biofuel production does not compete with conventional agriculture for food crops, arable land, fertilisers, water, etc. (see EU, 2018, Article 29). Consideration should also be given to the potential GHG emissions caused by changes in the use of land. Although the uptake of biofuels in the maritime transport sector is currently limited, marine biofuels may be produced using existing biofuel technologies that are technically compatible with marine engines. Consideration should be given to the feedstock available for the production of marine biofuels, which may limit their proportion in the future energy mix used by maritime transport (DNV GL, 2020a). Figure 5.3 presents the different possible pathways for producing different biofuels that have a potential use in shipping (Florentinus et al., 2012). Furthermore, EU laws set strict limits on the biofuels produced from food and feed crops (EU, 2018).

Ethyl and methyl alcohols

Ethyl and methyl alcohols are liquid fuels that can be used in existing internal combustion engines, subject to some modifications, and potentially in fuel cell applications.

Methanol can be produced from many different feedstocks, such as fossil natural gas, coal, farmed wood, wood waste and even CO_2 combined with electricity from renewables. The chemical composition remains the same, regardless of the source (IMPCA, 2015). Methanol is relatively easy to store and handle, and it is already being produced on a commercial scale from natural gas. Ethanol, on the other hand, is mainly produced through the fermentation and distillation of biomass containing sugar or starch, such as maize, sugar cane or wheat) (IRENA, 2013).

Methanol and ethanol do not contain sulphur and are relatively pure substances that are expected to produce very low PM emissions during combustion. In laboratory testing, a reduction in SO_x emissions of up to 99 % and in NO_x emissions of 60 % have been reported (Ellis and Tanneberger, 2015).

As ethanol is produced from biomass, it could in theory be considered a carbon-neutral fuel. However, most of the methanol available on the market is produced from natural gas. Therefore, methanol produced using natural gas as a feedstock has well-to-tank (WTT) emissions like other fossil fuels such as LNG or marine diesel oil. Bio-methanol produced from second-generation biomass such as waste wood has a much lower global warming potential than fossil fuels. Using WTW analysis, emissions from ethanol may be lower than from traditional fossil fuels, although their amount varies with production methods and feedstock (Ellis and Tanneberger, 2015). Ethanol (and methanol) produced using hydrogen combined with biogenic or atmospheric CO_2 and using renewable energy have the potential to be almost carbon neutral.

Alcohol as a fuel

Methyl alcohol (methanol, CH_3OH, often abbreviated as MeOH) is the simplest of the alcohols. A colourless, flammable liquid at ambient temperature, it is widely used in the chemical industry. Industrial grade methanol is commonly provided 99.85 % pure on a weight basis (Ellis and Tanneberger, 2015). Ethyl alcohol (ethanol, C_2H_5OH, often abbreviated as EtOH), is a colourless, flammable liquid with major uses, including as a solvent, fuel additive or fuel. According to European Standard EN 15376, ethanol as a blending component of petrol in the EU must contain 98.7 % ethanol and higher levels of saturated alcohols.

Hydrogen

Hydrogen (H_2) as an alternative fuel can be used on board ships using two separate energy conversion technologies: fuel cells or in internal combustion engines. In fuel cells, H_2 is combined with oxygen in a process that is the reverse of electrolysis. As a result of the exothermic electrochemical reaction, both heat and water are by-products of electricity generation. No air pollutant emissions are formed during this process. In an internal combustion engine, H_2 can be burned in the presence of air in the same way as traditional fuel oils or LNG, but in this case the combustion will produce NO_x as one part of the exhaust gas stream.

H_2 can be produced from natural gas through steam methane reforming and from coal through charcoal gasification. Sustainable H_2 can be produced through electrolysis, the process of running an electric current through water, thereby splitting water molecules into oxygen and H_2. If a renewable source of electricity is used, electrolysis is an almost carbon-free process. However, electrolysis is very energy demanding, which renders the production of green H_2 an inefficient and costly process. Water splitting using high-temperature, photobiological and photoelectrochemical processes are potential techniques for producing H_2 in future, which can make use of renewable energy sources (ITF, 2018; ABS, 2019). Figure 5.4 identifies the various possible routes for producing H_2.

Gaseous and liquid hydrogen (H_2)

Gaseous H_2 has a very high energy content by mass, but it is a very light gas with 1 kg occupying 5.4 m³ at standard temperature and pressure. Therefore, it results in a very low energy density. A large amount of storage space would be needed for gaseous H_2. Liquid H_2 reduces the storage space needed but requires extremely low temperatures (-253 °C) and pressures, still resulting in a relatively low energy density. Therefore, the high energy content of H_2 by mass is penalised by its low volumetric energy density.

H_2 can be considered a zero-carbon fuel with no carbon emitted when converted to electrical energy in fuel cells or mechanical energy in an internal combustion engine. The combustion of H_2 does not produce any GHGs — only water and energy. This means that it will be its WTT emissions alone that will make up its total WTW emissions. In a WTW analysis, if H_2 is produced from natural gas or through steam methane reforming or electrolysis from the mix of fuels used to produce electricity in the EU, the GHG emissions exceed the total emissions of conventional fuels. However, if the electricity used to produce H_2 is green, the corresponding GHG emissions are reduced by more than 85 % compared with those of conventional fuels (Lindstad, 2020).

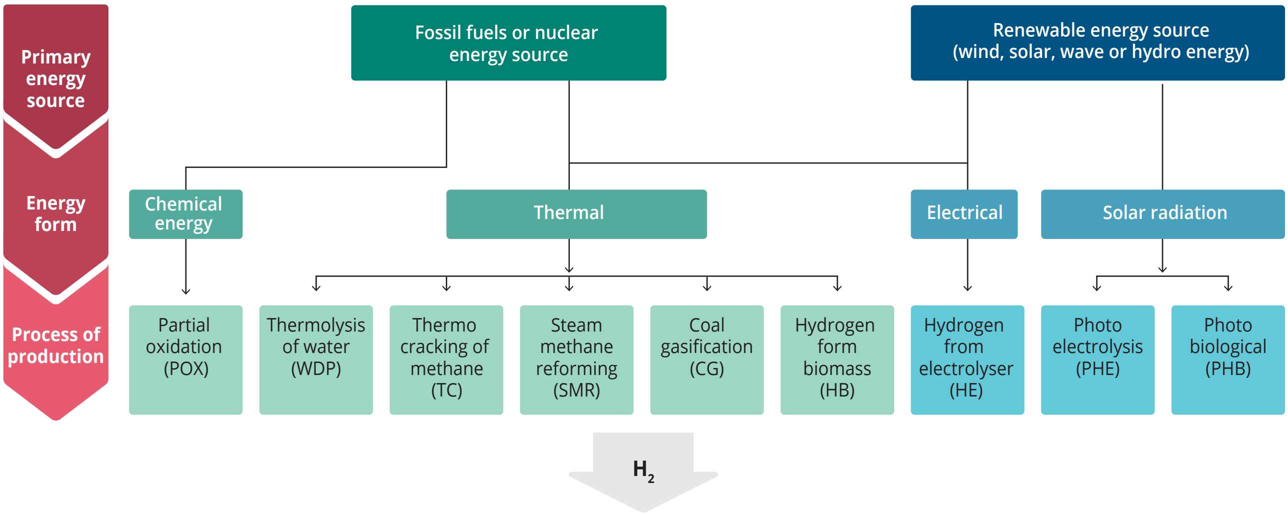
Ammonia

Ammonia (NH_3) has the potential to be used as an alternative fuel on ships, based on its physical and chemical properties. Its widespread use in industrial and agricultural processes may also facilitate its distribution using the existing infrastructure and supply chains.

Characteristics of ammonia (NH_3)

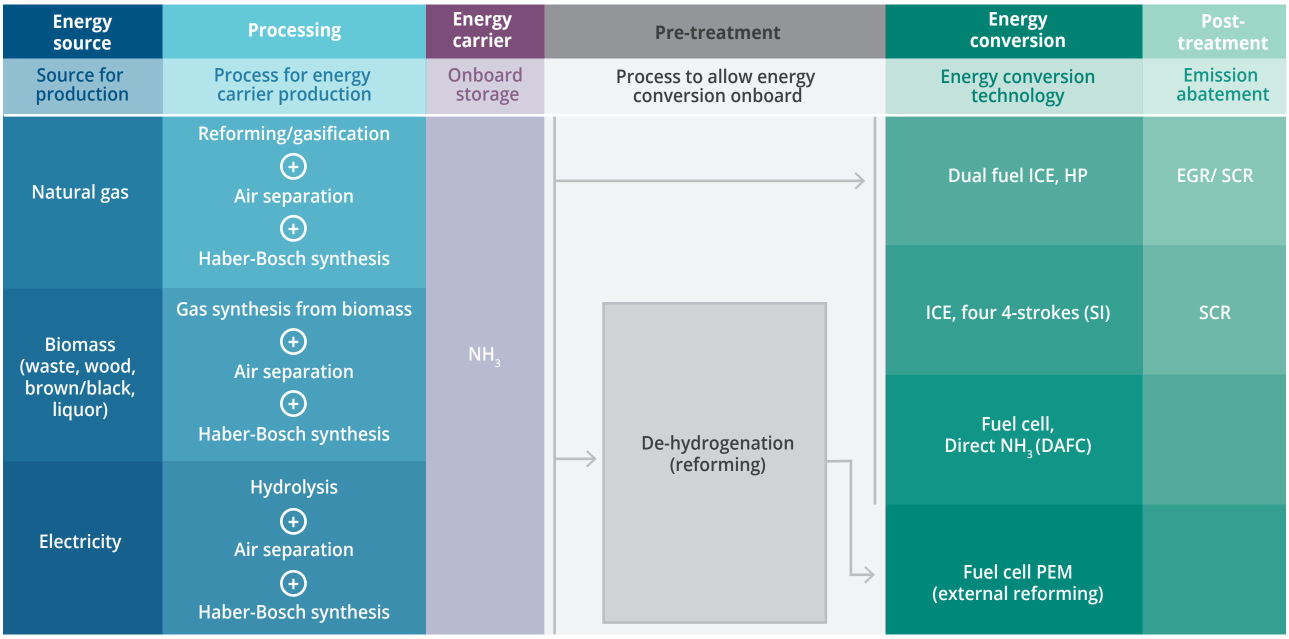
NH_3 is a compound of nitrogen and hydrogen, a colourless gas in ambient conditions with a characteristic pungent smell. It has higher energy density by volume than hydrogen and can be liquefied at 860 kPa and at ambient temperature, which makes it easy to store on board a ship. However, it is commonly stored at 17 bar (1 700 kPa) to keep it in a liquid state even when surrounding ambient temperature increases. Although NH_3 is common in nature and widely used, it can be toxic in concentrated form.

Figure 5.4 **Different pathways for H_2 production**



Source: Modified from Alazemi and Andrews (2015).

Figure 5.5 **Different pathways for NH_3 production**



Note: EGR, exhaust gas recirculation; HP, high pressure; ICE, internal combustion engine; PEM, proton exchange membrane; SCR, selective cathalytic reduction; SI, spark ignition.

Source: EMSA (2021).

On board ships, NH_3 can be used in combination with internal combustion engines and fuel cells. In combination with internal combustion engines, its expected performance is similar to that of conventional fuels in relation to power density and load response (de Vries, 2019). However, due to its toxicity and more stringent storage and handling requirements, NH_3 engines are still at the development stage. Further development of fuel cells may render them the main application for NH_3 on board ships (ABS, 2020).

NH_3 can be synthesised from fossil fuels or biomass using conventional or renewable energy. Currently, NH_3 is mainly produced from conventional fossil fuels, which are used to produce H_2 and to separate N_2 from air after liquefaction. H_2 is then combined with N_2 to produce ammonia in the Haber-Bosch process. If renewable energy sources are used to produce H_2 for further synthesis into NH_3, the production process can be considered almost carbon free (ABS, 2020). Figure 5.5 identifies the different possible routes for producing ammonia.

As NH_3 does not contain sulphur, its use as fuel does not result in SO_x or PM emissions. However, the combustion of NH_3 may result in NO_x formation. Still, it has a high heat of vaporisation, resulting in the fuel mixture having a cooling evaporative effect after injection and therefore reducing cylinder temperature at the start of combustion and helping to control NO_x formation.

NH_3 can be considered a zero-carbon fuel, with no carbon emitted when converted to electrical energy in fuel cells or mechanical energy in an internal combustion engine. NH_3 contains no carbon, and thus its combustion does not produce any CO_2. This means that it will be mainly its WTT emissions that will make up its total WTW emissions. However, there is a risk of nitrous oxide formation that needs to be evaluated further, as nitrous oxide is a strong GHG (Hansson et al., 2020). NH_3 itself is not a GHG, but it is a toxic gas. Therefore, potential NH_3 slips is an important factor to considered to prevent harmful emissions (de Vries, 2019).

Fuel cells

Fuel cells themselves cannot be considered an alternative fuel. They are in fact an energy conversion system, transforming the electrochemical potential energy of H_2 into electrical energy, which is then either consumed directly or, as in most cases, indirectly stored in batteries (Figure 5.6).

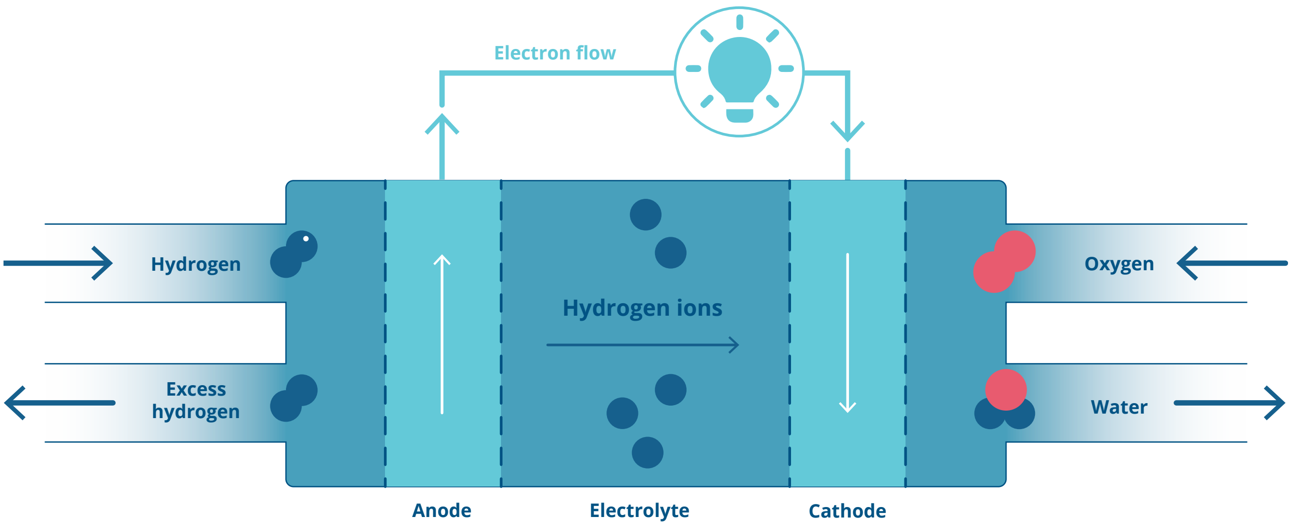
Fuel cells are primarily H_2 consumers. Several technical arrangements exist whereby different fuels are directly fed into the fuel cells, such as LNG or methanol, which are used as chemical carriers/sources of the H_2.

Fuel cell power production is a technology that has the potential to eliminate SO_x, NO_x and PM emissions and to reduce CO_2 emissions, especially when compared with emissions from diesel engines. In a WTW analysis, the reductions in emissions of GHGs of fuel cells would depend on the WTT emissions of the H_2 chemical carriers/sources. Fuel cells powered by low-carbon fuels (e.g. natural gas and other low-flashpoint fuels) will have local and regional benefits, as both emissions and noise are reduced. In the longer term, H_2 fuel generated from a growing number of renewable energy resources could lead to ships with near-zero carbon emissions.

New-generation batteries

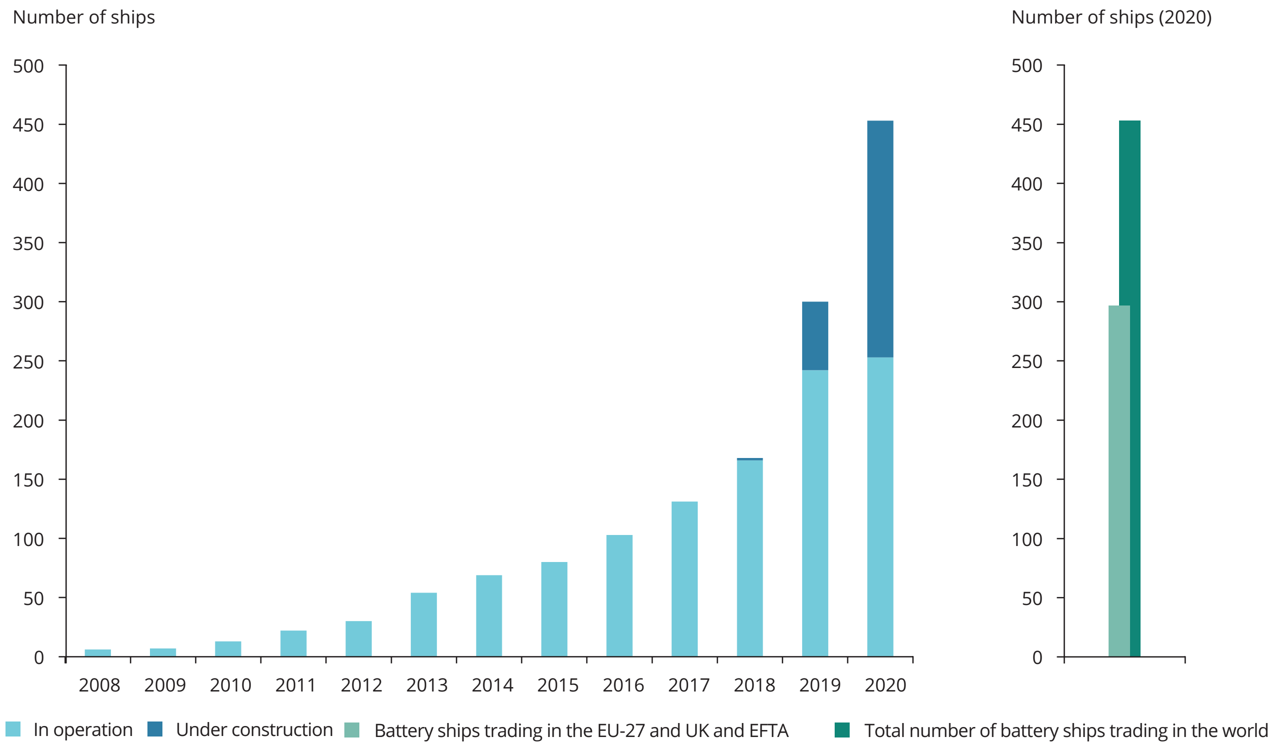
Batteries have been common elements of systems and machinery layout on board ships. However, their main use has been limited to providing starting power and support for emergency systems, safety equipment, communication and other less energy or power demanding solutions (i.e. support batteries). The challenge today is to ensure that batteries have the necessary power for heavy-duty onboard operations, such as propulsion and providing energy to diverse auxiliary systems throughout the ship (i.e. traction batteries). Traction batteries are largely based on lithium ion (Li-ion) chemistry; however, in future other lithium- and non-lithium-based chemistries are expected to gain ground.

Figure 5.6 Schematic diagram of a fuel cell



Source: Modified from Tronstad et al. (2017).

Figure 5.7 Numbers of ships equipped with batteries and their operational area



Note: EFTA, European Free Trade Area.

Source: Maritime Battery Forum (2020).

As the safety provisions for the use of fuel cells in shipping are still under development, the current deployment of fuel cells in the maritime transport sector is still limited. The advantages of fuel cells for ships are significant if highly efficient technologies are used. These involve achieving high temperatures. The most efficient fuel cells operate at temperatures in excess of 1 000 °C and require a careful assessment of the safety-related aspects.

Batteries

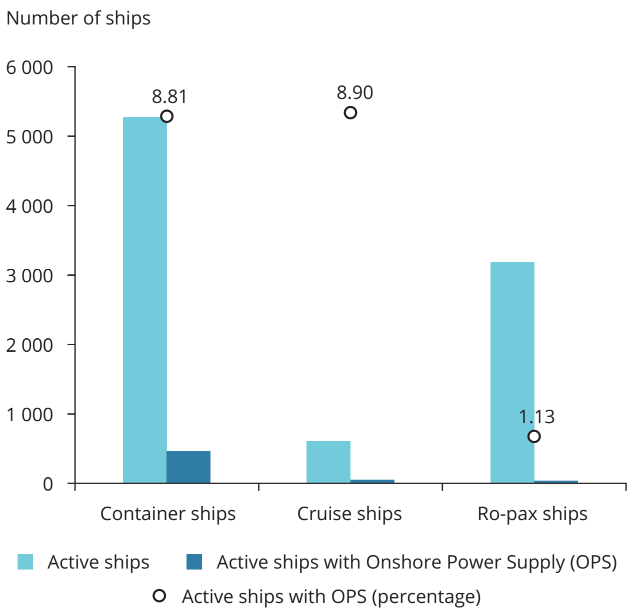
A battery is a device that stores electricity. It is therefore not an original source of power in the same way that traditional fossil fuels are. As with all other energy storage and energy conversion technologies, the use of batteries is also associated with some physical energy losses. However, in most cases these losses can be much smaller than in traditional fuel systems. Batteries can be used to create either an all-electric ship (i.e. one where batteries are used in much the same way as diesel) or a hybrid ship (i.e. one where the role of the batteries is to supplement the other fuels and enable the system to operate as optimally as possible). Considering the low energy density of battery-based options, all-electric ships are mostly viable for short-sea shipping, coastal trade, small ferries and riverine applications.

The potential environmental benefit of an all-electric vessel is unquestionable when considering the tank-to-propeller part of the value chain. Electrification of a vessel may completely remove the emissions of CO_2, NO_x, PM, SO_x and noise (noise depending on propulsion system). This is the case for an all-electric vessel, compared with one operating on traditional fossil fuels (i.e. MGO). For a hybrid vessel, the reduction in emissions will depend on the level of hybridisation (EMSA, 2020b).

In a WTW analysis, the reduction in GHG emissions of batteries will depend on the WTT emissions created by generating electricity. In order to be emission free, battery-powered vessels are dependent on the electricity being sourced from renewable energy. Several studies have investigated and compared the CO_2-e emissions from a life cycle perspective for a conventional combustion system and a battery system in the automotive industry. For maritime applications, very few life cycle assessments have been undertaken for onboard battery systems.

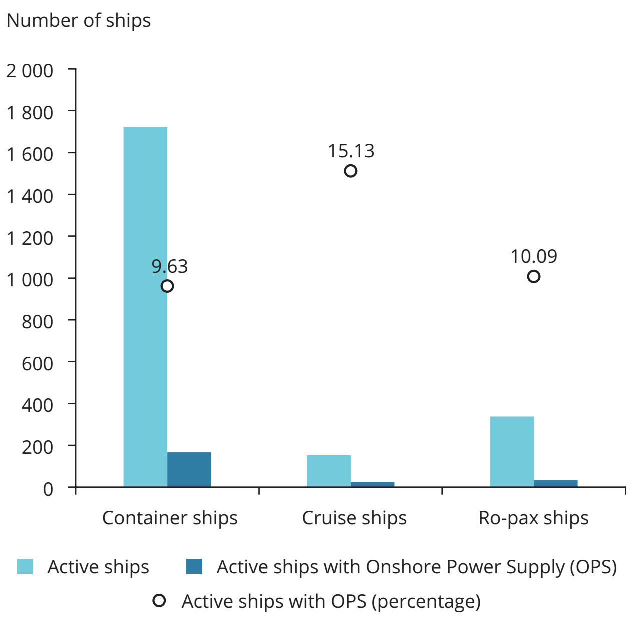
Batteries can be charged using either onboard electrical power generation or an onshore power supply (OPS). Many different onboard solutions for electrical power generation can be considered (co-generation, micro-generation, tri-generation) as well as waste heat recovery systems for producing electricity. Renewable energy sources can also be considered for charging batteries.

Figure 5.8 **Percentage of active ships worldwide equipped with OPS**



Source: IHS Markit (2020).

Figure 5.9 **Percentage of active ships calling at ports in the EU equipped with OPS**



Source: IHS Markit (2020).

The relatively high energy density and levels of power required for ship operations, such as propulsion or driving high-powered auxiliary systems, remain challenges for battery applications in ships. The integration of large battery systems on ships also represents a challenge because of their weight or volume, especially if conventional propulsion and fuel storage spaces are integrated into the system (which is the case in most hybrid applications). Furthermore, safety aspects and thermal runaway are issues that need to be addressed, as they provide an indication of current and forecast numbers of ships worldwide with batteries installed (either in all-electric or hybrid ships) (Figure 5.7). Of all the ships that are actively trading and have batteries, half of them are hybrid ships and roughly 18 % are all-electric ships. In terms of ship types, passenger ships and ferries represent the segment currently making the most use of batteries.

Onshore power supply

OPS facilities can serve as a clean power supply for maritime transport in maritime and inland navigation ports, where air quality is poor or noise levels are high.

However, various technical challenges and uncertainty about the demand for OPS have led to limited adoption of this alternative solution. Although a sizeable majority of ships are equipped with the potential for some electrical connection to shore, these typically involve low-voltage OPS for limited energy supply. This can be used in parallel with onboard energy or applied during periods when the ship is not in service, whilst at berth, with reduced power or energy demand.

There is a limited number of ships in the world equipped with the necessary elements for high-voltage OPS (i.e. 8.80 % of the world's container ships, 8.90 % of cruise ships and 1.10 % of Ro-pax ships, or roll-on, roll-off passenger ships) (Figure 5.8). In the EU, 9.60 % of the container ships, 15.10 % of the cruise ships and 10.10 % of the Ro-pax ships calling at ports are equipped with high-voltage OPS (Figure 5.9). In addition, there are also ships that are 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 structural spaces for cable routing, but also in the main switchboards.

5.1.2 Energy efficiency and ship design

Improved ship design and operation can contribute to reducing GHG emissions from ships. To that end, the International Maritime Organization (IMO) in 2011 introduced two mandatory energy efficiency standards for ships: an energy efficiency design index (EEDI) for new ships (technical measure) and a ship energy efficiency management plan (SEEMP) for all ships (operational measure).

'The EEDI threshold varies depending on ship type and size, although those covered are responsible for approximately 85 % of the CO_2 emissions from international shipping. The EEDI is being implemented in phases. In phase 0 (2013-2015), new ships were required to have a design efficiency at least equal to the average performance of ships built between 1999 and 2009 (called the reference line). In phase 1 (2015-2020), new ships had to be 10 % more energy efficient than that reference line' (EC, 2019b). As a result of discussions at the IMO to significantly strengthen the EEDI requirements, the existing phase 2 has been shortened (2021) with the reduction factor compared with the baseline increased to 20 %, and phase 3 is anticipated (after 2022) to have reduction rates increased by between 30 % and 50 %, depending on the ship type. In addition, the IMO is working on introducing additional requirements affecting all ships, such as a technical requirement to reduce carbon intensity, based on a new energy efficiency existing ship index (EEXI), together with a new operational carbon intensity indicator (CII). An EEXI would be required to be calculated for every ship, which would then indicate its energy efficiency compared with a baseline. In the case of ships above 5 000 GT (gross tonnage), the CII would determine the annual reduction factor needed to ensure continuous improvement in the ship's operational carbon intensity within a specific rating level.

The Energy Efficiency Design Index (EEDI)

The EEDI indicates the energy efficiency of a ship in terms of g CO_2 (generated) versus tonne-mile (cargo carried-distance travelled) calculated for a specific reference ship operational condition. The lower the EEDI value, the better the technical/design energy efficiency of the ship. Ship designers and builders are free to choose the technologies to satisfy the EEDI requirements in a specific ship design thus driving ship technologies to more energy efficient ones over time. On the other hand, SEEMP is a management tool and establishes a mechanism for ship operators to improve the energy efficiency of a ship during its operation lifecycle.

In 2018, the technical energy efficiency of ships calling in EU/European Economic Area ports was generally comparable to that of the world fleet (except for small container ships). Most of the monitored ships built after 2015 already comply with energy efficiency standards applicable over the period 2020-2025 (EEDI phase 2). Younger ships from the monitored fleet tend to have lower installed power.

The main objective of operational energy efficiency indicators is to monitor the performance of a ship when operating in real conditions. In contrast to technical energy efficiency indices, operational indicators are influenced by factors that vary over time and often diverge from the ship's design conditions, including the distance travelled and time spent at sea, average cruising speed, amount of cargo transported, loading conditions, including ballast, displacement (related to loaded draught), oceanographic and weather conditions, and energy requirements at berth. Operational energy efficiency indicators are key to tracking the actual operational performance of ships and are essential to the implementation of any environmental management system (ISO 14001).

Concerning operational energy efficiency in terms of the annual efficiency ratio (AER), bulk carriers and tankers are comparable, although smaller sized segments tend to be less efficient. The operational energy efficiency (AER) of container ships is generally much better than their theoretical energy efficiency at reference design speed (EMSA, 2018).

5.1.3 Speed reduction

Reducing speed, or slow steaming, is the deliberate reduction of the cruising speed of a ship. Slowing down the speed reduces the ship's fuel consumption and all the associated costs. Overall, slow steaming is shown to improve the efficiency of the main engines and contribute to reducing the environmental pressures of maritime transport (GL Reynolds, 2019).

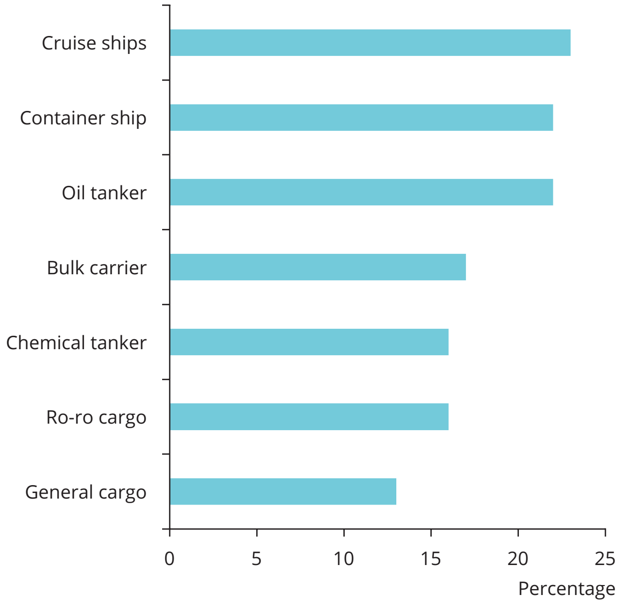
There is a cubic relationship between the speed and the power necessary to propel the ship. The engine power remains proportional to the cube of the speed. Therefore, slight increases or reductions in the cruising speed will substantially affect fuel consumption and consequently CO_2 emissions. It has been estimated that reducing the speed of a ship by 10 % may decrease its related CO_2 emissions by at least 10-15 % and possibly up to a 20 % (Corbett et al., 2009; Eide et al., 2009; Longva et al., 2009; EMSA, 2019). Other studies show that a 30 % speed reduction could deliver a 33 % reduction in emissions for bulk carriers, tankers and container ships (Faber, 2017; CE Delft, 2019). Aside from reducing GHG emissions, reducing speed also reduces the emissions of other air pollutants, such as NO_x, SO_x and BC, and hence provides a benefit for human health. In addition, recent studies estimate that a 10 % speed reduction may reduce noise and vibrations generated by the engines by 40 %, as well as reducing ship strikes on marine mammals by around 50 % (Leaper, 2019).

Most ships calling at EU ports have reduced their speed compared with 2008 (i.e. up to an 18 % average speed reduction in the period 2008-2019; EMSA, 2019) (Figure 5.10).

In particular, container ships, cruise ships and oil tankers have all experienced significant average reductions in speed. This, however, has been less significant for general cargo ships, and the average speed of refrigerated cargo ships has even increased in the same period (EMSA, 2019).

While there are definitive benefits in reducing speed, there are also some concerns about this strategy, as reducing the speed will increase the travel time, so the benefits of reduced fuel consumption may be offset by the total length of the ship's voyage. Furthermore, reducing the speed below the range in which the ship is designed to operate could ultimately affect the performance of the engines, potentially reaching critical loads and increasing maintenance costs.

Figure 5.10 Weighted average speed reduction (%) in ships calling into EU ports by ship type over the period 2008-2019



Source: EMSA (2019).

5.1.4 Wind power

Wind-powered systems may produce electricity on board or may directly assist in propelling the ship (i.e. wind-assisted ship propulsion, WASP). As a renewable, inexhaustible and naturally replenished source of energy, wind power has the potential of improving the energy efficiency of ships, thus contributing to reducing the environmental pressures of the maritime transport sector. Wind can supply a substantial part of the power needed to operate a ship, decreasing both its fuel consumption and its emissions. Still, the overall performance of wind power depends on multiple factors, such as the operation of the ship, the route, including the direction in which the route is sailed, the characteristics of the wind power system on board, the ship type, and whether it is a new ship designed to accommodate wind power.

In relation to WASP, several technologies are currently being developed and tested, including the use of soft or rigid sails, wing sails, hull sails, towing kites, rotors and wind turbines. In terms of absolute savings, the various WASP technologies are highly dependent on the speed of the vessel. In principle, ships do not necessarily need to slow down for at least some of the WASP technologies to become cost efficient. It has been estimated that, by 2030, using WASP could lead to reductions in the total CO_2 emissions from maritime transport of up to 3.5-7.5 million tonnes (CE Delft, 2016).

In the case of wind power technologies retrofitted onto existing ships, fuel savings may vary from 5 % to 25 %, depending on the specific ship, operation and system retrofitted. In the case of new ships designed to use wind power technologies that are fully integrated, the related fuel savings can be above 30 % (WASP project, 2019-2023).

5.1.5 Exhaust gas cleaning systems

Several types of emission after-treatment systems exist, which have the capacity to mitigate the production of air pollutant emissions such as SO_x, NO_x and PM. Some of these are after-treatment systems that remove the pollutants from the exhaust gases resulting from the combustion processes on board ships. Others are based on primary control techniques, reducing the formation of the pollutant at source ahead of combustion (i.e. exhaust gas recirculation).

Exhaust gas cleaning systems (EGCSs), commonly referred to as 'scrubbers', are one of the most mature after-treatment technologies and are designed to remove the SO_x matter from the exhaust gases. SO_x removal efficiency can reach 95 % or higher, depending on the specific system and installation. A portion of PM is also removed (Gregory and Confuorto, 2012). As a fraction of PM, BC emission reductions have been estimated at between 25 % and 70 % (IMO, 2018a). Regarding the potential contribution to GHG reductions, in a WTW analysis, using high-sulphur fuels in combination with EGCSs have been reported to at best reduce emissions by up to 3 % or 4 % compared with using low-sulphur fuels (i.e. MGO; Lindstad, 2020). Other studies point to the fact that using either low-sulphur or high-sulphur fuels in combination with EGCS results in similar additional CO_2 emissions. These additional CO_2 emissions in the case of EGCS would be dependent on the ship type (IMO, 2020a).

EGCSs can be broadly classified into wet and dry systems. Wet systems use sea or freshwater or both for the removal of air pollutants. Dry systems are normally used in shoreside installations, although there are some maritime applications that use packed beds of granulated hydrated lime as the scrubbing medium together with calcium sulphate as the reaction product.

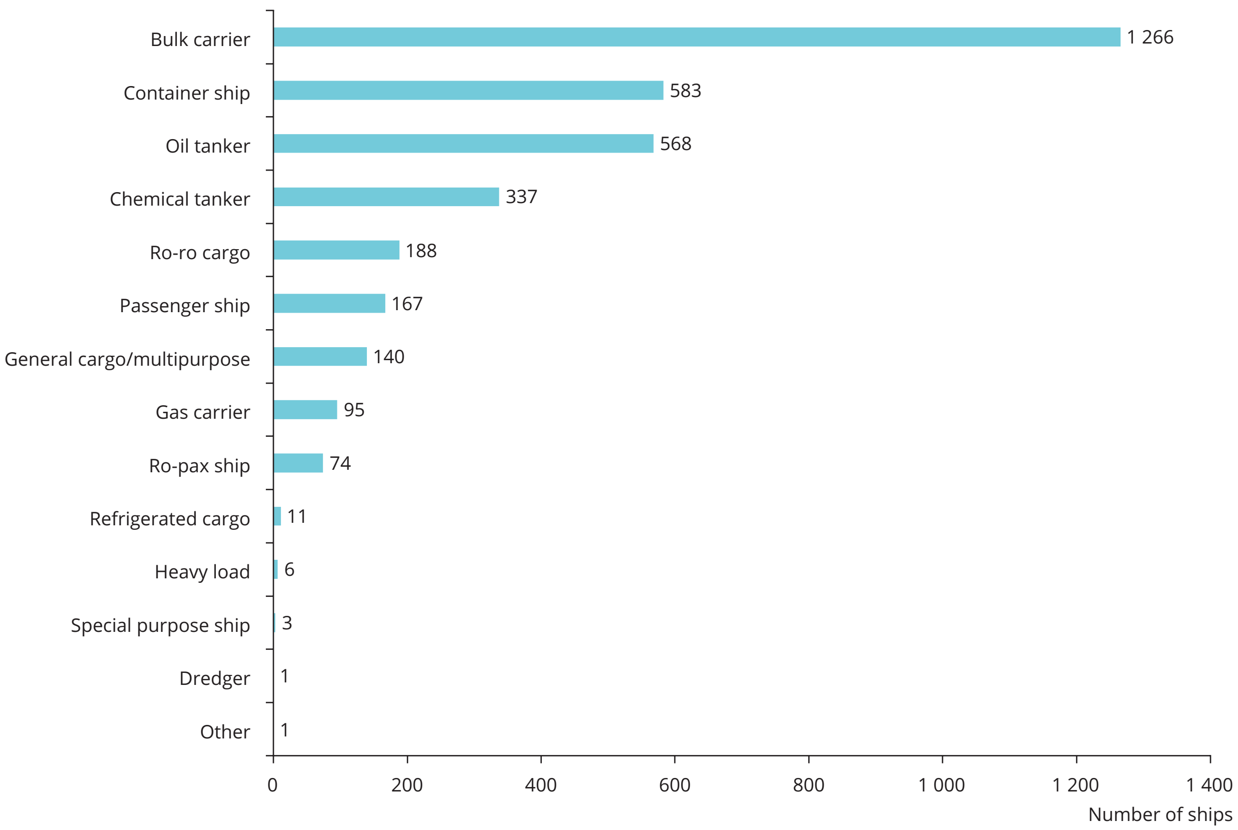
Wet systems can also be classified depending on the operation mode: 'open' or 'closed'. In open loop EGCSs, water is taken from the sea, used for exhaust gas cleaning, then treated as appropriate and discharged back to the sea (typically around 45 m^3 seawater per MWh of combustion unit power if 2.7 % sulphur fuel is consumed). In closed loop EGCSs, freshwater is normally used, which is treated with an alkaline chemical such as sodium hydroxide for neutralisation and exhaust gas cleaning. The majority of the wash water is then recirculated (a small quantity of the wash water is bled off to a treatment plant before being discharged to sea) (Gregory and Confuorto, 2012). Under EU rules, only ships equipped with EGCSs operating in closed mode are allowed to use fuel with a very high sulphur content of more than 3.50 % m/m.

As EGCSs use water to remove the pollutants, effective controls may be needed to minimise the potential negative effects, if any, on the marine environment caused by the resulting overboard discharges (e.g. discharge water, bleed-off). Concerns about the negative effects include acidification (change in pH values) and releases of heavy metals and polycyclic aromatic hydrocarbons (PAHs). In order to address the potential negative impact of EGCSs, the EU submitted a request to the IMO in May 2019, which resulted in a new work stream on the evaluation and harmonisation of rules and guidance on the discharge of water from EGCS into the aquatic environment, including conditions and areas. This activity should be completed at IMO level by 2022. Within this context, the EU continues to steer development by contributing to defining proposals for a robust risk assessment underpinning a possible regulatory framework bearing in mind that some EU Member States are not allowed to discharge open loop effluents in port areas.

Residues (i.e. sludge from wash water treatment) and bleed-off water from EGCSs are considered waste types under the laws on port reception facilities and should therefore only be discharged ashore (EU, 2019a).

EU rules on sulphur content in fuels allow the use of EAMs such as EGCSs as an alternative to using low-sulphur marine fuels, provided that they continuously achieve reductions of sulphur dioxide emissions that are at least equivalent to the reductions that would be achieved by using marine fuels (EU, 2016b). As of 15 June 2020, the total number of ships worldwide fitted with EGCSs in service stood at 3 440 (Figure 5.11).

Figure 5.11 Number of EGCS installations by ship type in 2020



Source: Compiled from EMSA Services data.

5.2 Measures to mitigate pressures and impacts on the marine environment

There are multiple measures that can help mitigate the pressures and impacts on the marine environment. For example, with regard to water pollution, the installation of treatment systems for water discharges on board ships or in ports could help mitigate the impacts that they produce when discharged at sea, and the use of biocide-free anti-fouling paints on hulls would help reduce the input of contaminants to the water from leaching. It is also crucial to have contingency plans in place and the necessary means to control accidental oil spills. In relation to non-indigenous species (NIS), both ballast water treatment and hull cleaning systems aiming to avoid NIS transfers can contribute to reducing the risk of new introductions or the spread of species within a sea area. Measures can also be taken to reduce the impacts on the sea floor, such as minimising the sediment dredged and disposed of and the use of appropriate techniques and equipment for reducing the impacts from its dumping. With respect to underwater noise, maritime spatial planning could be a relevant tool to avoid adverse effects from the continuous noise produced by ships on noise-sensitive species, as could ship operators' practice of slow steaming. On top of this, the implementation of reporting systems would be relevant for issues for which there are almost no data available, such as ship strikes or lost containers.

Many of these measures need to be implemented by ship operators or port authorities, and therefore no quantitative data are yet available at European level that could help provide a picture of the extent of their implementation. This section therefore focuses on oil spill responses and maritime spatial planning, which are two main tools that need coordination at the national level and have to be put in place by EU Member States.

5.2.1 Oil pollution response

Each EU Member State will have its own oil and chemical spill response strategy and contingency plan, and at EU level requests for assistance in the event of an emergency pollution incident may be triggered through the Emergency Response Coordination Centre (ERCC) located in DG ECHO (Directorate-General for European Civil Protection and Humanitarian Aid Operations). In addition, there are regional agreements in place that provide cooperation mechanisms for responding to marine pollution covering different areas of EU waters, i.e. the Barcelona Convention through the Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea (REMPEC), Bonn Agreement, Bucharest Convention, Copenhagen Agreement, Helsinki Convention through the Helsinki Commission (HELCOM) Response, and Lisbon Agreement). Apart from the assistance that Member States may receive from each other, EMSA has been tasked to provide Member States, upon request, with additional means of response. To that end, EMSA has developed several services, which are described in Figure 5.12.

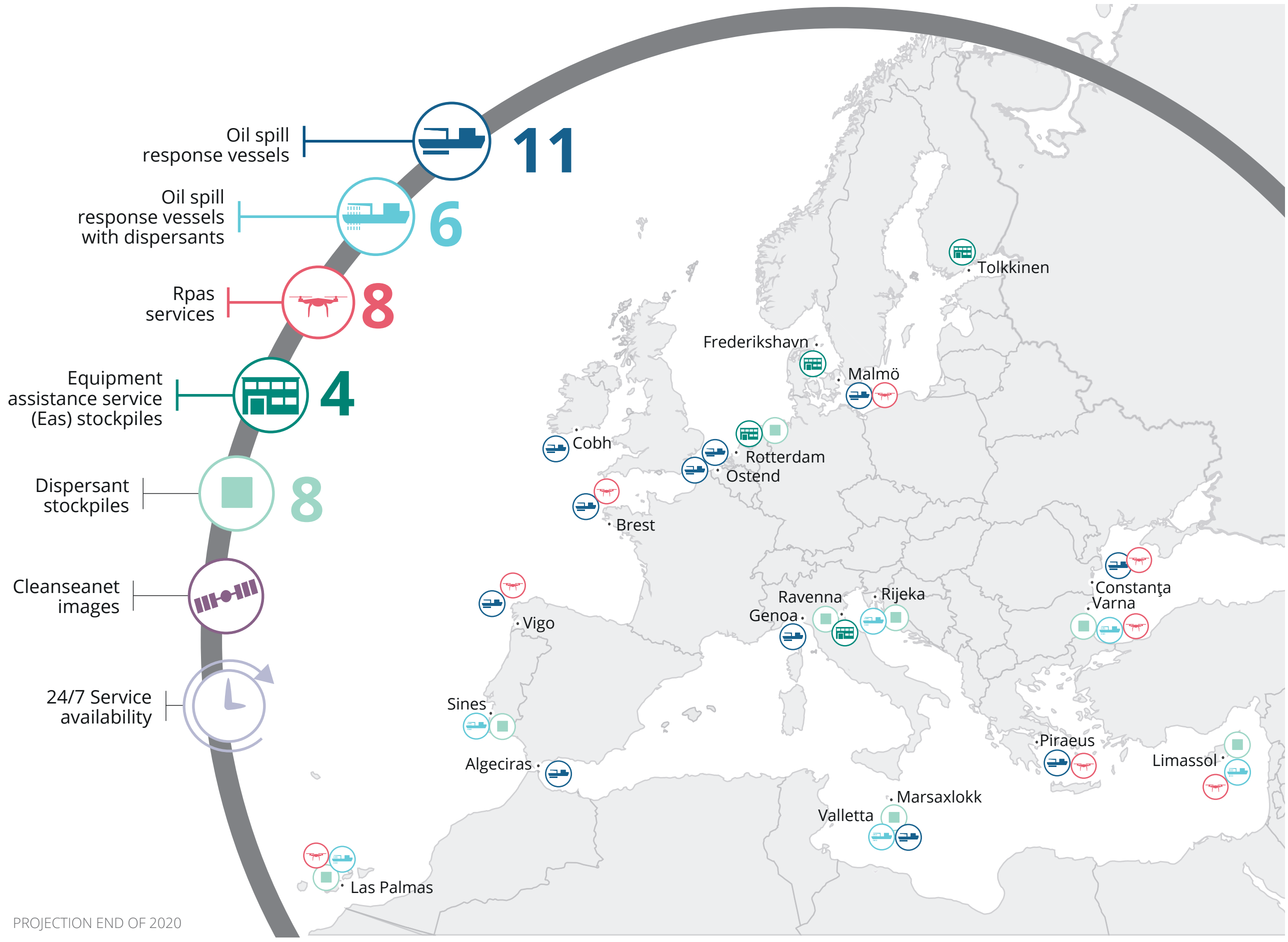
When oil is spilled at sea it normally spreads out and moves on the sea surface with wind and currents while undergoing several chemical and physical changes. These processes are collectively termed weathering, and they determine the fate of the oil (Figure 5.13).

Some of these processes, such as natural dispersion of the oil into the water and evaporation of the lighter hydrocarbons in the oil, lead to the removal of the oil from the sea surface and facilitate its natural breakdown in the marine environment. Others, particularly the formation of water-in-oil emulsions, cause the oil to become more persistent and to remain at sea or on the shoreline for prolonged periods of time. The dissolution into smaller oil droplets might also result in the enhanced bioavailability of toxic components in the oil, increasing their negative effects in the water column. Dispersants have also been shown to be toxic in themselves, albeit to a lesser extent at present compared with the older types (Almeda et al., 2014; Brakstad et al., 2014). Whereas there is little knowledge available on the behaviour of the new generation of low-sulphur fuel oils when spilled in the sea and on the chemical composition of, for example, PAHs and metals, recent studies indicate that one cannot expect the new generation of low-sulphur fuel oils to react in a similar way to other oils and that there is an urgent need for more studies on the topic (Hellstrøm, 2017; Daling and Sørheim, 2020).

The speed and relative importance of weathering depend on factors such as the quantity spilled, the oil's initial physical and chemical characteristics, weather and sea conditions and whether the oil remains at sea or is washed ashore (ITOPF, 2011).

Depending on the physical and chemical characteristics of the oil spilled, the amount of water-in-oil emulsion to be collected could be 10 times more than the initial quantity spilled. As time passes, the initial slick will break into smaller ones and will cover a wider surface, requiring new responses to deal with each of the treatable slicks. An oil pollution response is therefore always constrained by tight time limits if it is to be as efficient as possible, considering the oil's characteristics and the potential of having to work in all weather conditions.

Figure 5.12 EMSA pollution response services



Note: RPAS, remotely piloted aircraft system.

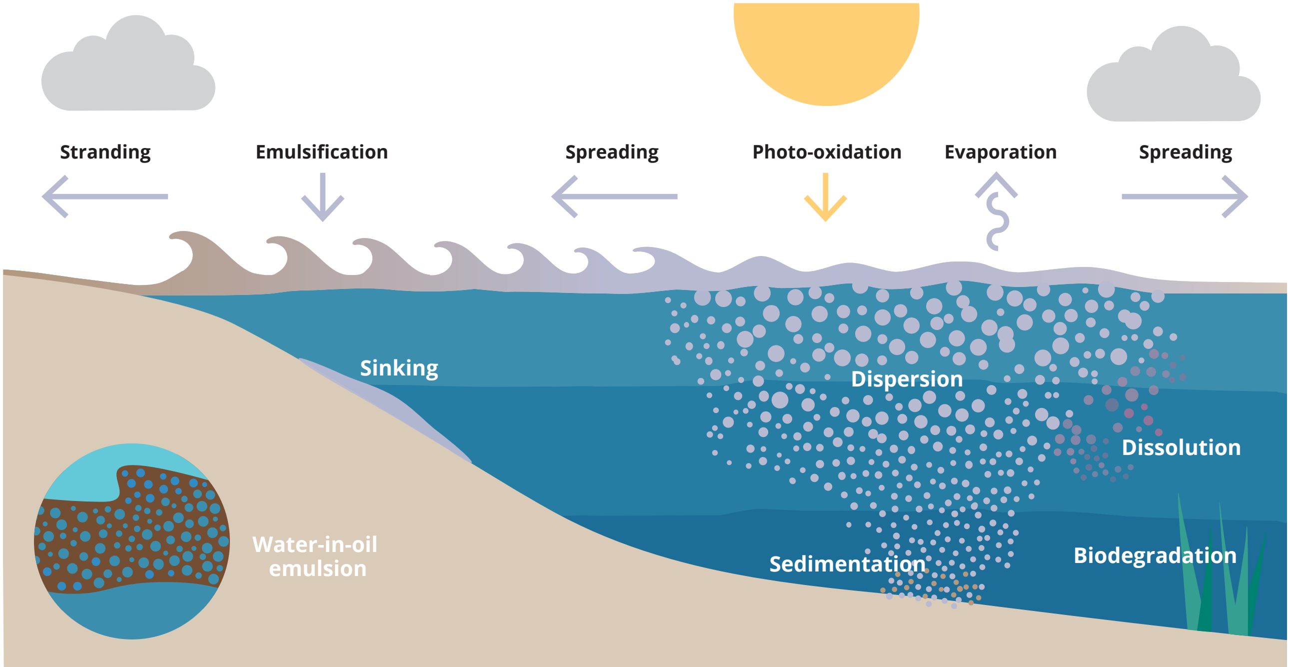
Source: Compiled from EMSA Services data.

There are currently three main techniques used to combat an oil spill:

- **Mechanical recovery**. This technique uses booms to contain the spread of the oil and increase the thickness of the layer of oil. Following this, skimmer devices are used to pump the oil off the surface of the water. There are different types of skimmer with different efficiency ratios. A classic operation will require smaller vessels to tow the booms in a U shape, thus concentrating the oil towards the apex of the booms, and another vessel equipped either with sweeping arms or a skimmer will then pump the oil where the concentration is greatest. However, a certain amount of water will also be collected in the process, requiring either a big storage capacity or the capacity to separate the oil from the water on board. Once this separation process has been achieved, in accordance with the MARPOL Convention regulations and with the authorisation of the states concerned, the clean water could be released at sea. This allows the recovery ship to remain in operation for longer. In addition, booms can be used to provide barriers on coastal sites such as estuaries, salt marshes and other sensitive habitats.

- **Use of dispersant products**. Dispersants are surface active agents that accelerate the natural dispersion of oil. Dispersants facilitate the dissociation/dissemination of oil slicks on the surface into a multitude of droplets spread throughout the water column (a few metres to a few dozen metres deep). The purpose of dispersants is two-fold: first, the dispersion of surface slicks in the water mass, meaning that they are no longer affected by the wind, which is important, as wind is one of the main factors moving slicks around; and, second, fragmentation of the slick into a multitude of droplets, which facilitates the breakdown of oil by bacteria naturally present in water (Cedre, 2014). The use of a dispersant will always be decided on the basis of a positive result from a spill impact mitigation analysis. Dispersants are not effective on all types of oils, and they should be used before the weathering process has started to alter the initial characteristics of the oil.

Figure 5.13 Weathering processes acting on oil at sea



Note: Once oil is stranded on the shoreline some of these processes will no longer apply.

Source: ITOPF (2021), © ITOPF.

Dispersants are more effective when there is strong sea movement, either due to the weather or created using the spraying boat's propellor to facilitate the mixing of the product with the oil. In the case of a major spill, the use of dedicated aerial sprayers will allow a wider area to be sprayed in a short time compared with using a boat.

- ***In situ* burning**. This last technique is the most controversial and has rarely been used. It was used during the Deepwater Horizon offshore spill to reduce the magnitude of the spill, which could not be contained by only mechanical recovery and the use of dispersants. It requires special fire booms to first concentrate and corral a certain thickness of oil and then ignite it.

Other techniques based on bacteria or other substances acting as 'herders' or collectors have been developed but have not been used in the context of a major spill in the open sea.

5.2.2 Reducing the risks of ships as vectors of non-indigenous species

Many technologies have been developed to mitigate the risks of ships introducing NIS. These may involve physical filtration of the ballast water, its chemical disinfection, the use of oxidising and non-oxidising biocides, ultraviolet technology, de-oxygenation, heat, cavitation or the application of magnetic fields. However, not all of these methods are appropriate, as they have different energy, space or timing requirements that some ships may not be able to accommodate because of their type or operation. The ballast water treatment system (BWTS) installed on board to treat the ballast water before it is discharged at sea is often used as a combination of these technologies.

Each BWTS must be type approved to strict guidelines set out by the IMO (IMO, 2018d), and ship owners and operators must have an International Ballast Water Management Certificate. To obtain the certificate, a ship must be surveyed and have a ballast water management plan (BWMP) addressing the procedures for ballast water exchange, treatment or both. Those BWTSs using active substances in chemicals have to undergo independent testing and auditing to ensure that the chemicals they use do not cause more environmental damage than the NIS would if they were not treated (IMO, 2008). In 2019, approximately 50 % of ships under the scope of the Convention for the Control and Management of Ships' Ballast Water (BWM Convention), which are registered to flags that are party to the BWM Convention and call into EU ports, had a BWMP on board (a figure that rises to 61 % when ships operating globally, i.e. those calling into EU ports or working solely in areas outside the EU, are considered using the same criteria). In addition, more than 80 type-approved BWTSs are available on the market for installation on board ships, and research continues to identify new technologies to meet or adapt to this treatment challenge (IMO, 2020c).

Table 5.1 Ballast water treatment standards

Standard	Element	Condition
D-1 Standard — Ballast water exchange	Physical	At least 95 % volumetric exchange of water in the ballast tanks. This is equal to pumping through the volume of each ballast water tank three times
	Geographical	Exchange should occur at least 200 nm from nearest land and in water 200 m deep. If not possible, then exchange should take place as far from the nearest land as possible, and at least 50 nm from the shoreline in 200 m depth of water
D-2 Standard — Ballast water treatment	Organisms	< 10 viable organisms ≥ 50 μm minimum size per m³
		< 10 viable organisms < 50 μm and ≥ 10 μm minimum size per ml
	Indicator microbes	Toxicogenic *Vibrio cholerae* (O1 and O139): < 1 cfu per 100 ml or < 1 cfu per 1 g (wet weight) zooplankton samples
		Escherichia coli: < 250 cfu per 100 ml
		Intestinal enterococci: < 100 cfu per 100 ml

Note: Cfu, colony-forming unit; nm, nautical mile.

By 2024, ships have to have on board a BWTS to treat their ballast water and also meet strict water quality standards in terms of organism levels before the ballast water is discharged to the sea (the D-2 standard; Table 5.1). However, there is a phased introduction of this requirement. In the meantime, to reduce the risk of NIS introductions, ships must undertake ballast water exchanges at certain distances from the shore (the D-1 standard) and achieve a 95 % exchange of the water in their ballast tanks. This is done to reduce the risk of NIS introductions.

The movement of NIS can also be facilitated by ships through biofouling. Hull fouling has now become a significant issue. The IMO has recognised this threat and produced guidelines for the control and management of ship biofouling to minimise the transfer of invasive aquatic species and guidance for minimising the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft (IMO, 2011; IMO, 2012b). In the EU, both the international BWM Convention and these guidelines are recognised as the reference standards to prevent NIS from being introduced into its waters.

The problems associated with biofouling are also addressed in the context of improving the energy efficiency of ships, as it is important to minimise biofouling to reduce the drag on their hulls.

5.2.3 Maritime spatial plans

In preparing their maritime spatial plans, Member States must identify potential conflicts between sectors (including environmental protection/nature conservation). This is applicable to shipping and the environment, where the maritime spatial plans can define concrete zones for shipping to reduce potential impacts on sensitive areas or vulnerable species/habitats. Some of the zones related to shipping and port activities that can be included in the plans are:

- IMO traffic routeing systems ([9]);
- inshore traffic zones (understood as designated areas between the landward boundary of a traffic separation scheme and the adjacent coast);
- areas where shipping is restricted (e.g. acoustic refuges for noise-sensitive animals);
- port areas;
- port waiting areas;
- areas of future port development;
- sites of disposal of dredged material (dumping sites).

([9]) Traffic separation schemes and other ship routeing systems exist in most of the major congested shipping areas of the world, having contributed to a dramatic reduction in the number of collisions and groundings. The IMO's responsibility for ship routeing is enshrined in Chapter V of the International Convention for the Safety of Life at Sea (SOLAS Convention), which recognises the IMO as the only international body responsible for establishing such systems.

Countries may eventually also submit new routeing systems or updates or amendments to existing ones to the IMO, including elements such as traffic separation schemes, separation zones or lines, recommended routes, precautionary areas, areas to be avoided and deep-water routes. These updates or amendments should only be submitted if they can contribute to the achievement of GES (e.g. to avoid biologically important areas or to establish acoustic buffer zones for mitigating the impact on noise-sensitive animals).

Regarding shipping lanes, it is up to each Member State to define their width (mainly for safety reasons), although guidance has been developed in relation to the delimitation of those (VASAB, 2016-2019).

5.3 Port-based solutions

The term 'green port' describes the actions that ports undertake to transform their processes, structures or policies to lessen their environmental and climate impact. Ports are also a key enabler for achieving green shipping fleets. Green port activities will have an important role to play in reaching the objectives of the European Green Deal. The main green port activities concern energy and fuels, climate change mitigation and adaptation, environmental pollution reduction, waste and noise management, maritime and hinterland transport connections, linkages to circular economy models, and management, policy and finance.

Fuel and energy are some of the most prominent focal points of green port development because they can contribute to significant reductions in GHG emissions. Green port development in the sphere of energy and fuels involves the energy use of the port, the availability of alternative fuel-bunkering infrastructure and OPS for ships. Some notable sources of energy that are part of green port development initiatives are hydrogen fuel, biofuel, methanol, batteries, OPS, and wind and solar energy installations.

5.3.1 Shore-to-ship power

Shore-to-ship power, or shore-side electricity, can reduce emissions while ships are berthed in port by providing power from shore-side electricity rather than from the onboard auxiliary generators. This allows ships to turn off the auxiliary engines while they are docked in port, reducing their negative impact on local communities due to noise and air pollution.

Member States must assess in their national rules the need for shore-to-ship power for both inland waterway vessels and seagoing ships in inland and maritime ports (EU, 2014a, Article 4.5). Shore-to-ship power should be installed as a priority in the TEN-T core network ports, and in other ports by 31 December 2025, unless there is no demand and the costs are disproportionate to the benefits, including environmental benefits.

Shore-to-ship power is especially applicable to ships operating on dedicated routes and vessels that consume large amounts of power and emit high levels of air pollutants when berthed. Typical vessel types include ferries, cruise ships, LNG carriers, tankers and container ships (EAFO, 2020a). Based on information from the European Alternative Fuel Observatory (EAFO), at least 31 ports from 12 EU Member States have already implemented high-voltage shore connections (see the map in Figure 5.14). This means that, at present, in the EU there is a total of 36 available shore-to-ship power supply facilities (Figure 5.14; EAFO, 2020a).

When it comes to the availability of shore-to-ship power (Image 5.1), various elements should be considered including the power requirements (or peak load requirements) for the ships calling at the port, the operating profile (i.e. use of energy- and power-intensive equipment), time spent at berth, safety, security and cost.

5.3.2 Liquefied natural gas bunkering facilities

EU standards on the deployment of an alternative fuels infrastructure requires all ports in the core part of the TEN-T to be equipped with LNG refuelling stations by 2025 (EU, 2014a). LNG bunkering is already well advanced and deployed in several ports in the EU. Out of a sample of 97 EU ports, 33 % of them reported having LNG bunkering facilities available in 2019, most of these being mobile installations. Furthermore, one in four of the ports surveyed have ongoing LNG bunkering projects (ESPO, 2020).

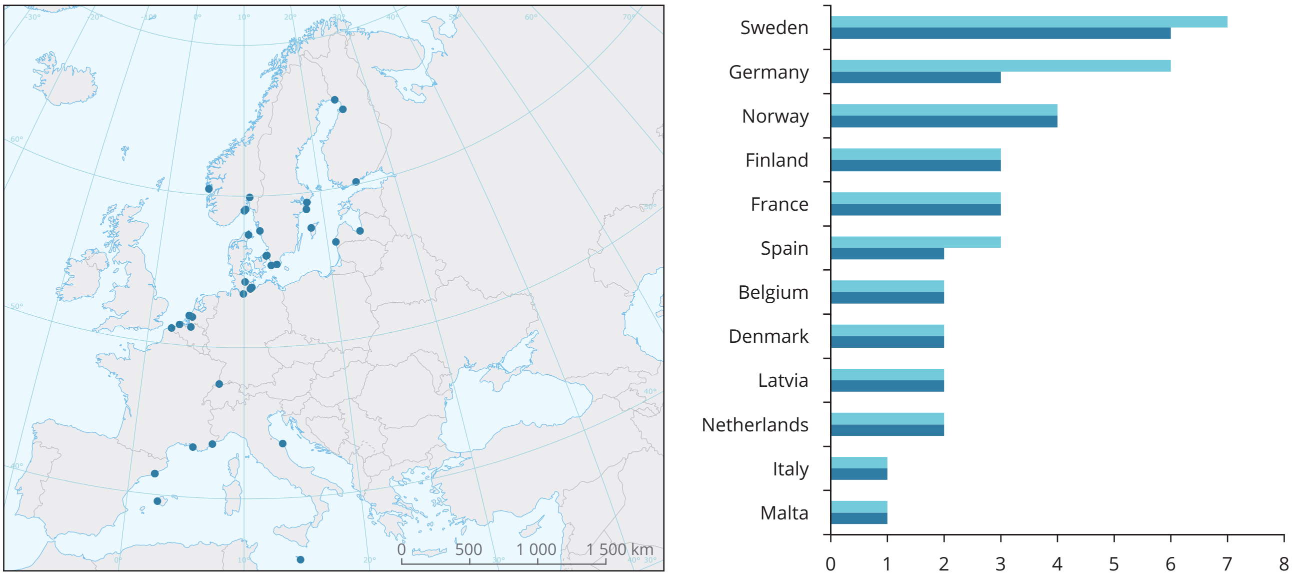
In 2020, a total of 59 ports in the EU had LNG installations, totalling 71 facilities (Figure 5.15; EAFO, 2020b).

Annex 4 provides an overview of the ports with LNG facilities in the European Economic Area.

5.3.3 Port call optimisation

There are several ways to reduce the fuel consumption of a ship, thereby contributing to reducing air emissions. Ports, in cooperation with ships, play an important role in reducing the ship's fuel consumption through port call optimisation. Optimising speed, draught and time in port leads to reduced costs, a cleaner environment, and more reliable and safer

Figure 5.14 Number of ports and OPS facilities in the European Economic Area (as at December 2020)



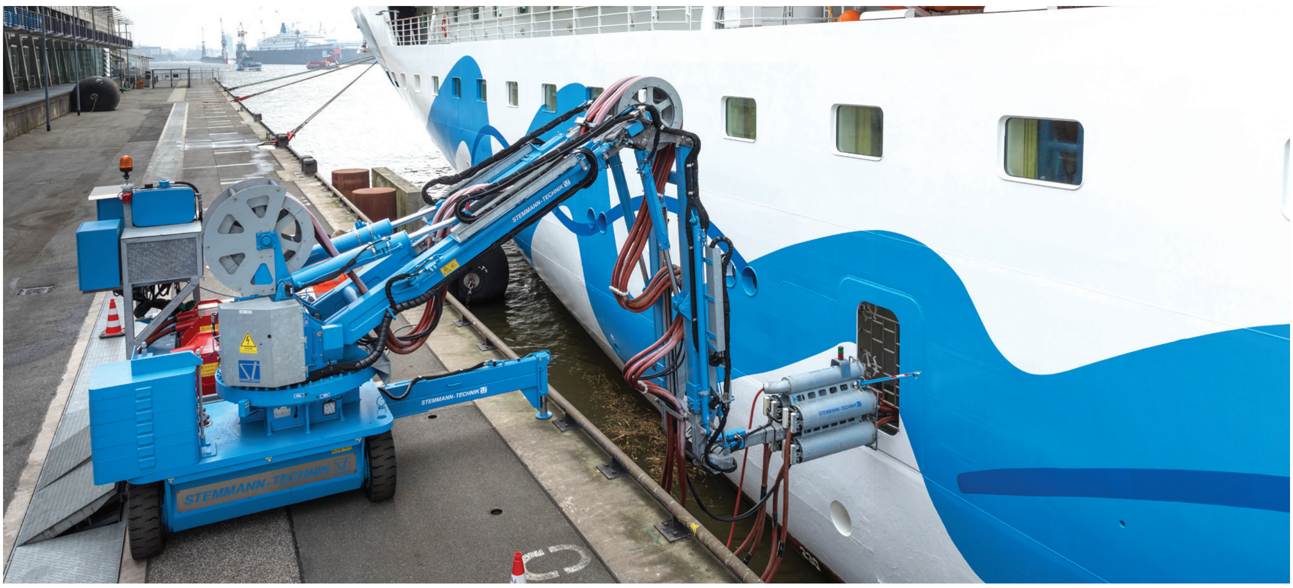
Reference data: ©ESRI

Number of ports and Onshore Power Sypply (OPS) facilities in the EU

- Location of ports
- Total number of OPS facilities
- Ports with OPS facilities

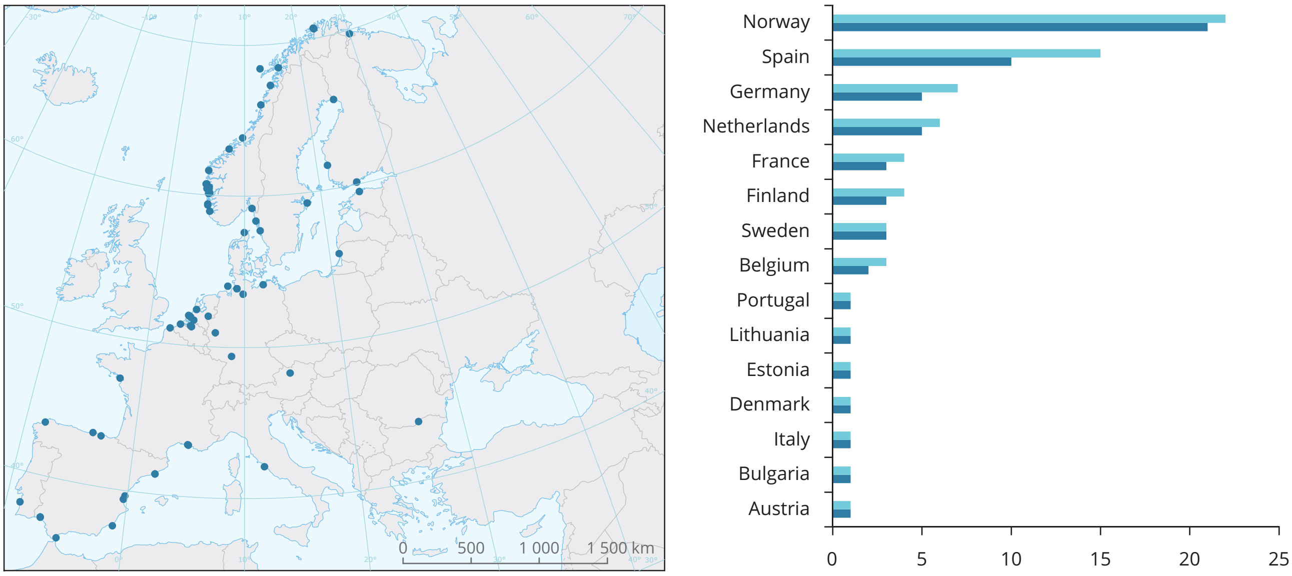
Source: EAFO (2020a).

Image 5.1 OPS provided through cables and connectors by the shore side, Port of Hamburg, 2018



Source: © HPA, Christian Bruch.

Figure 5.15 Number of ports and LNG facilities in the European Economic Area in 2020



Reference data: ©ESRI

Number of ports and Liquified Natural Gas (LNG) facilities in the EU

- Location of ports
- Number of LNG facilities
- Ports with LNG facilities

Source: EAFO (2020b).

shipping. Port call optimisation is not only related to the 'ship-to-port' communication but also seeks to improve hinterland connections and ultimately the entire logistical chain (International Task Force on Port Call Optimization, 2018). A port call is a particularly important event and a potential bottleneck in the entire chain. The benefits of 'just-in-time' arrival in terms of emission savings would potentially be significant, as it would allow smart routeing and steaming.

Port operation has impacts on energy-efficient ship operations, as reduced speed at sea is closely related to the minimisation of a ship's time in port. Just-in-time arrival may support that process by eliminating waiting times in port by giving early notice of berth availability. This facilitates optimising speed at sea. Improved cargo handling would be another important element to reduce ships' time in port.

Furthermore, a longstanding problem in the shipping industry is the complexity of and time involved in submitting reports when arriving in and departing from ports. Ship operators, masters and agents are still burdened with having to fill in paper documents and distribute these to various government authorities, including port, maritime, safety, security, customs, border control and health authorities. This increases costs and causes delays, reducing the competitiveness of maritime transport.

The IMO aims to harmonise the data exchange required during a port call, by standardising electronic messages, which is done through the IMO Compendium on facilitation and electronic business, which facilitates the exchange of ship-to-shore information to ensure the interoperability of the various national single windows. In the EU, rules aim to simplify and harmonise the administrative procedures applied to maritime transport, by making the electronic transmission of information standard and by rationalising reporting formalities (EU, 2010b). To achieve this, Member States have developed their own national single windows (NSW) linked to SafeSeaNet, e-Customs and other electronic systems. The national single window aims to simplify the administrative burden by providing a place where all maritime information is reported once by ship data providers, at either national or port level, and made available to all relevant authorities. Certain parts will also be made available to other Member States through SafeSeaNet.

5.3.4 Environmental certification

In 2007, the EU called for the development of a sustainable port sector and, among other things, encouraged the adoption of port environmental management systems (EC, 2007). The Port Environmental Review System (PERS) is one such system requiring several commitments from port authorities such as environmental monitoring and the periodical publication of an environmental report. Certification of the ports' environmental management system is also possible by accredited bodies. Based on PERS, ports may also pursue environmental certification under ISO 14001, a recognised international standard specifying the requirements for an effective environmental management system, and from the EU Eco-Management and Audit Scheme (EMAS), which is the premium management instrument developed by the European Commission to allow companies and other organisations to evaluate, report and improve their environmental performance.

5.3.5 Port fees and incentives

'There is a range of options that port management bodies can apply to influence the environmental performance of shipping' (EC, 2017b). One is to offer incentives to the shipping industry to carry out more environmentally friendly maritime operations (EC, 2017b).

'Among the multitude of possible measures to tackle the adverse environmental impacts of maritime operations, 'port pricing' or 'environmental charging' has been receiving increasing attention and has translated into a number of practical, bottom-up initiatives, voluntarily implemented by port management bodies' (EC, 2017b).

Environmental certificates

The Environmental Ship Index (ESI) identifies seagoing ships with good performance in reducing air emissions. This initiative started in 2011, and currently over 8 000 ships benefit from it at more than 50 ports. The Green Award is a certification and incentive programme for shipping. Over 250 certified ships identify their management companies as meeting the Green Award requirements, thus benefiting from the scheme. The Clean Shipping Index (CSI) labels ships according to their environmental performance, accounting for not only air emissions but also water discharges and waste. The Blue Angel is an environmental label organised by the Federal Government of Germany for the protection of people and the environment. The ecolabel 'Eco-friendly Ship Design' specifies a range of criteria that must be complied with.

Regulation (EU) 2017/352 establishing a framework on market access to port services and financial transparency of ports states that port infrastructure charges may vary in accordance with the port's economic strategy and spatial planning policy. This can be used to promote more efficient use of the port infrastructure, short-sea shipping or the high environmental performance, energy efficiency or carbon efficiency of transport operations (EU, 2017b, Article 13.4).

Overall, 30 ports in the EU are operating at least one environmental charging scheme. Eleven of them are located in the Hamburg-Le Havre port range, between the Netherlands and Belgium. Seven of them are in the Baltic Sea and six in the Mediterranean Sea, while only one was detected in the North Sea. No ports in the Black Sea are yet operating these schemes. In general, larger ports tend to have more financial capacity and human resources to put in place and monitor an environmental charging scheme.

Of these 30 ports, 25 of them offer rebates on port dues that range from 0.5 % to 20 % to vessels that are certified under the Environmental Ship Index, the Green Award, the Clean Shipping Index and the Blue Angel ecolabel.

When it comes to the type of ships that can benefit from discounts, in most instances environmental charging schemes do not discriminate against a particular ship type, as long as the ship has one of the above certificates (or even an agreement with Puertos del Estado in Spain). In some other instances, discounts target specific ship categories: this is the case for LNG-fuelled (or other environmentally friendly marine fuelled) vessels but also for vessels that use OPS.

5.3.6 Port reception facilities

The availability of adequate port reception facilities (PRFs) for ships' waste is crucial for the effective implementation of waste management plans in ports. These facilities mostly receive and collect ship-generated waste, including cargo residues, garbage, oily water and sewage, from the port's regular vessel traffic (Image 5.2). In addition, PRFs often process the waste further, by sorting, treating and recycling it, adding value to it. In some cases, new products can even be generated and put on the market. Procedures in place must aim at not prolonging the ship's stay in port unnecessarily.

The availability of PRFs in ports is the responsibility of Member States under the Directive regulating the availability of port reception facilities and such facilities are paid for partly by the ships and partly by the port authorities. To promote responsible waste disposal, part of the costs of the facilities is included in a general indirect fee that is paid by every ship using the port, supplemented by a direct fee based on the actual amount of waste disposed of. This should promote regular waste disposal and balance the discharge between all ports (EU, 2019a).

How the waste is processed after disposal at the PRF is of the utmost importance. The following processes have varying impacts on the environment:

- special advanced treatment, such as incineration, sterilisation, bioremediation or energy recovery;
- disposal in a port reception landfill; or
- follow-up processing for recycling or re-use.

Some types of waste require particularly careful management and disposal, such as expired pyrotechnics, batteries, used wires, ropes and tails, and medical waste.

Image 5.2 Example of a port reception facility for waste

Source: © Euroshore.

It is important for the ship's master to plan onboard waste management properly and have information on the specific reception facilities available at each port called at on the journey. For this purpose, ports publish on their websites and other public databases a list of their PRFs, including maximum amounts that can be accepted, fees and contacts. Once waste has been disposed of, a waste receipt is issued to the master of the ship.

5.3.7 Circular economy in ports

Ports play a crucial role as facilitators of the transition to a circular economy, as they are part of a strategic infrastructure for international trade that plays a key role in the transfer of goods traffic between maritime and land-based transport. As value-added centres, ports support the creation of a productive and logistical environment in the areas where they are located. They can therefore be drivers for the development and implementation of circular economy initiatives and the creation of new value chains.

Circularity enabled by ports is an emerging area, focusing on leveraging the port's logistical capacity for linking locations with resources that have to be recirculated with locations with a demand for such resources. Specialised recycling or remanufacturing facilities could be considered. When such opportunities are explored, they build on and expand the activities within the port or region (i.e. port clusters).

One of the key elements is the governance model of the port and the regulations applicable to the infrastructure. Some of the circular economy strategies developed at national level include recommendations for the maritime and port sector. However, these strategies are not always adjusted to the type of port and its actual capacity to engage with a circular economy strategy.

The Circular Economy Action Plan

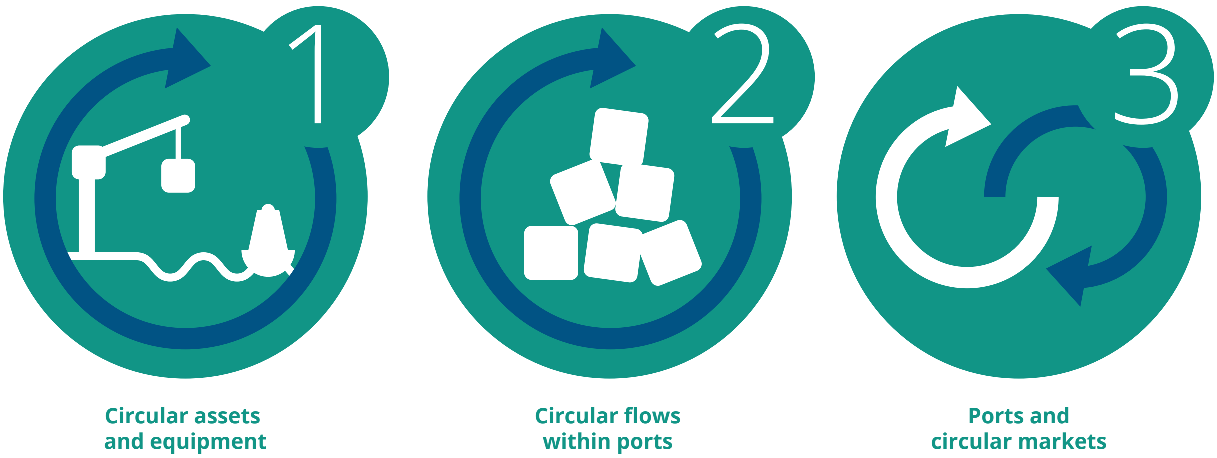
The concept of the circular economy is very broad and has multiple definitions. The European Commission states that a circular economy aims to maintain the value of products, materials and resources for as long as possible by returning them to the product cycle at the end of their life while minimising the generation of waste. It has further adopted the Circular Economy Action Plan (CEAP), which consists of a programme of actions with the aim of accelerating the transformative change required by the European Green Deal. This action plan puts in place the framework for a sustainable product policy and a partnership between the key stakeholders in the value chain for implementing the circular economy.

The areas in which port authorities and companies in the port can intervene to promote a circular economy can be summarised as (see Figure 5.16):

- circular assets and equipment — optimising capacity and extending the lifetime of port assets and infrastructure, such as buildings, cranes, quays and buoys, through maintenance and smarter use (sharing, renting, etc.), including green procurement;
- circular flows within ports and between ports and surrounding areas — new uses for would-be waste generated by port activities, such as ship waste and by-products of industries operating within ports, and port development activities (recycling, upcycling, cascading, etc.);
- ports and circular markets — ports enabling other industries (both on- and offshore) to become more circular by developing new activities that connect the supply of and demand for circular resources as the material moves through the port.

Table 5.2 describes some examples of circular economy initiatives at European ports.

Figure 5.16 Three areas of intervention in circular economy activities at ports



Source: Technical University of Denmark, Loop-Ports project funded by EIT Climate-KIC (Loop-Ports project, 2018-2020).

Table 5.2 Examples of circular economy initiatives in European ports

Area	Description of the initiative
1	Port of HaminaKotka (Finland) — digitalisation through a 3D operating system. This allows intensification of daily port operations, as well as effective maintenance and repair of port facilities.
	Port of Valencia (Spain) — the enlargement of cranes at Valencia terminals, so that they can attend to bigger vessels in the port, instead of disregarding them.
2	Port of Boulogne-sur-Mer (France) — fish by-products used as raw materials and ingredients for the nutraceutics, functional food, cosmetics and animal nutrition markets.
	Ports of Goro and Garibaldi (Italy) — to ensure the sustainable production of seafood, a circular value chain is created by implementing measures to limit lost nets, report lost nets, and collect and recycle recovered nets. Lastly, biodegradable nets are being developed.
3	Port of Frederikshavn (Denmark) — full circle decommissioning of ships and rigs by building a dedicated quay with specialist facilities that will support 100 % repurposing of both machinery and materials.
	Port of Moerdijk (Netherlands) — piloting return logistics to add value to waste tyres by replacing incineration with pyrolysis to obtain gas, oil and biochar for producing new goods and generating energy.

Oily waste (MARPOL Annex I) is, in volume, the most important waste stream collected by PRFs (Euroshore, 2021). Depending on the quantities delivered in each port, several techniques for processing these oily wastes, such as filtration, centrifugation, dewatering, flocculation or distillation, are being developed. These pre-processed materials are then further treated so that the resulting products contribute to the circular economy. However, measures like a harmonised EU end-of-waste status could be relevant if we are to benefit further from these initiatives (MARPOL Annex I, 2006).

In the EU, garbage (MARPOL Annex V), is the second most important volume of ship waste collected. The segregation into different waste fractions is often limited on board. Ships may also have difficulty finding segregated reception facilities ashore. The situation is therefore not fully aligned with the environmental rules in force in the European countries where the garbage is received (MARPOL Annex VI, 2006). This generates problems of compliance with the waste management and transport rules in these countries. Moreover, delivering a mixture of the different waste fractions limits the percentage of waste entering a recycling process. A lot of waste is potentially recyclable. Between the potential and the reality, there is a gap that can be reduced by improving collaboration between ships and PRFs, supported by legal enforcement and efficient control.

This might help stakeholders to concentrate on areas where the circular economy could be enhanced for the benefit of the environment.

6
Monitoring and reporting

Monitoring is key for the effective and timely implementation of the various sets of laws, rules and standards. Furthermore, information gathered through monitoring is critical for the evaluation of the state of the environment. Within this context, EU agencies assist the European Commission and the Member States and the regional sea conventions in the effective implementation of both international and EU-relevant binding laws. EMSA develops technological solutions that implement monitoring and reporting services, enhancing capacity in areas that are the ultimate responsibility of the Member States. These include the development of specialised tools and instruments to support Member States in their control and monitoring responsibilities and their reporting obligations to the European Commission. The EEA facilitates the reporting and monitoring of environmental data at EU level. This chapter provides a description of these key monitoring and reporting services.

6.1 Services for air emissions

6.1.1 THETIS-EU (sulphur)

THETIS-EU (EMSA, 2010) serves as a platform to record and exchange the results of individual compliance verifications performed by Member States as envisaged in the Directive on the reduction in the sulphur content in marine fuels (EU, 2016b). A risk-based approach has been implemented on the platform, partly based on the exchange of alerts, which allows competent authorities to target ships for compliance verification.

Since 1 January 2015, when the system became operational, the results of over 60 000 specific inspections on ships (an average of 700-900 per month) have been recorded in THETIS-EU (Figure 6.1). The results of these inspections allow EMSA to establish that the sulphur in fuel standards are being effectively implemented, with compliance rates in the maritime transport sector of over 95 % (EMSA, 2020a; see also Figure 6.2).

Initially developed to support the Sulphur Directive, THETIS-EU has since evolved to support other laws on port reception facilities (PRFs; EU, 2000b), ship recycling (EU, 2013a) and ship and port facility security (EU, 2004).

6.1.2 THETIS-MRV

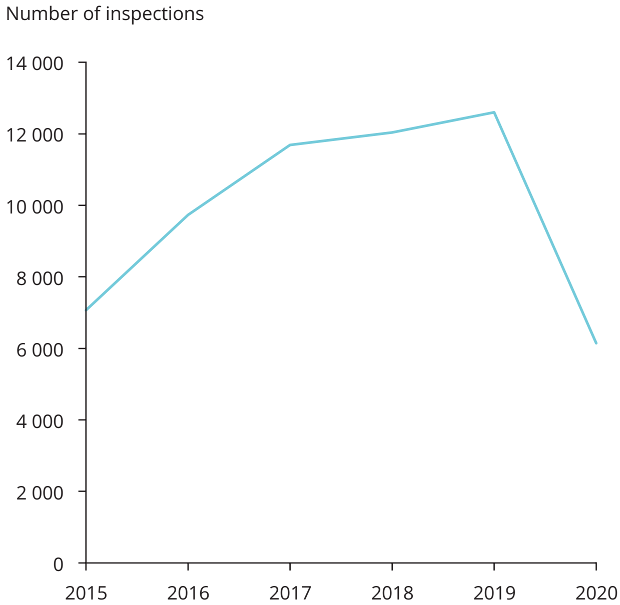
Since 7 August 2017, THETIS-MRV (EMSA/THETIS-MRV, 2017) has served as a robust integrated web-based automated reporting and notification system that allows the publication of reliable data on ships' carbon dioxide (CO_2) emissions and other relevant information on the fleet, above 5 000 GT (gross tonnage), calling at ports in the European Economic Area.

Extending the potential of the original THETIS information system, EMSA designed a purpose-built tool for all relevant parties (companies, verifiers, EU Member States, flag states of non-EU ships visiting EU ports and the European Commission; EU, 2015). This tool supports them to fulfil their monitoring and reporting obligations in a centralised and harmonised way while preserving the confidentiality of commercial or industrial information.

The scope of THETIS-MRV is also aligned with the EU monitoring, reporting and verification (MRV) system, with international initiatives to introduce efficiency standards for existing ships also covering operational measures, and it contributes to the removal of market barriers related to the lack of information.

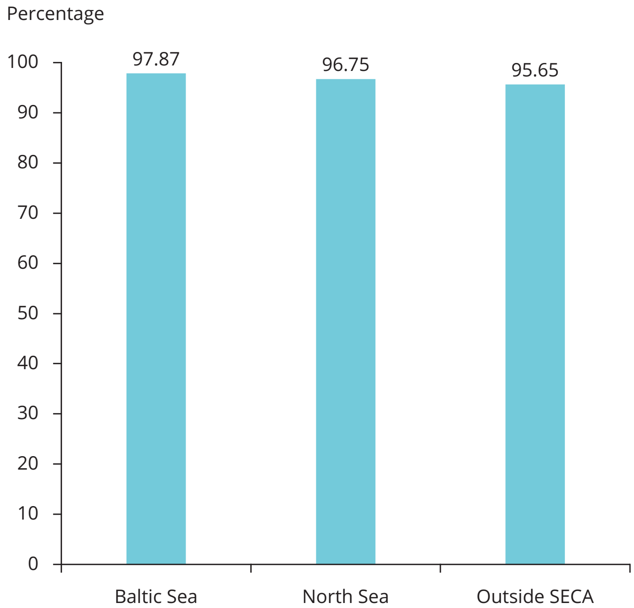
On 30 June 2019, for the first time, the European Commission published information on the CO_2 emitted by ships over 5 000 GT when performing maritime transport activities related to the European Economic Area. This information covered around 11 650 ships of various types, services and cargo carried, ranging from roll-on, roll-off (Ro-ro) passenger ships to bulk carriers, tankers and container ships. Furthermore, the European Commission published a report analysing the emissions data reported to inform the public and allow an assessment of the CO_2 emissions and the energy efficiency of maritime transport (Figure 6.3).

Figure 6.1 Total yearly sulphur inspections



Source: EMSA (2020a).

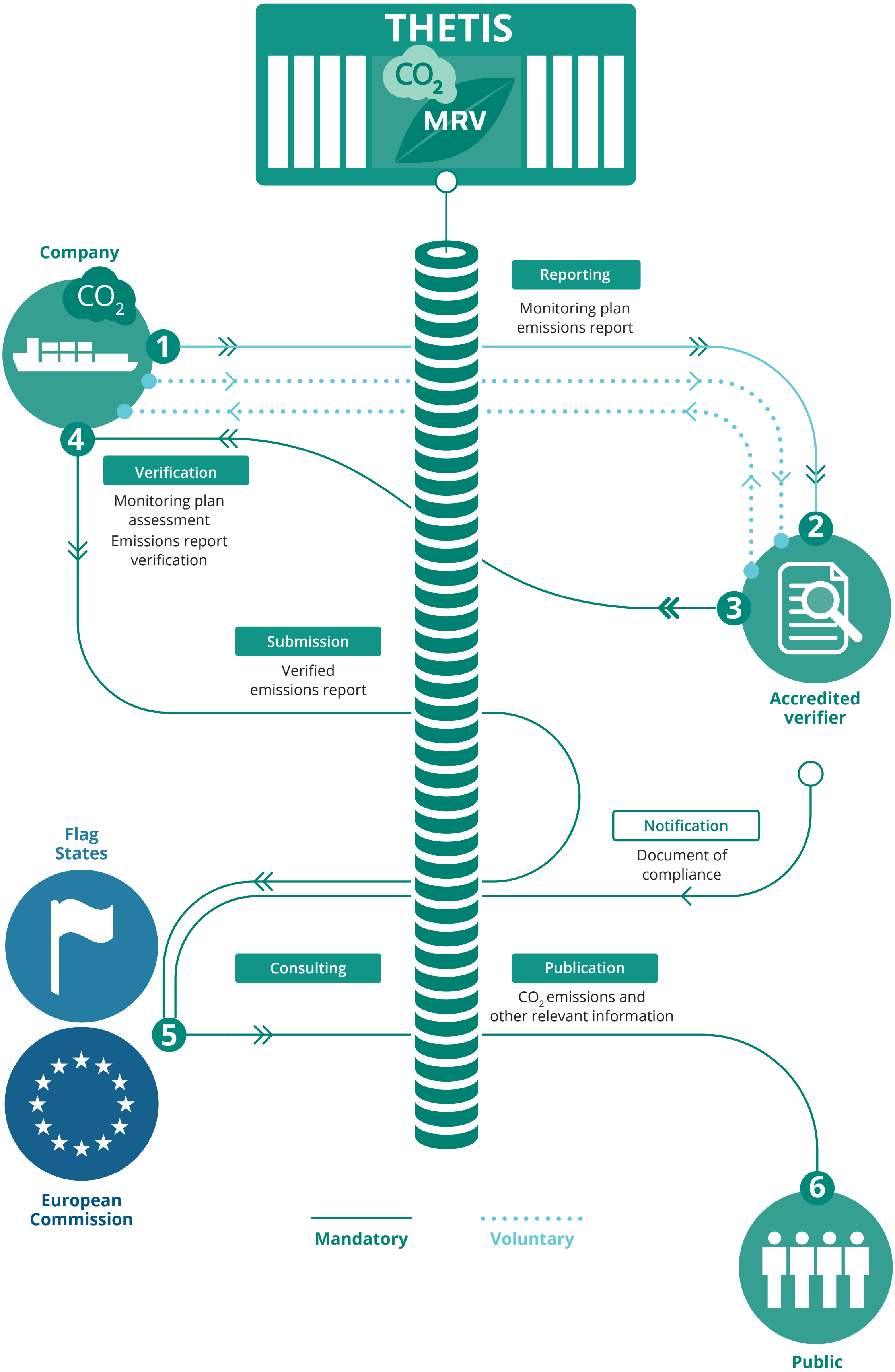
Figure 6.2 Rates of compliance with the sulphur fuel standards, based on fuel samples analysed in 2019



Note: SECA, sulphur emission control area.

Source: EMSA (2020a).

Figure 6.3 THETIS-MRV infographic



Source: Compiled from EMSA Services data.

6.1.3 Remotely piloted aircraft systems

Monitoring the emissions from a ship's smokestack by remotely piloted aircraft systems (RPASs) helps to enforce the standards, as the information obtained can then be shared among the relevant authorities. RPASs are used as aerial platforms with gas sensors ('sniffers') that measure the amount of sulphur oxides (SO_x) versus CO_2 in a ship's plume. This relationship can ascertain the sulphur content of the fuel being used on board, which is then compared with the legal limits. RPASs also carry sensors to assist in the identification of the vessel (Image 6.1). This operational information can be complementary to other emission monitoring activities undertaken by Member State authorities to ensure that all vessels in transit in European waters comply with the legal requirements.

EMSA provides an RPAS service capable of measuring the amount of SO_x emitted by individual ships travelling into or in the European emission control areas and, in general, territorial seas, exclusive economic zones and pollution control zones of Member States. The combination of real-time on-site data from an RPAS, together with the maritime information available through EMSA, and the availability of Member States' sulphur inspectors can be considered a cost-effective solution for monitoring emissions as well as a deterrent. The RPASs can also be used to make measurements of nitrogen oxide (NO_x) emissions from ships, and therefore support the monitoring of the nitrogen emission control areas from 2021.

6.2 Services for marine environment protection

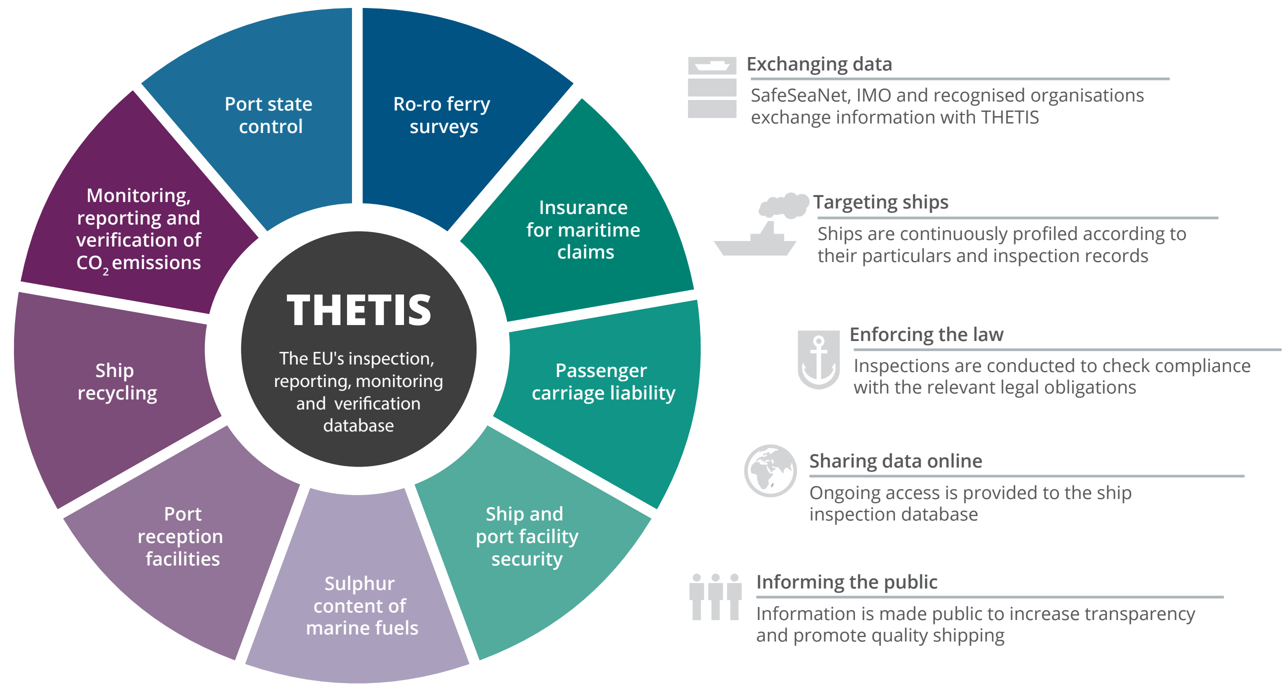
6.2.1 THETIS

THETIS is the information system developed by EMSA to support the port state control inspection regime (EMSA/THETIS, 2021; see also Figures 6.4 and 6.5). This information system is crucial for the implementation of that regime (EU, 2009a) but also to support the implementation of other EU rules on Ro-ro ferries and high-speed passenger craft (EU, 1999), vessel traffic monitoring (EU, 2009b), recognised organisations (EU, 2009c, 2009d), insurance for maritime claims (EU, 2009e) and liability for the carriage of passengers (EU, 2009f). The system serves both the EU and the wider region covered by the Paris Memorandum of Understanding on Port State Control (Paris MoU), which includes Canada, Iceland, Norway and Russia.

Image 6.1 EMSA remotely piloted aircraft in operation

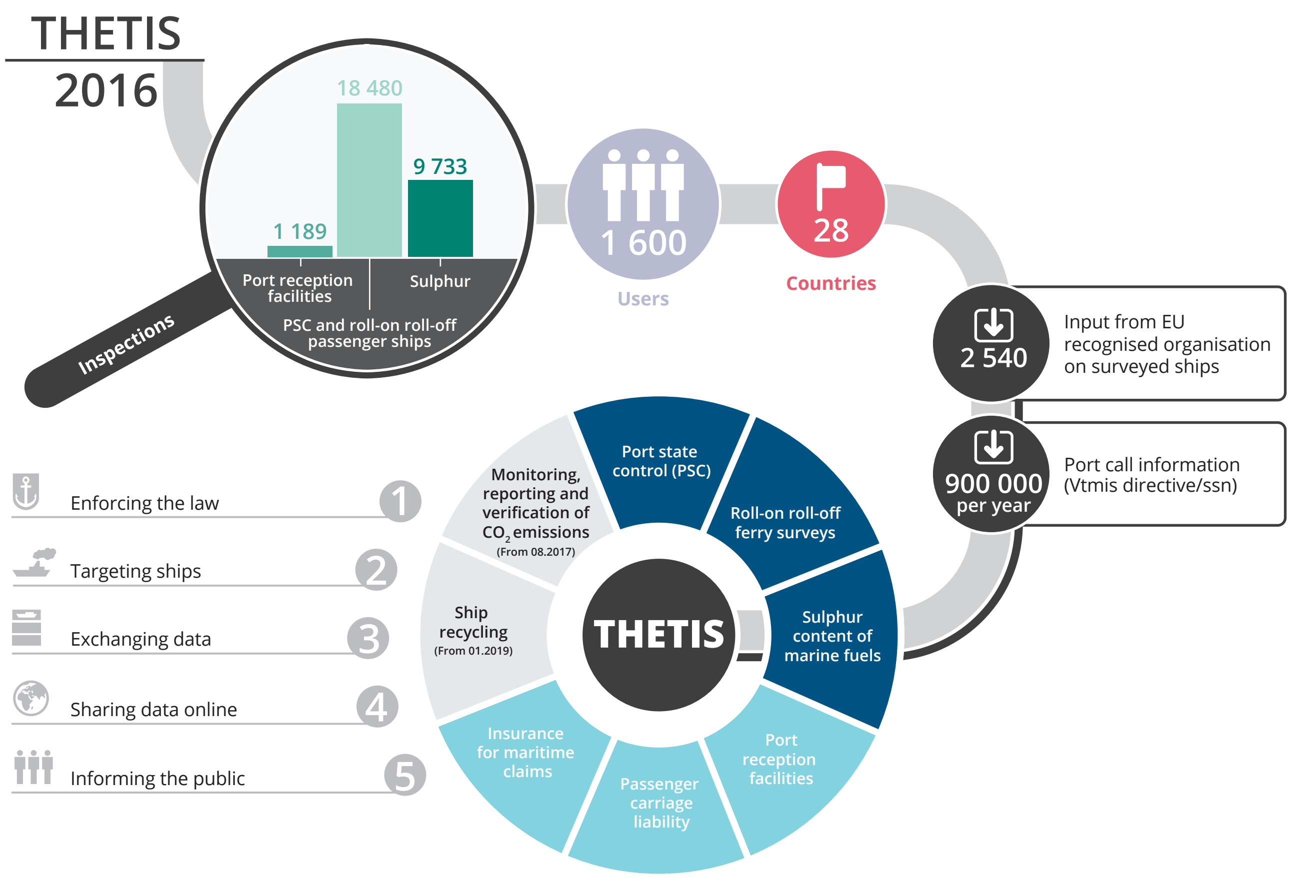
Source: © EMSA Services.

Figure 6.4 THETIS information system



Source: Compiled from EMSA Services data.

Figure 6.5 THETIS Information system: key tasks and facts and figures



Source: Compiled from EMSA Services data.

To facilitate planning of inspections, the system is linked to the EU SafeSeaNet system. SafeSeaNet provides information on ships in, or expected at, all Member States' ports. THETIS indicates which ships have priority for inspection and allows the results of inspections to be recorded. Through THETIS these reports are made available to all port state control authorities in the EU and included in the Paris MoU.

Under the port state control regime, the MARPOL Convention is among those that port state control officers verify on board ships during their inspections. The outcome of the inspections is reported in THETIS including all MARPOL Convention-related deficiencies. Since 2015, the number of inspections with MARPOL-related deficiencies has remained consistently at around 20 % every year (around 2 400 annual inspections; Figure 6.6). Of that 20 % of inspections with MARPOL related deficiencies, 62.5 % of them were deficiencies in certificates and documents, and 37.5 % were deficiencies in pollution prevention.

6.2.2 THETIS-EU (PRF)

Since January 2016, THETIS-EU (EMSA, 2020a) has served to record and exchange information about PRF-related inspections. Up to 31 December 2019, over 12 000 inspections had been recorded, and the number of inspections per year has grown from around 1 000 in 2016 to almost 5 000 in 2019 (Figure 6.7). Around 25 % of these inspections resulted in the identification of non-compliance (NC; Figures 6.7). Over 33 % of those non-compliances were due to failure to offload the waste on board the ship at the port of inspection (Figure 6.8).

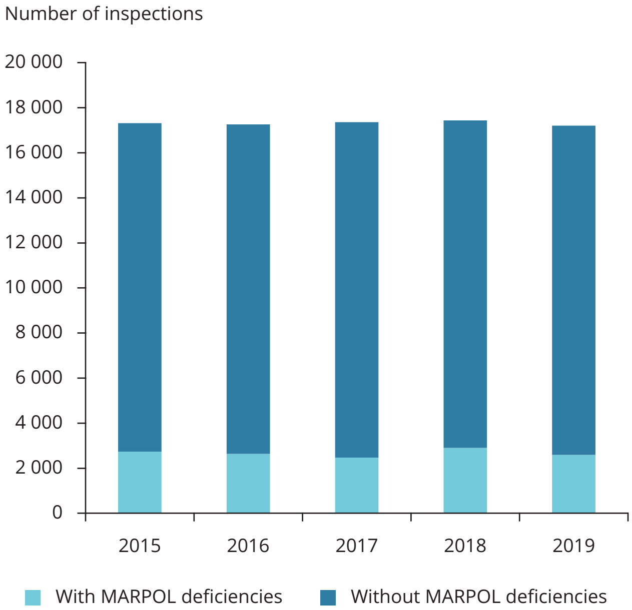
6.2.3 European Marine Casualty Information Platform

The European Marine Casualty Information Platform (EMCIP) is a database and a data distribution system operated by EMSA, the European Commission and the EU and European Economic Area countries. EMCIP provides the means to store data and information on marine casualties and incidents involving a wide spectrum of types of ships, including occupational accidents related to ship operations and accidents causing damage to the environment (Figure 6.9). It also enables the production of statistics and analysis of the technical, human, environmental and organisational factors involved in accidents at sea.

The notification of marine casualties and incidents and data resulting from safety investigations to EMCIP has been mandatory for all EU Member States since 2011 (EU, 2009g). This has allowed EMSA to assist the European Commission and the Member States with the analysis of such data, the development of trend monitoring mechanisms, proposals for safety recommendations, the improvement of existing EU rules and the promotion of new technical standards.

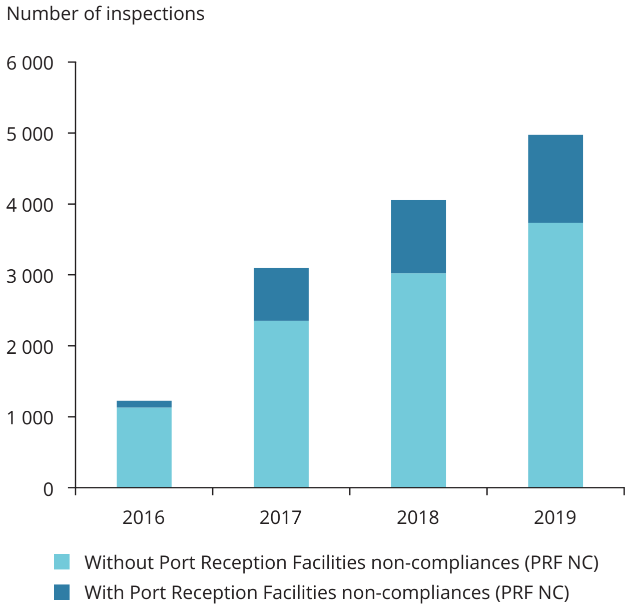
EMCIP is also connected to the Global Integrated Shipping Information System (GISIS) managed by the International Maritime Organization (IMO), thus supporting the dissemination of investigation data reported by the EU and European Economic Area countries at a global level without any duplication of effort. The database's taxonomy was developed by EMSA in consultation with Member States, based on European research and international recommended practice and procedures. Information about marine casualties and incidents is also made accessible to the public, such as the investigation reports published by the accident investigation bodies and 'anonymised' data on casualties and incidents notified by Member States' authorities.

Figure 6.6 **Port state control inspections with and without MARPOL Convention related deficiencies**



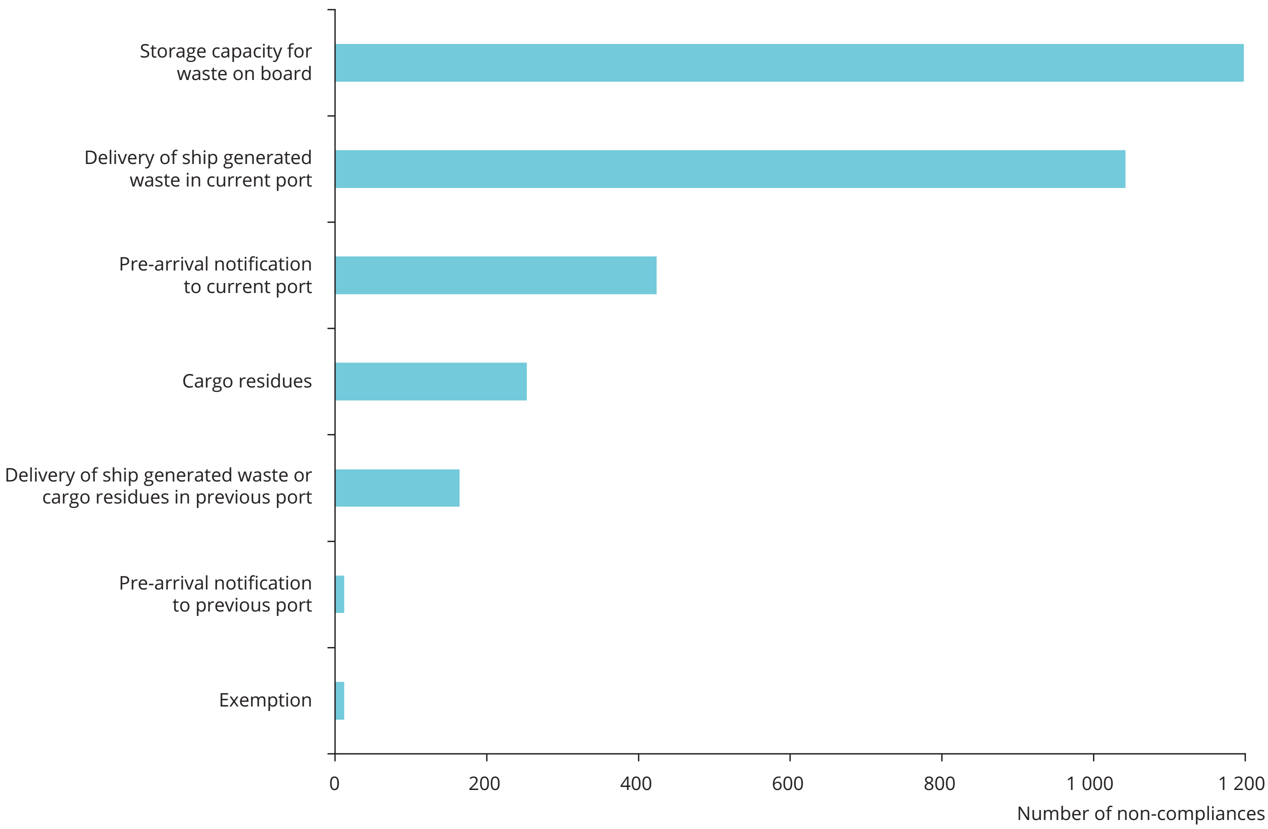
Source: Compiled from EMSA Services data.

Figure 6.7 **Number of PRF inspections**



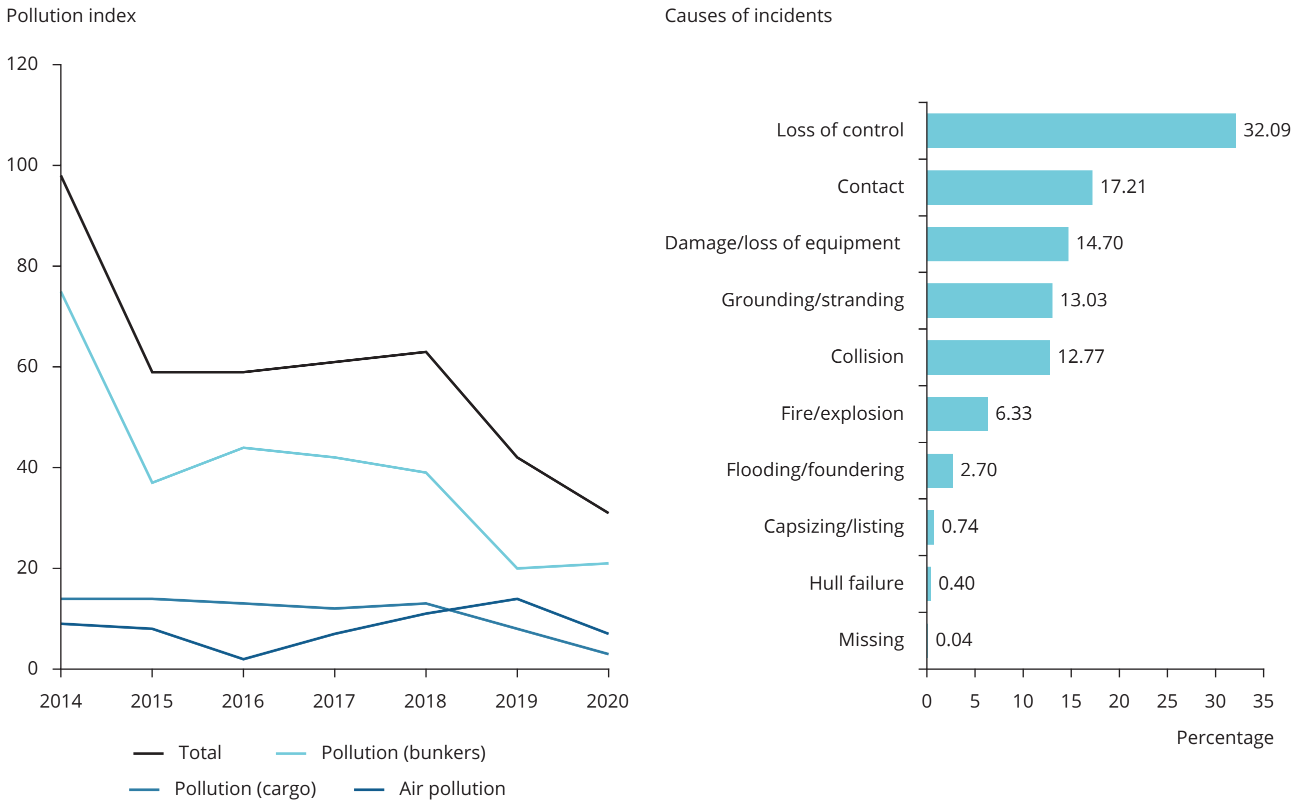
Source: EMSA (2020a).

Figure 6.8 **Total number of PRF non-compliances per type, 2016-2019**



Source: EMSA (2020a).

Figure 6.9 EMCIP information on numbers of pollution incidents resulting from marine accidents (left) and the causes of incidents (right), 2014-2020



Source: EMCIP (2021).

6.2.4 CleanSeaNet

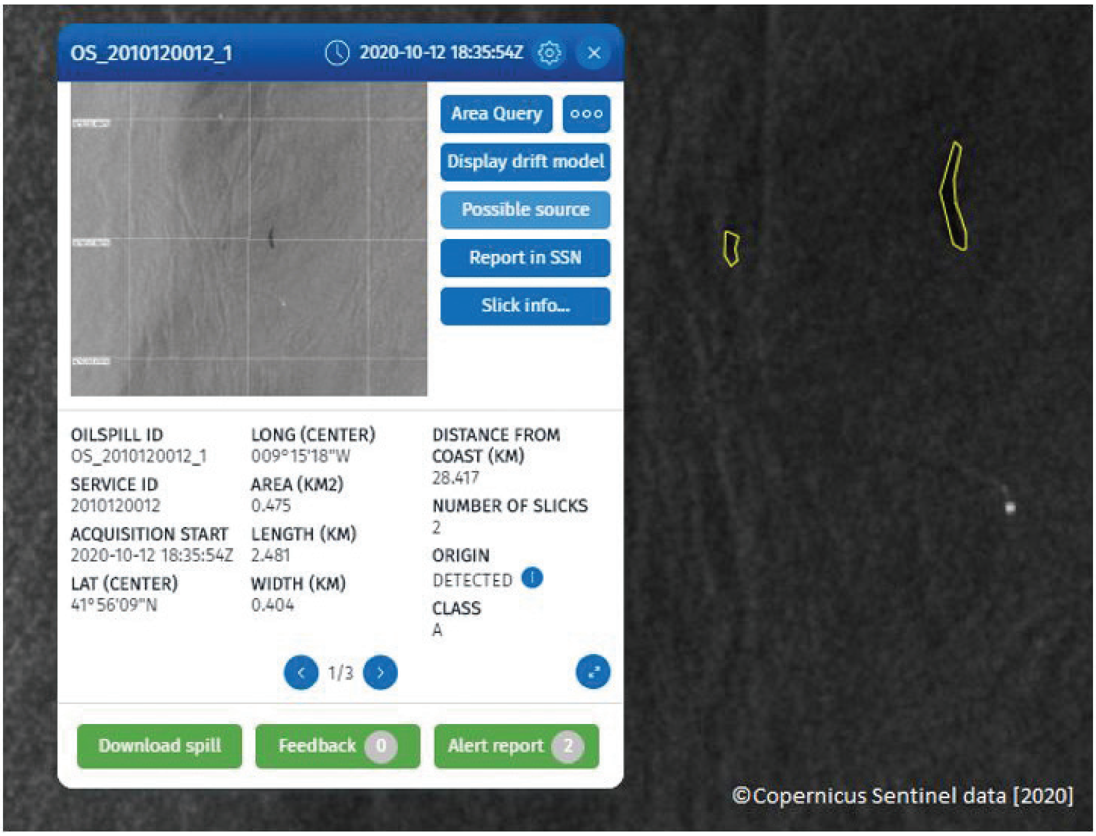
CleanSeaNet is the European satellite-based oil spill monitoring and vessel detection service developed and operated by EMSA since April 2007. The CleanSeaNet service is a key element in this operational chain, linking into the national chains. It is based on the regular and widespread monitoring of European maritime areas using satellite images. These images, mainly from synthetic aperture radar (SAR), but also from optical missions, are analysed to:

- detect possible oil on the sea surface, including discharges of mineral oil;
- identify potential polluters; and
- monitor the spread of oil during maritime emergencies.

SAR images are the result of electromagnetic pulses generated by a radar that are reflected by the ocean surface. By measuring the roughness of the sea surface, the resulting images display features that stand out against the background. For example, ships appear as bright spots, while oil spills appear as dark shapes (Figure 6.10). Images can be acquired regardless of weather conditions and cloud cover and are not dependent on daylight.

The service now delivers over 7 000 images from six satellites per year, with over 3 million km² monitored every day, and detects over 7 000 possible spills per year. It is available to all EU Member States, European Free Trade Area/ and European Economic Area countries and candidate countries, as well as to neighbouring countries in their seaareas, in the context of the European Neighbouring Policy projects. When a possible oil spill is detected, an alert message is sent to the relevant coastal state within 20 minutes of the satellite acquiring the image. The end user can also visualise the image, the possible spills and identified ships, together with vessel traffic information, directly in EMSA's web interface. Upon receiving the alert report from CleanSeaNet, the national authority decides how to respond, which could be sending an aircraft or patrol vessel to verify the detection and potentially obtaining confirmation that an illegal discharge is taking place. An authority may decide that it is not operationally relevant to follow up the alert if the discharges are legal under MARPOL regulations or because of the size of the soill or the distance to the coast.

Figure 6.10 **Example of an oil spill (composed of two parts, designated as slicks) detected in a Sentinel-1 satellite SAR image acquired in October 2020 near Galicia (Spain)**



Source: Image taken from the SafeSeaNet Ecosystem graphical user interface, the common web interface providing access to EMSA's maritime applications and data sets.

6.2.5 SafeSeaNet

Following the accident involving the crude oil tanker MV *Erika* off the French coast in 1999, the EU adopted several laws to improve the prevention of accidents at sea and to combat marine pollution. Among those, it established the SafeSeaNet, the EU maritime information and exchange system, 'with a view to enhancing the safety and efficiency of maritime traffic, improving the response of authorities to incidents, accidents or potentially dangerous situations at sea, including search and rescue operations, and contributing to a better prevention and detection of pollution by ships' (EU, 2002).

The main objective of SafeSeaNet is to provide a European platform for maritime data exchange between maritime administrations in the Member States to ensure the implementation of EU legislation in the area of vessel traffic monitoring. It comprises a network of national SafeSeaNet systems in Member States and a central SafeSeaNet system acting as a nodal point, which interacts with the national systems. EMSA in cooperation with the Member States and the European Commission is responsible for the technical implementation and the documentation of the central SafeSeaNet system.

SafeSeaNet has been set up as a network for maritime data exchange, linking together maritime authorities from across Europe. It enables EU Member States, Norway and Iceland to provide and receive information on ships, ship movements and hazardous cargoes. The main information elements that are contained in the system and made available to users are as follows:

- automatic identification system (AIS) based on near-real-time ship positions (i.e. one identification every 6 minutes);
- archived historical ship positions (over several years);
- additional information from AIS-based ship reports (e.g. name or identification number, flag, dimensions, course, speed, destination and ship type);
- estimated and actual times of arrival and departure;
- details of hazardous goods carried on board;
- information on safety-related incidents affecting ships;
- information on pollution-related incidents affecting ships;
- details of waste carried on board/to be offloaded (from June 2015);
- ship security-related information (from June 2015);
- information on the location of remaining single-hulled tankers;
- information on the location of ships that have been banned from EU ports.

Accurate knowledge of dangerous or polluting goods being carried on board ships is essential for the preparation of effective operations to tackle pollution or the risk of pollution at sea.

To streamline and accelerate the transmission and use of what may be huge amounts of information on cargo, this information is sent electronically to the competent authority or port authority concerned. For the same reasons, information is exchanged between the competent authorities of the Member States electronically. SafeSeaNet facilitates this exchange of information in electronic format and makes it available 24/7.

In the event of an accident or incident at sea, the master of the ship should immediately report to the coastal station responsible for that geographical area, including any situation liable to lead to pollution of the waters or shore of a Member State, such as the discharge or threat of discharge of polluting products into the sea (a pollution report or PolRep), or if any containers or packages are lost by a ship or seen drifting at sea (Lost & Found Containers/Objects). These incidents may result in specific incident reports (e.g. a PolRep or Lost & Found Objects) that will be automatically distributed using SafeSeaNet to other Member States' authorities located along the ship's planned route. In the specific case of PolReps, the incident reports are also automatically distributed to CECIS, the Common Emergency Communication and Information System, managed by DG ECHO (Directorate-General for European Civil Protection and Humanitarian Aid Operations).

SafeSeaNet enables the monitoring of maritime activities and could facilitate the measurement of pollution density emissions in the future. In addition, where AIS is allowed to be shared, it can underpin route/voyage and port call maximisation, supporting the most efficient and therefore sustainable speed and management of the vessel.

7 Future trends in maritime transport and trade

Maritime transport is largely dependent on trade patterns and changes associated with it. Drastic changes in production and consumption patterns, such as those experienced during the COVID-19 pandemic, may lead to adjustments in the sector. This chapter analyses the current state of the EU seaborne trade of goods, as well as potential future scenarios for maritime transport and ports, and how these may affect the environment. It also includes a discussion of how climate change can affect the maritime transport and port sectors from an economic point of view.

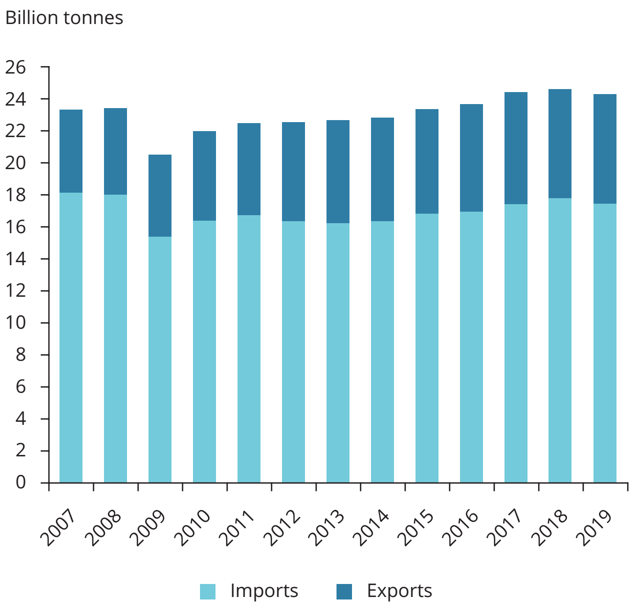
7.1 Seaborne trade of goods to and from the EU

Maritime transport is driven by international consumption and production patterns. In this section, the current state of and trends in the trade of goods to and from the EU by sea is discussed. It introduces general trends in the trade of goods in and out the EU, and then focuses on seaborne trade, identifying the types of goods shipped and major origin and destination countries.

7.1.1 Volume of goods shipped by sea

The volume of goods traded to and from the EU by all modes of transport slowly increased from 23.3 billion tonnes to 24.3 billion tonnes over the period 2007-2019 (Eurostat, 2020b). This equates to a total growth of 4.2 % over 12 years, or 0.33 % annually. The total volume traded decreased by 13 % between 2008 and 2009, following the global financial crisis (Figure 7.1).

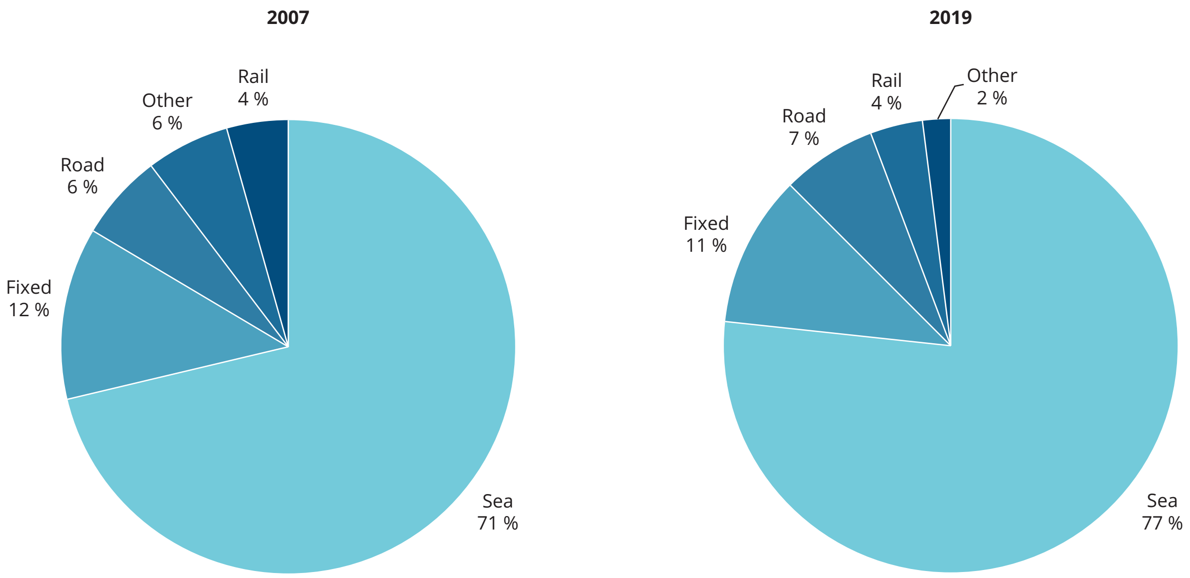
Figure 7.1 Volume of goods traded to and from the EU



Source: Eurostat (2020b).

The EU imports a considerably higher volume of goods than it exports (although in economic terms the EU has had a trade surplus since 2012). In 2019, exports comprised only up to 28 % of the total volume traded, although they increased in volume by 32 % between 2007 and 2019 while imports fell by 3.7 %. Imports are determined by EU consumption patterns and where the goods are produced. Considering the economic value of imported goods (assuming that broadly all categorised consumption and intermediate goods are ultimately consumed by EU households), then in 2018 the value of goods imported for household consumption was equivalent to 18 % of the EU total (Eurostat, 2020b).

Figure 7.2 **Mode of transport (%) used by goods traded to and from the EU in 2007 and 2019**



Source: Eurostat (2020b).

The majority of goods transported into and out of the EU are shipped using maritime transport (see Figure 7.2). In 2019, maritime transport accounted for 77 % of the total volume of goods traded, a slight increase from 71 % in 2007. Fixed transport (i.e. pipelines) is the second most important mode of transport, followed by road and then rail.

7.1.2 Types of goods shipped by sea

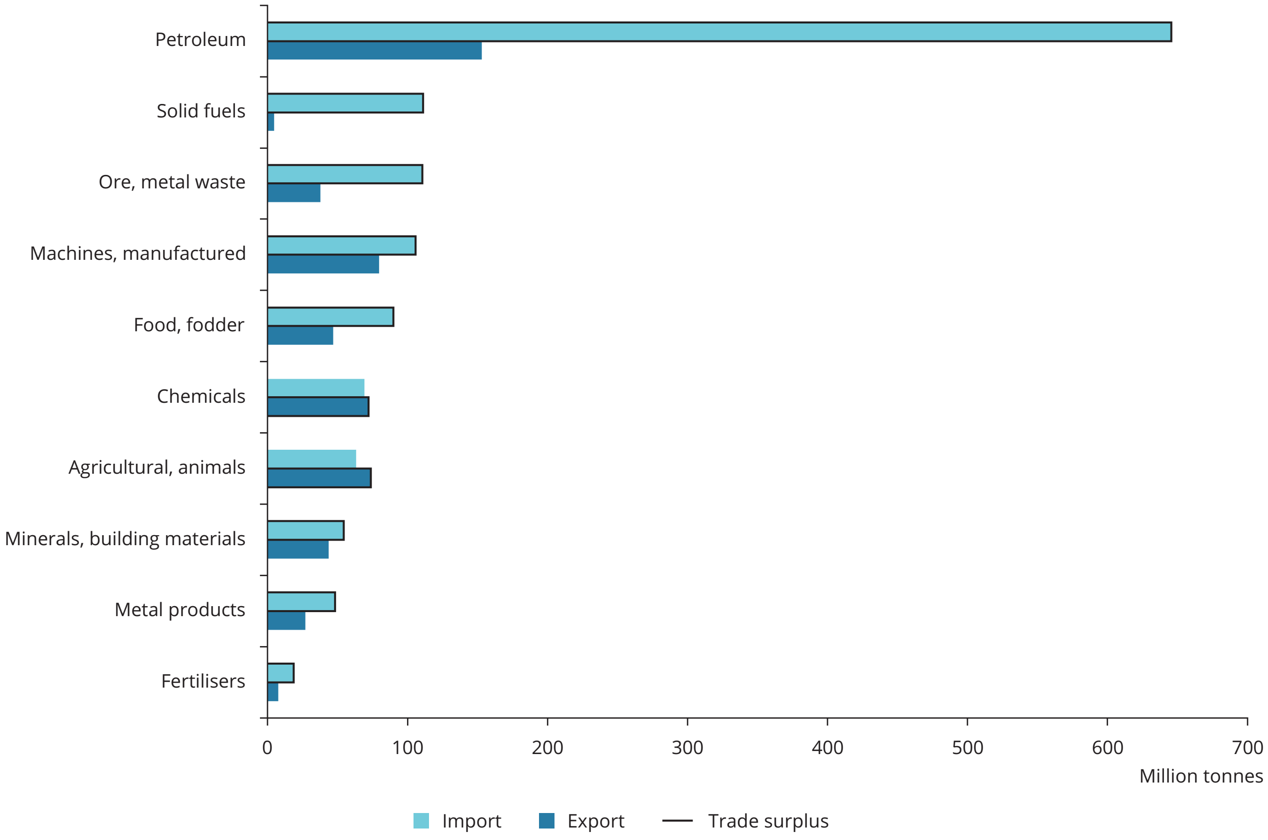
The types of goods imported to and exported from the EU, in volume, using maritime transport in 2019 are shown in Figure 7.3. They are classified into various product groups in accordance with the Standard goods classification for transport statistics (revised) . In terms of total volume of goods shipped (i.e. imports and exports), the leading category is petroleum products, which in 2019 made up 43 % of the total tonnage traded, 81 % of which was imports. Machinery, transport goods, manufactured goods and miscellaneous articles were the second most voluminous, making up 10 % of the total tonnage shipped, 57 % of which was imports. This category includes manufactured consumer items, such as electronics, furniture, and cars, as well as finished products for industry, such as tractors and machinery.

The EU had a small positive trade balance by tonnage for only two categories: agricultural products and live animals (46 % of volume was imports), which includes unprocessed fruit, vegetables, cereals, meat and wood; and chemicals (49 % of volume was imports). In addition to petroleum, the EU had a very large trade deficit for solid fuel (e.g. coal), of which 96 % of the volume was imports, ores and metal waste (75 % of volume imports), and fertilisers (71 % of volume imports).

7.1.3 Destinations of shipments by sea

The EU's main trading partners by tonnage shipped by sea (imports and exports) are Russia, the United States, China, Norway and Brazil (when petroleum shipments are included). In 2019, these five countries accounted for 41 % of the total seaborne volume traded into and out of the EU. Their total share has increased slightly by 1.5 % since 2007. However, during the period between 2007 and 2019, their relative share shifted. While Russia remains the top seaborne destination by weight for EU goods (with 13 % of total volume), the United States retained its second-place position but its share increased from 8 % to11 %. Norway and Brazil both slipped down one place to fourth and fifth position, respectively, in 2019, with a decreasing absolute and percentage share of total volume. In contrast, China moved up to become the EU's third largest trading partner by weight. As petroleum accounts for 43 % of the total trade volume and therefore could be dominating these trade patterns, Figure 7.4 includes trade in petroleum.

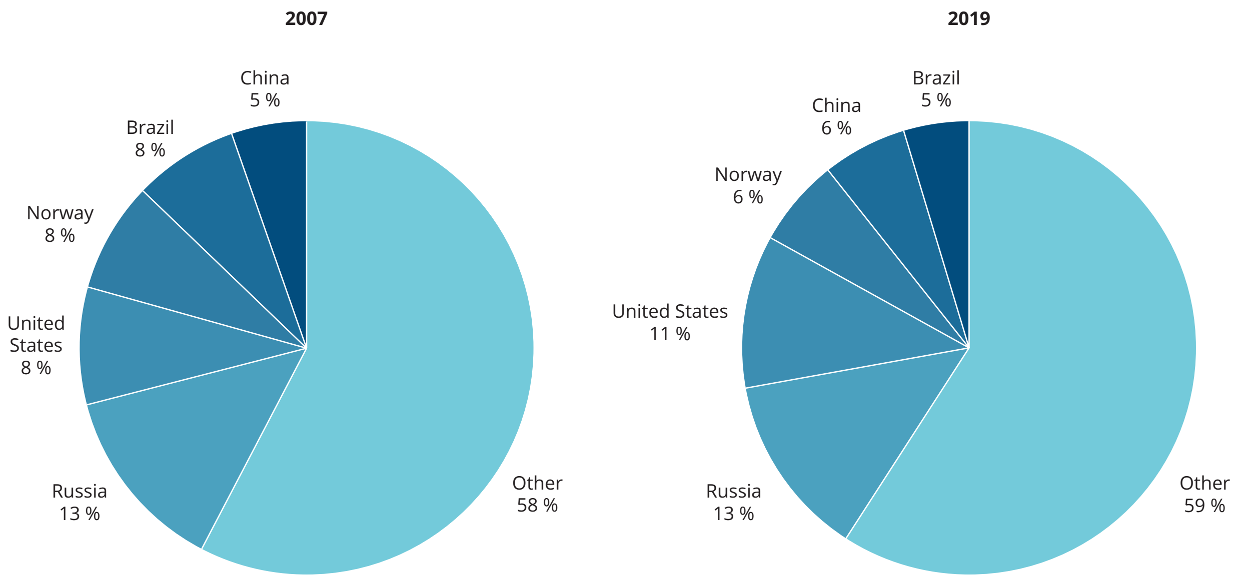
Figure 7.3 Types of imported and exported goods (by tonnage) shipped by sea, 2019



Note: Bars outlined in black indicate a trade surplus or deficit in that product group.

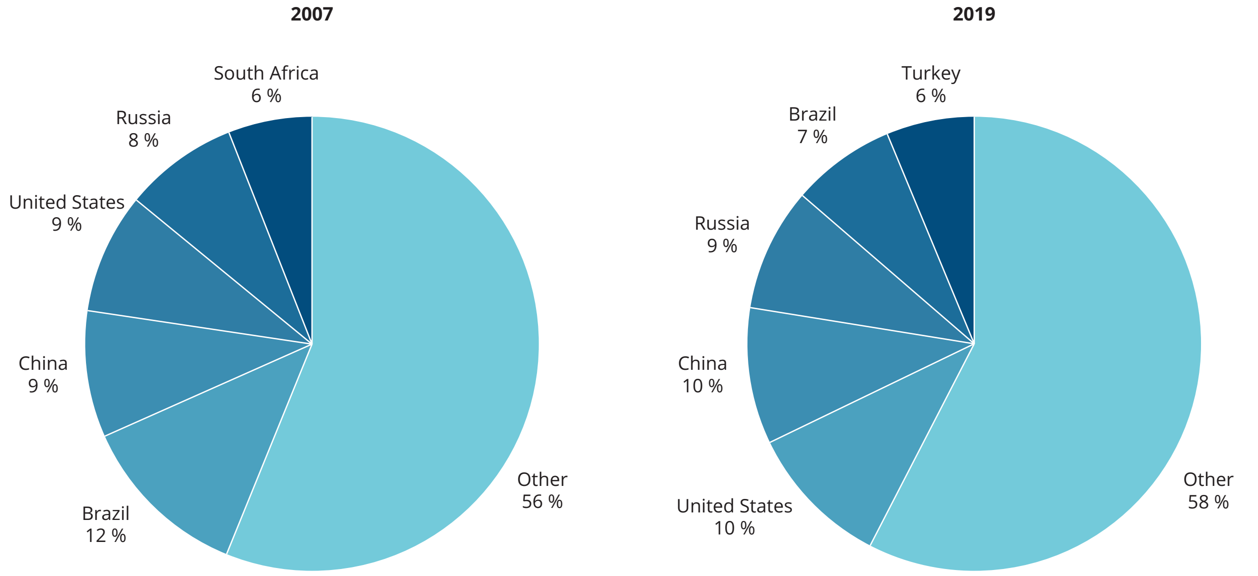
Source: Eurostat (2020b).

Figure 7.4 Top EU seaborne trading partners (by tonnage) — including petroleum — in 2007 and 2019



Source: Eurostat (2020b).

Figure 7.5 Top EU seaborne trading partners (by tonnage) — excluding petroleum — in 2007 and 2019



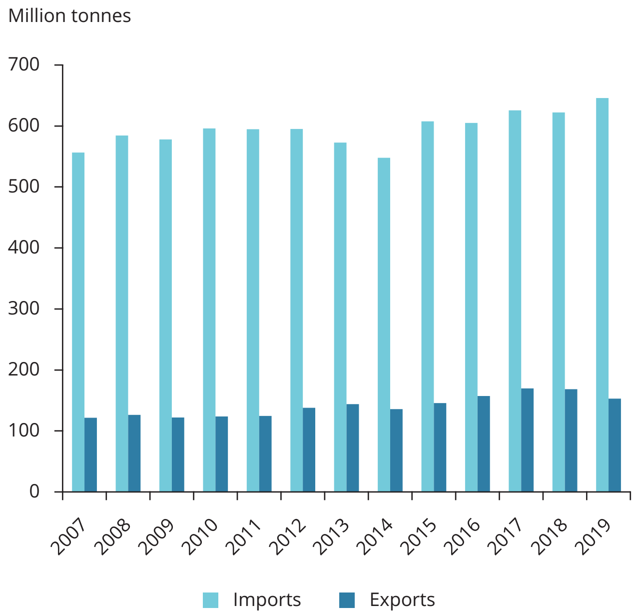
Source: Eurostat (2020b).

When petroleum shipments are excluded, there is a slight shift in the relative importance of seaborne trading partners by volume (see Figure 7.5). In 2019, Russia was only the third largest non-petroleum trade partner by volume, falling from the top position when petroleum is included (Figure 7.4). The United States was the top non-petroleum trading partner, excluding petroleum, followed by China, Russia, Brazil and Turkey. The relative importance of trading partners (excluding petroleum) shifted during the period 2007-2019, with Brazil's share of non-petroleum trade falling from 12 % to 7 % (a fall from first to fourth most important partner by volume) and South Africa's share falling from 6 % to 2.4 % (a fall from fifth to 11th most important partner by volume). Conversely, Turkey has seen its importance rising, moving from 4.3 % of seaborne non-petroleum trade by volume in 2007 to 6.3 % in 2019 (and moving into fifth place).

7.1.4 Shipments of petroleum

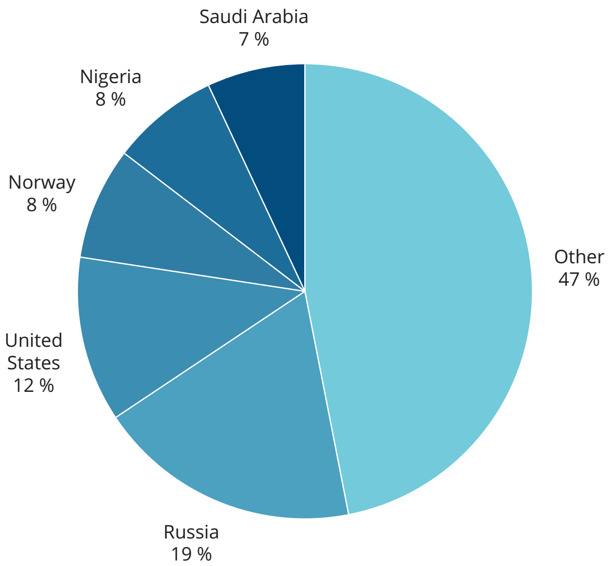
Imports and exports of petroleum are growing in absolute terms (Figure 7.6). Petroleum also has a growing share of total seaborne trade, up to 43 % from 41 % in 2007.

Figure 7.6 EU Seaborne imports and exports of petroleum, 2007-2019



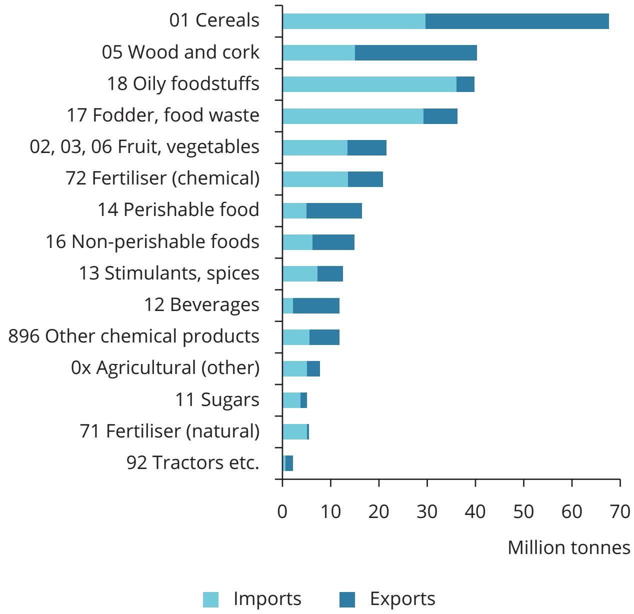
Source: Eurostat (2020b).

Figure 7.7 **Top EU seaborne trading partners for petroleum imports and exports, 2019**



Source: Eurostat (2020b).

Figure 7.8 **Farm to Fork Strategy — related product groups: tonnage of goods shipped to and from the EU by sea, 2019**



Source: Eurostat (2020b).

Seaborne trade in petroleum fluctuates with changes in the petroleum market and economic conditions (Figure 7.6). The low point in trade in 2014 followed 3 years of historically high prices in the oil markets, while the jump upwards in 2015 and 2016 reflects decadal low oil prices (IEA, 2016). In 2019, the majority of petroleum trade volume was in crude petroleum (58 %), with 31 % of the volume in fuel derivatives (such as gasoline and jet fuel) and 8 % in gaseous hydrocarbons (e.g. liquefied petroleum gas). In 2019, the EU's major trading partners for petroleum were Russia, the United States, Norway, Nigeria and Saudi Arabia (Figure 7.7). The last two — Nigeria and Saudi Arabia — are notable in that they do not feature in the top 10 of the EU's seaborne trading partners by volume.

7.1.5 Shipments of food products

The European Commission Farm to Fork Strategy (EC, 2020f) identifies the integrated nature of the EU's food system, which involves both European and international consumers, farmers and processors, and international maritime transport. Along with the EU's Common Agricultural Policy and other policies, the Farm to Fork Strategy will shape future European production and consumption patterns related to agriculture and food and the international shipping of these goods. For example, the Farm to Fork Strategy aims to reduce the EU's dependency on importing critical inputs, such as feed materials, while maintaining food security and growing sector incomes. Figure 7.8 illustrates the EU's reliance on maritime transport for trade in Farm to Fork Strategy-related product groups (EC, 2020f).

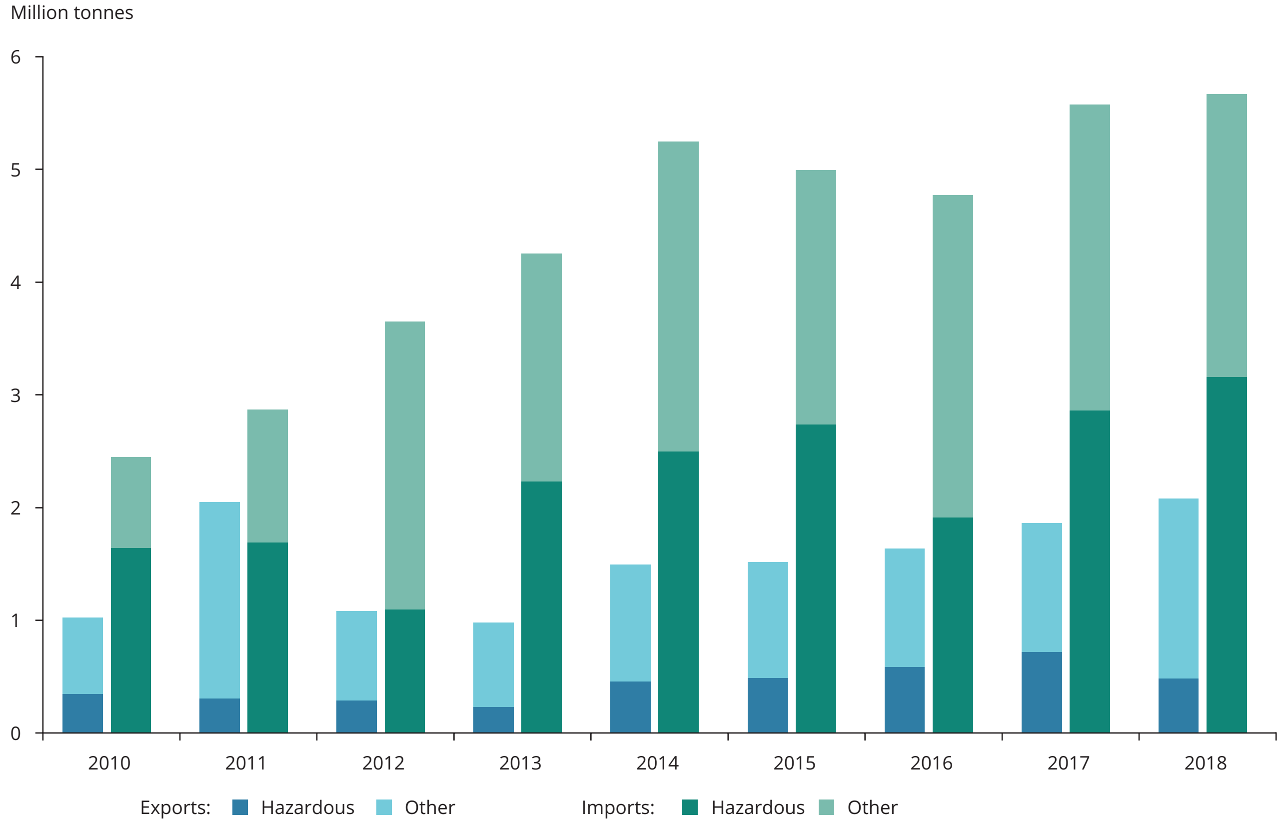
In terms of mode of transport, 81 % of the total tonnage of Farm to Fork Strategy-related product groups was shipped into and out of the EU by sea in 2019. Of these, 43 % were exports and 57 % imports. By volume, cereals, wood and cork, fodder and food waste, and oily foodstuffs generated the greatest volumes of trade (Figure 7.8). Furthermore, the EU's relative dependency on imports can be highlighted. The top five product groups in terms of the scale of their European trade deficit (i.e. where Europe imports more than it exports) are natural fertilisers (93 % of the volume is imports), oilseeds and oleaginous fruits and fats (e.g. oils and nuts; 91 % imports), animal feed and food waste (e.g. soy feed additives; 81 % imports), sugars (75 % imports) and chemical fertilisers (65 % imports). Conversely, the top five product groups where the EU has the largest proportional trade surplus in terms of tonnage shipped by sea (i.e. exports more than it imports) are beverages (81 % of the volume is exports), perishable foodstuffs (70 % exports), tractors and farm machinery (68 % exports), wood and cork (63 % exports) and non-perishable foodstuffs (58 % exports).

7.1.6 *Shipment of hazardous and non-hazardous waste*

Waste shipments are one indicator of the EU's potential international environmental impacts and pose a potential risk to ocean ecosystems when transported by sea. International shipments of waste grew four-fold between 1992 and 2016 to more than 200 million tonnes (EC, 2020g). Waste shipments include the transport of any substance or object that is being disposed of or will be recycled or recovered. The EU plays a large role in the international waste trade. In 2016, EU exports of waste to countries outside the EU accounted for approximately 40 million tonnes, or 20 % of the global export waste market (EC, 2020g). A number of countries are the destination of an increasing share of the waste trade, especially China, India and nations in South East Asia. The EU also imports waste, although in 2016 this amounted to only 13 million tonnes (EC, 2020g).

While most of the international waste traded consists of metals, paper, plastics and minerals, there is also significant trade in waste that is especially dangerous to human health and the environment. The EU Waste Shipment Regulation stipulates that the EU must be notified of all trade in this so-called 'amber list' waste, which cannot be shipped to non-OECD (Organisation for Economic Co-operation and Development) countries to avoid unsafe treatment or disposal (EU, 2006b). This waste is divided into degrees of danger: 'hazardous' waste includes medical waste, waste from chemical production, waste electronics containing dangerous compounds or other similar waste, while the rest of the amber list waste is considered non-hazardous but is still monitored (e.g. household waste). The total volume of this amber list waste shipped into and out of the EU has more than doubled over the period 2010-2018, increasing by 123 % to 7.75 million tonnes (Figure 7.9). Hazardous waste made up 47 % of amber list shipments in 2018. Only 27 % of amber list waste shipments are exports. The majority are imports (73 %) and, of these, 91 % of imported waste (in 2018) is for recovery of materials (e.g. of valuable compounds).

Figure 7.9 Volume of trade in waste notified under the Waste Shipment Regulation for all modes of transport, 2010-2018



Source: Eurostat (2020c).

7.2 Overview of scenarios on maritime transport and ports

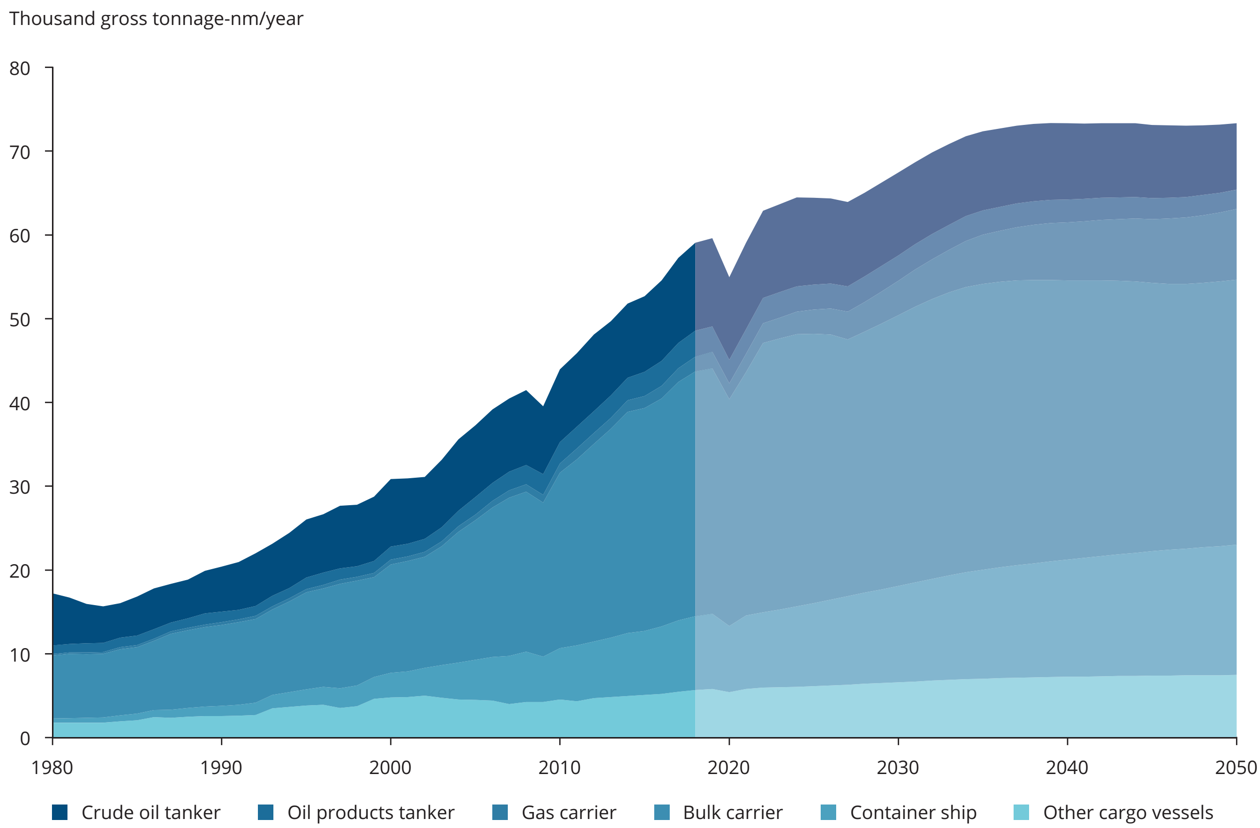
A scenario can be defined as a 'consistent and plausible picture of a possible future reality' (EEA, 2009). In a dynamic world with unpredictable factors and uncertain results, scenarios can help decision-makers by illustrating possible future realities to assist in planning and in the identification of risks and opportunities, including potential extreme developments (EEA, 2001; Kosow and Robert, 2008; EEA, 2011; Notten, 2013; Wiebe et al., 2018). Scenarios are not predictions of the future: by simplifying and streamlining multiple potential drivers of development into a cohesive story (or stories), scenarios support discussion and clarify options, but by simplifying they may inevitably omit relevant drivers or external factors that will eventually influence the future (Wiebe et al., 2018). Scenario development exercises generally involve multiple scenarios to depict different possible cases, including a 'business as usual' scenario to be used as a reference point and potential alternatives under different external conditions or if different decisions or policies were to be enacted (EEA, 2011; Kok et al., 2011).

In this section, several scenarios are presented to reflect potential future trends in shipping developed by different actors with different objectives. These summarise overarching trends in shipping volumes and the environmental impacts of maritime transport and ports. The section concludes with a short discussion of the effects of the COVID-19 pandemic on maritime shipping and ports.

7.2.1 Expected shipping transport volumes

International shipping is expected to grow during the next few decades. An increase in transport volumes for all ship categories until the year 2050 has been projected, except for oil transport where tonne-miles will be reduced by more than 30 %. The largest relative trade increases are expected for natural gas carriers and container ships (Figure 7.10; DNV GL, 2020b).

Figure 7.10 World seaborne trade and projected trade in tonne-miles by vessel type



Source: DNV GL (2020b).

The forecast estimates a total increase of 24 % from 2018 to 2050 and 9 % growth in trade between 2030 and 2050. However, the estimates do not include any COVID-19-related pattern that might affect world seaborne trade in future years (DNV GL, 2021).

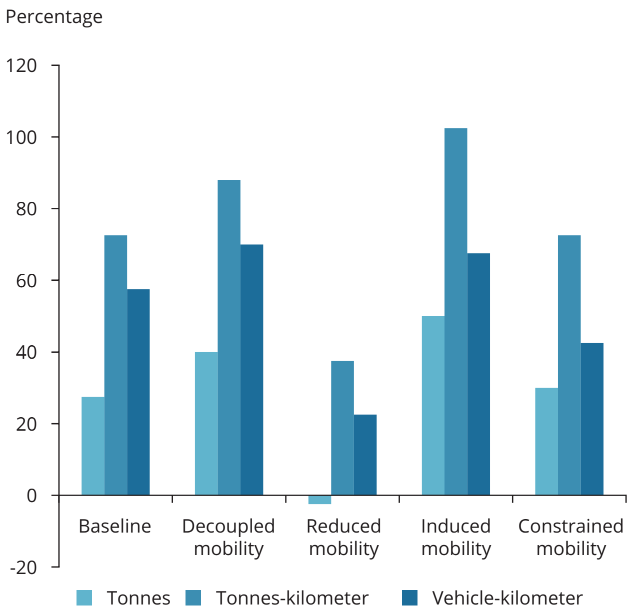
The COVID-19 pandemic has had a major impact on global shipping, affecting all segments from passenger ships to container ships and oil tankers. The FuelEU Maritime impact assessment study shows that international maritime transport activity (intra- and extra-EU) was projected to be 21 % lower in 2020 relative to 2015. From 2021 onwards, however, the same study projects the activity to start recovering and to grow strongly by 2025 and beyond (i.e. 20 % growth for 2015-2030 and 50 % for 2015-2050), due to the rising demand for primary resources and container shipping (EC, 2020h).

Substantial growth in EU maritime transport, including short-sea shipping, is projected. Forecasts project an increase of around 100 % for intra-EU shipping and 150 % for extra-EU shipping by 2050 compared with 2005 levels. The reasons include technological, economic and globalisation trends. Ship efficiency is expected to increase because of improved ship technology and because, in parallel, other transport modes may become more congested. The increases in exported and imported goods due to globalisation trends is also leading to long-distance journeys, mainly relying on maritime transport (Petersen et al., 2009; Sessa and Enei, 2010).

For the next decade, an annual growth in short-sea shipping in Europe is expected in the range of 3-4 % (Ecorys et al., 2012). A number of scenarios estimate that short-sea shipping, covering national and a part of international maritime transport activity, may grow by 23-24 % by 2030 relative to 2015 and by 46-49 % by 2050. Overall, inland waterways and short-sea shipping activity is projected to grow by 23-24 % by 2030 relative to 2015 and by 47-50 % by 2050 (EC, 2020h). Increasing volumes of trade with neighbouring countries is also projected (e.g. Turkey, Russia and North Africa). On the other side, short-sea shipping may face uncertainties due to limited harmonisation in cross-border operations. The largest annual growth rates in the demand for short-sea shipping are expected in the Baltic Sea, with a 2.1 % increase, and in the Mediterranean Sea, with a 1.95 % increase. Regarding cargo types, the largest increase in short-sea shipping until the year 2025 is expected for large containers and roll-on, roll-off (Ro-ro) cargo (COWI et al., 2015).

Still, various uncertainties and a wide spread of results across different forecast scenarios can be observed, for example regarding scenarios for EU maritime freight (see Figure 7.11; Petersen et al., 2009). The graph shows the variation in sea freight for one baseline and four exploratory scenarios for the period 2005-2030. The results for three of the scenarios and the baseline show an increase in the tonnes transported, which, in the case of the 'induced mobility' scenario, reach 50 % compared with 2005. This scenario is characterised by strong economic growth and weak social sustainability. In contrast, the 'reduced mobility' scenario shows a slight decrease in total tonnes transported. The 'reduced mobility' scenario is characterised by weak economic growth coupled with strong social and environmental sustainability. The graph also shows that the tonne-kilometre maritime freight traffic is expected to increase across all scenarios, including within the baseline, with increases of between 38 % and 104 %.

Figure 7.11 **Potential changes in maritime freight traffic (tonnes, tonne-km and vehicle-km) for four scenarios, 2005-2030**



Source: Petersen et al. (2009).

7.2.2 Key themes and scenarios for shipping and ports

Table 7.1 presents an analysis of 20 scenario studies published since 2006 on maritime transport and ports. In terms of geographical scope, 15 out of the 20 have a global perspective, three have an EU focus, and two have a national focus. In terms of timescale, nine studies have an outlook up to 2030, nine up to the 2050s, one up to 2070, and one predicts trends up to 2100. Most studies include a business as usual reference scenario in addition to alternative scenarios. The focus of and definition of alternative scenarios (and the indicators and variables considered and reported) differ depending on the objectives. Key themes include the following:

- Governance and policy changes. Eleven of the scenarios include the impacts of government policy change on socio-economic and environmental factors. Variables include environmental policy regulations, ship and port regulations, strength of global institutions and cooperation, and social pressure for environmental protection.
- Energy and climate changes. Twelve scenarios include potential maritime transport and port greenhouse gas (GHG) emission pathways, expected climate change impacts or linked opportunities for the sector, or developments in fuel mixes. Variables include environmental policy, temperature rise, alternative fuels and energy sources, and fuel prices.
- Economic and technological developments. Eleven scenarios project trends in the development of the sector, focusing on aspects such as transport volume, growth in demand, number of ships and ship size in the future. Variables include transport volumes, ship number, size, and capacity, and trends in global trade.

Table 7.1 Overview of screened scenario studies on shipping and ports

Scenario study	Organisation	Governance and policy changes	Economic and technological developments	Energy and climate changes
'SuPort: Appraising Port Sustainability — 4Futures' (2012)	ARUP (Covil, 2012)			✓
Future trends in the Baltic Sea (2010)	WWF		✓	
Blue growth study (2012)	Ecorys, Deltares, Oceanic Dévelopement	✓		✓
Global marine trends 2030 (2014a)	Lloyd's Register Marine, QinetiQ, University of Strathclyde	✓	✓	✓
Global marine fuel trends 2030 (2014b)	Lloyd's Register Marine, University College London's Energy Institute	✓	✓	✓
Energy transition outlook 2018: A global and regional forecast to 2050 (2018a)	DNV GL		✓	✓
Energy transition outlook: Maritime forecast 2050 (2018a)	DNV GL		✓	✓
UNEP GEO-4: Environment For development (2007)	UN Environment Programme	✓		
SOER 2015: The European environment — State and outlook (2015)	European Environment Agency	✓		
Alternative future scenarios for marine ecosystems (2006)	Pinnegar et al.		✓	✓
Transport, energy and CO_2 — Moving towards sustainability (2009)	International Energy Agency/OECD		✓	✓
New lens scenarios (2013)	Shell International B.v	✓		
Sky scenario — Meeting the goals of the Paris agreement (2018)	Shell International B.v	✓		✓

Table 7.1 Overview of screened scenario studies on shipping and ports

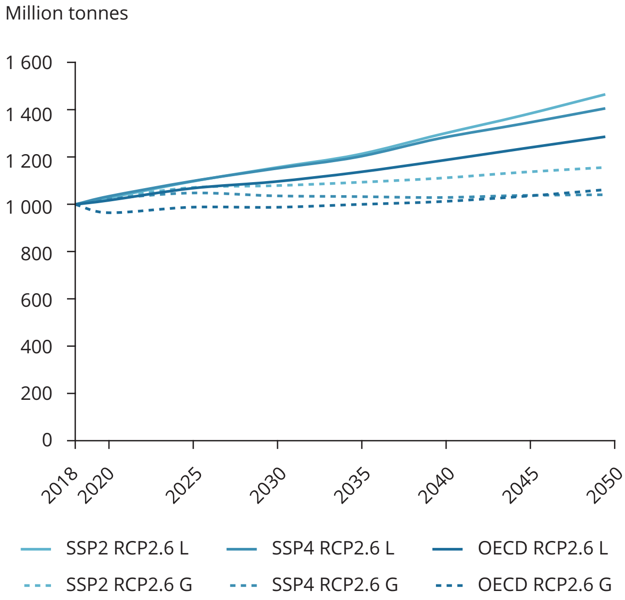
Scenario study	Organisation	Governance and policy changes	Economic and technological developments	Energy and climate changes
Scenario planning to inform Australia's national inquiry into freight and supply chain priorities (2017)	Perez-Franco, Centre for Supply Chain and Logistics Deakin University	✓		
Brave new worlds? Container transport in 2043 (2018)	Fenton et al.		✓	
Analysis of recent trends in EU shipping and analysis and policy support to improve the competitiveness of short sea shipping in the EU (2015)	COWI, Cenit, Vito for DG MOVE	✓		✓
Global trends to 2030 — Impacts on ports industry (2015)	Deloitte China	✓		
Third IMO greenhouse gas study 2014 (2015)	International Maritime Organization	✓	✓	✓
Fourth IMO greenhouse gas study (2020)	International Maritime Organization	✓	✓	✓
Low carbon pathways 2050 (2016)	Lloyd's Register Marine		✓	✓
Ramboll maritime outlook 2030 (2019)	Ramboll Management Consulting		✓	

7.2.3 *Greenhouse gas and air pollutant emission scenarios related to maritime transport*

Environmental impacts related to maritime transport result from air emissions including GHGs, sulphur oxides (SO_x), nitrogen oxides (NO_x) and particulate matter (PM). In relation to GHGs, projections up to the year 2050 are based on the Representative Concentration Pathways (RCPs) for the future demand for coal and oil transport, and Shared Socio-economic Pathways (SSPs) for future economic growth that have been developed for the Intergovernmental Panel on Climate Change (IPCC, 2014) or the OECD long-term baseline projections.

In 2020, the fourth IMO GHG study presents three long-term business as usual (BAU) scenarios for maritime transport carbon dioxide (CO_2) emissions (Figure 7.12). In these scenarios, the emissions from shipping are projected to have increased from 1 000 Mt CO_2 in 2018 to 1 000-1 500 Mt CO_2 in 2050, which is equal to an increase of from 0 % to 50 % over 2018 levels and from 90 % to 130 % of 2008 levels by 2050. For all three scenarios, the use of energy mixes is expected to limit the global increase in temperature to under the 2 °C target (IMO, 2020a). However, the emission projection scenarios for the next few decades are expected to be a few per cent lower than predicted because of the decrease in CO_2 emissions due to the COVID-19 pandemic in 2020 and 2021 and depending on the recovery rate (IMO, 2020a).

Figure 7.12 Business as usual projection of CO_2 emissions



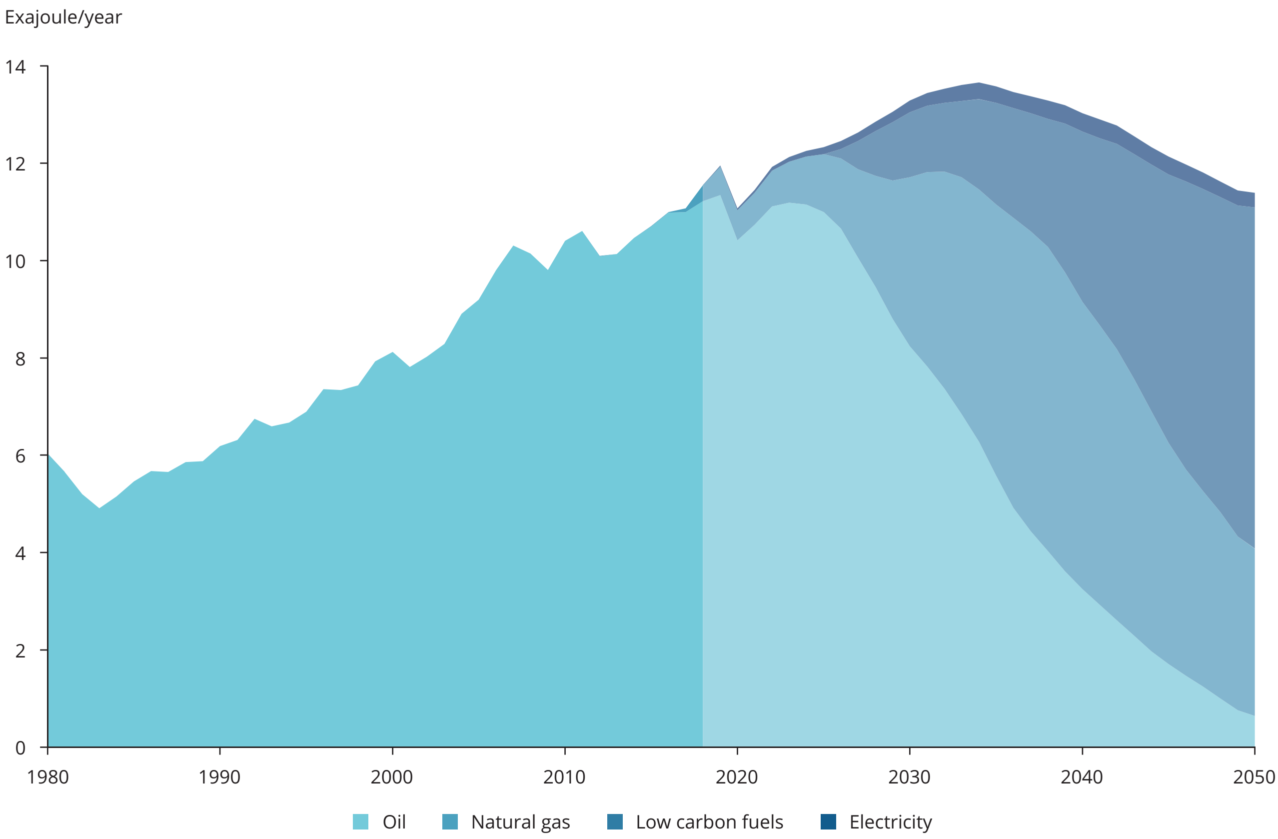
Source: IMO (2020a).

On the positive side, projections for air pollutants from international maritime transport show a substantial global reduction of SO_x and PM until 2050, albeit to different degrees at a regional level for non-sulphur emission control areas (SECAs). Globally, SO_x emissions are expected to be reduced by 40-80 % by 2050 compared with emissions in 2012 (IMO, 2015b). This is mainly because of the entry into force of the global sulphur cap, limiting the sulphur content of fuels to a maximum 0.50 % m/m in non-SECAs starting from 1 January 2020. However, as opposed to SO_x, an increase in NO_x emissions of up to 300 % was projected in the period 2012-2050 (IMO, 2015b).

Projections published in support of the Sustainable and Smart Mobility Strategy include baseline scenarios in which international maritime transport is projected to be dominated by the use of fossil fuels. Natural gas would provide around 17 % of energy demand by 2050, driven by the SO_x and NO_x requirements of Annex VI to the MARPOL Convention of the International Maritime Organization (IMO) (as well as by the Sulphur Directive in the EU, transposing IMO rules and promoting other low-sulphur sustainable alternative fuels) and the assumed availability of refuelling infrastructure for liquefied natural gas (LNG). Heavy fuel oil and marine diesel oil would provide the rest of the fuel use (EC, 2020h).

Operational procedures (i.e. adequate speed, improved route planning, etc), ship design (i.e. hull and propeller design) and the use of fuel mixes may have major influences on the environmental performance of maritime transport. Regarding the last, several projections on the future fuel mix are available. Based on projections of future trade demand, regulatory developments, and technology and fuel advances, some modelling of the future fuel mix has been developed. In 2050, the fuel mix scenario will evolve from being almost completely dominated by oil fuels to a more diversified mix, mainly dominated by low-carbon fuels (60 %) and natural gas (30 %), while traditional fossil fuels may drop down to a share of 5 %. However, these projections lack detail in the share of the different low-carbon fuels, as this will depend on a number of aspects, such as future production costs, fuel availability and installed infrastructure (Figure 7.13).

Figure 7.13 World maritime subsector energy demand by energy carrier (exajoule/year), 1980-2050



Note: For this Figure natural gas includes liquefied natural gas (LNG) and liquefied petroleum gas (LPG). Low carbon fuels include ammonia, hydrogen and synthetic fuels.

Source: DNV GL (2020b).

Other studies estimate similar future fuel mixes. Some still predict a large share of conventional fossil fuels in 2030, up to 47 % and 66 %. In the case of LNG, a maximum of 11 % of the marine fuel mix is forecast by 2030. Hydrogen use may increase of up to a 9 % share. The same forecasting plays no relevance, for instance, to methanol as a marine fuel (Lloyd's Register Marine, 2014).

Associated with an increase in the use of LNG, methane emissions may also increase, which will reduce the overall reduction in GHG emissions (IMO, 2015b). Depending on a low or high share of LNG in the fuel mix, studies estimate an increase in methane emissions by a factor of between 100 % and 300 % in the period 2012-2050. In the mid-term, it is expected that fossil fuels will still be heavily used, as alternative fuels still have several challenges to overcome before they can be broadly implemented. Energy sources such as methanol (high cost), biofuels (low availability), electricity (storage and batteries) and hydrogen (challenges related to storage) need to overcome a number of issues (Lloyd's Register Marine, 2014; Fridell et al., 2015; Fenton et al., 2018).

A recent analysis of the CO_2, ship age and scrappage data sets covering the 11 000 ships included in the EU emissions monitoring, reporting and verification (MRV) scheme, looked at the speed at which new and existing shipping infrastructure must be decarbonised to reach the 1.5 °C Paris Agreement target (Bullock et al., 2020). The study, which used ship-specific assumptions of asset lifetimes, concluded that investing in efficient alternative technologies for future new vessels might not be enough to cut maritime sector CO_2 emissions in line with the 1.5 °C Paris Agreement target. The sector does, however, have significant potential to reduce emissions without premature scrappage through a combination of slow steaming, operational and technical efficiency measures, and the timely use of alternative zero-carbon fuels.

7.2.4 Major technological future trends

In addition to discussing potential future shipping volumes and the associated environmental impacts, several other major future trends have been identified for maritime transport and the port sector related to expected technical and socio-economic developments, as well as governance and policy change.

Maritime transport

- An increase in vessel size, especially of container ships, is expected to continue for the next decade as a result of economies of scale and increased energy efficiency (IEA, 2009; WWF, 2010; Deloitte China, 2015). Increases in size of 30 % for container ships for deep sea shipping and 10 % for bulk ships are projected (DNV GL, 2020b). Conversely, some studies have mentioned a potential trend in increased flexibility including medium-sized vessels that call into ports more frequently (Perez-Franco, 2017; Fenton et al., 2018).

- Conventional fossil fuels are expected to continue to be used at least in the medium term, as alternative fuels still face a number of challenges (Lloyd's Register Marine, 2014; Fridell et al., 2015; Fenton et al., 2018). LNG may play a role, especially in short-sea shipping, in the short and mid-term because of its lower SO_x and NO_x emissions (Ecorys et al., 2015; Pavlenko et al., 2020). However, it is expected that ships may start using increasing proportions of carbon-neutral fuels as the sector moves towards gradual decarbonisation.

- Slow steaming may play a role in reducing GHG emissions, which also favours a reduction in costs. An increase in the modernisation of and investments in new ships with lower GHG emissions is likely, including energy efficiency improvements, advanced hull designs and coatings (Fridell et al., 2015; DNV GL, 2018b).

- Global warming could present opportunities for maritime transport, such as new routes including the Northern Sea Route and Northwest Passage. The Northern Sea route reduces the distance between northern Europe and north-eastern Asia by 40 % and could increase opportunities for ports in northern Europe (Pinnegar et al., 2006; Covil, 2012; Fridell et al., 2015). However, these new routes would also pose threats to Arctic ecosystems and, should they arise, these new Arctic routes and activities would need to be managed sustainably (EEA, 2017).

Ports

- Assuming different pressures arising from climate change (mild and severe) and developments in the maritime sector (growth and contraction), various scenarios for port development have been described (Covil, 2012). With severe climate change, infrastructure will become obsolete before reaching the end of its traditional design lifetime, and, with an additional economic contraction, ports could have problems obtaining insurance against climate risks. In a more environment-oriented scenario, stricter environmental regulations for ports and shipping companies could be expected, including international agreements such as a global price for carbon. Another trend identified is the development of ports as intermodal hubs, including improved hinterland connections and becoming active parts of the supply chain (Deloitte China, 2015; Perez-Franco, 2017).

- The following may also be applicable: implementing the circular economy using a definition that is more widely applicable to the sector; developing inclusive schemes in which emission plans and renewable energy use strategies address the sustainability objectives of ports; promoting new, emerging and consolidated technologies in an integrated pool of solutions to allow better management of the potential circular flows that occur in ports; and creating up-to-date information sharing platforms with a strong focus on intersectoral solutions.

- Digitalisation is expected to allow the optimal use of port infrastructure (e.g. optimisation of loading and offloading, better coordination with hinterland transport networks). Better route planning and fleet optimisation is expected. A growth in the use of the fleet of up to 11 % is expected between 2016 and 2050 (Deloitte China, 2015; Perez-Franco, 2017; DNV GL, 2018b; Ramboll Management Consulting, 2019).

- Port infrastructure will need to adjust to expected sea level rise due to climate change and the associated increasing intensity and frequency of coastal floods. For example, ports will need to adapt to an expected increase in the projected 100-year flood event height of 2 m by the 2080s (Covil, 2012).

7.2.5 *Effects of COVID-19 on international trade*

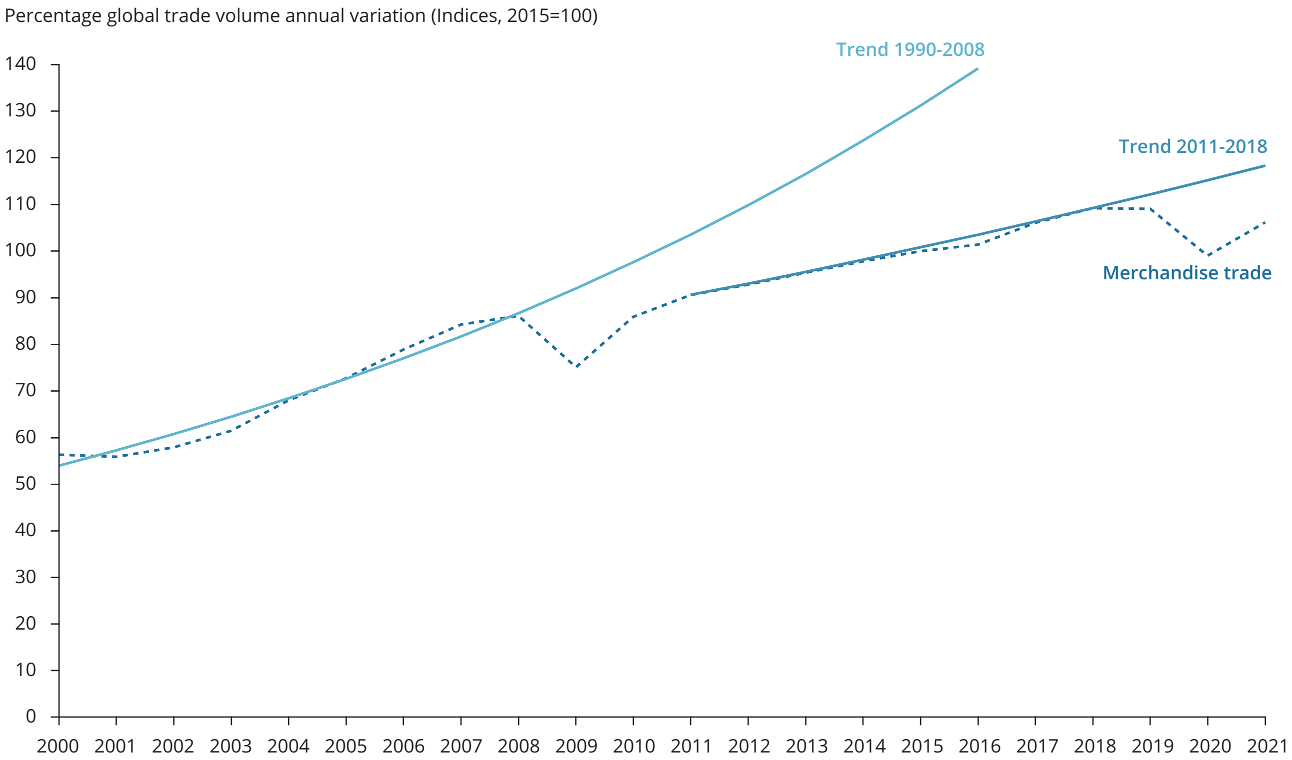
The projections and trends in previous sections were estimated without considering the economic crisis triggered by the COVID-19 pandemic. It is certain that the COVID-19 lockdown will have economic effects on international trade at least in the short and mid-terms.

The first effects on maritime transport in the EU were observed in February 2020, when almost half of the ship departures (46 %) were cancelled on major Asia to northern Europe shipping routes. Other estimates suggest that more container ship tonnage was lying idle than during the financial crisis in 2008. Ports have been impacted by the contingency measures countries adopted during the crisis, including delaying port clearance and refusing ships entry (EC, 2020i).

The World Trade Organization (WTO) estimated a significant decrease in world trade of up to 9.2 % in 2020 as COVID-19 disrupted economic activity. In particular, because of pandemic, during the first half of 2020 the number of ships calling at EU ports declined by between 14.4 % and 29 %, compared with the same period in 2019. The decline is expected to affect nearly all regions, especially exports from North America and Asia and sectors with complex supply chains. In 2021 the world trade volume should recover by up to 7.2 %; however, the estimates are subject to uncertainty due to the pandemic's evolution (WTO, 2020b). The updated forecasts for the EU economy show a decrease in gross domestic product (GDP) of 7.4 % in 2020 and a forecast growth of 6.1 % for the year 2021 (EC, 2020l; WTO, 2020b).

Figure 7.14 shows estimated global trade performance (all trade), which includes high levels of uncertainty and therefore describes different possible crisis trajectories rather than predicting future developments.

Figure 7.14 World merchandise trade volume (all trade)



Source: WTO (2020b).

After the financial crisis in 2008-2009 shipping activities recovered relatively quickly. Within the first quarter of 2010, the gross weight of seaborne goods handled by the main ports in EU Member States reached 90 % of the pre-crisis value (Amerini, 2010). However, because of the COVID-19 restrictions, whole sectors of national economies have been shut down, including tourism, parts of the retail trade and manufacturing, and are directly affected in ways they were not during the financial crisis (WTO, 2020a). Accordingly, there may not be the same degree or speed of recovery as that seen following the 2008 financial crisis.

7.3 Effects of climate change on maritime transport and ports

The main effects of climate change on seaports may be summarised as follows:

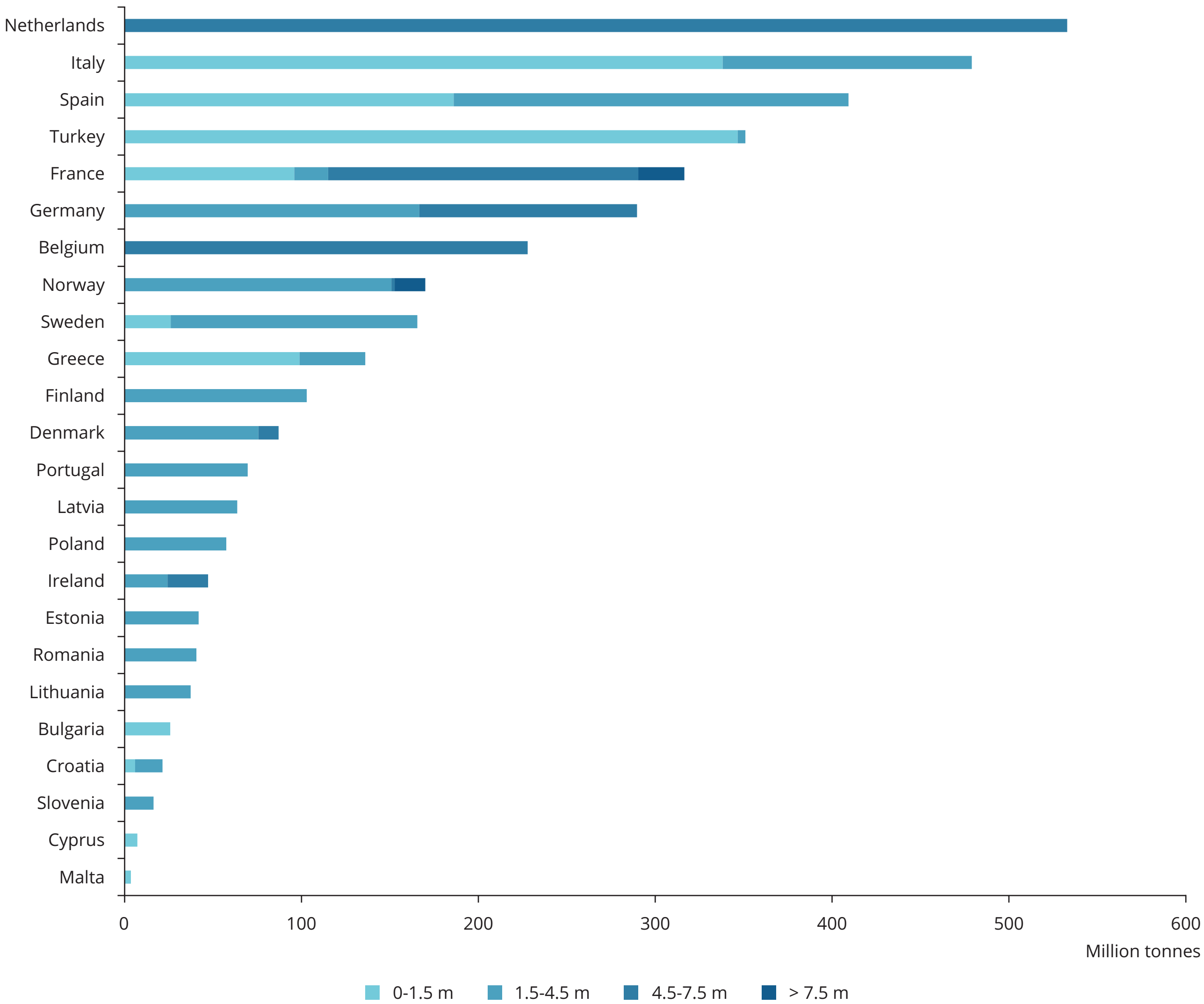
- **Sea level rise and sea storm surges**. Shoreline retreat will be observed everywhere. However, the magnitude depends on local morphology and human-induced subsidence. An increase in overall water levels, including storm surges, has been projected along the North Sea coast. The following effects may be observed (Christodoulou and Demirel, 2018):
  - increased water levels in port facilities, putting low-level infrastructure (in terms of height) at risk of regular and permanent inundation;
  - changes in wave propagation patterns and wave penetration into ports;
  - damage to port infrastructure and/or cargo;
  - sedimentation and dredging issues in ports and navigation channels;
  - increased port construction and maintenance costs.
- **Reduced ice cover**. Ice cover will be reduced because of the increased temperatures, which may lead to the following effects (Christodoulou and Demirel, 2018):
  - opening up new northern shipping routes and reducing ice loading on infrastructure such as piers;
  - extension of shipping seasons;
  - reduction in fuel costs as a result of shorter routes.
- **Increased summer temperatures**. All EU regions may be affected by higher summer temperatures. The frequency, intensity and duration of heat waves all over the EU are projected to increase. This can lead to the following effects on maritime transport (Christodoulou and Demirel, 2018):
  - damaged infrastructure, equipment or cargo;
  - reduced asset lifetime;
  - increased energy consumption for cooling cargo;
  - reduced costs of removing snow and ice.
- **Increased precipitation**. Nordic countries are expected to experience increased precipitation in summer, while in southern regions precipitation is likely to decrease. The potential effects on shipping are (Christodoulou and Demirel, 2018):
  - flooding of seaports;
  - inundation of infrastructure on land and damage to cargo and equipment;
  - navigation restrictions in inland waterways.

While ports can be resilient to sea level rise and storm surges of under 1 m and can operate without interruption by adopting soft adaptation strategies, this would not be the case for inundations of more than 1 m. The number of ports that face the risk of inundation is expected to increase by more than 50 % from 2030 to 2080 (852 ports in total). The number of seaports that face the risk of being inundated by more than 1 m is projected to be 185 by 2030 and to increase to 334 in 2080. In 2030, the number of seaports projected to face inundation levels higher than 3 m is 70, which is expected to increase to 109 in 2080. The cases of seaports projected to be exposed to inundation levels above 1 m should be analysed in detail and adaptation strategies considered. The three main approaches to adaptation are the following: (1) construction of storm defences; (2) elevation of the seaport to compensate for projected increases in sea level; and (3) relocation of the seaport. However, for seaports likely to be inundated at levels if between 1 m and 3 m, beach nourishment might be needed (Christodoulou and Demirel, 2018).

The economic impacts of climate change on EU seaports handling more than 0.5 million tonnes annually were analysed by Christodoulou et al. (2019). The risk level for these seaports was assessed by considering the present-day estimated sea level (ESL) and the projected increase in ESL from the present to 2100. Following this evaluation, exposure to sea level rise and to extreme weather events were measured in relation to the volumes of cargo handled by the seaport on an annual basis. Disruptions caused by an increase in ESL of more than 3 m are projected to affect ports that handle in total more than 2 billion tonnes of cargo annually after 2050 (IPCC, 2014). The highest values are projected to occur in the North Sea and on the Atlantic coast, while in the Black Sea and the Mediterranean Sea the impacts are projected to be milder but more frequent.

Figure 7.15 and Map 7.1 show the effect on countries and ports, respectively, of sea level increases in Europe.

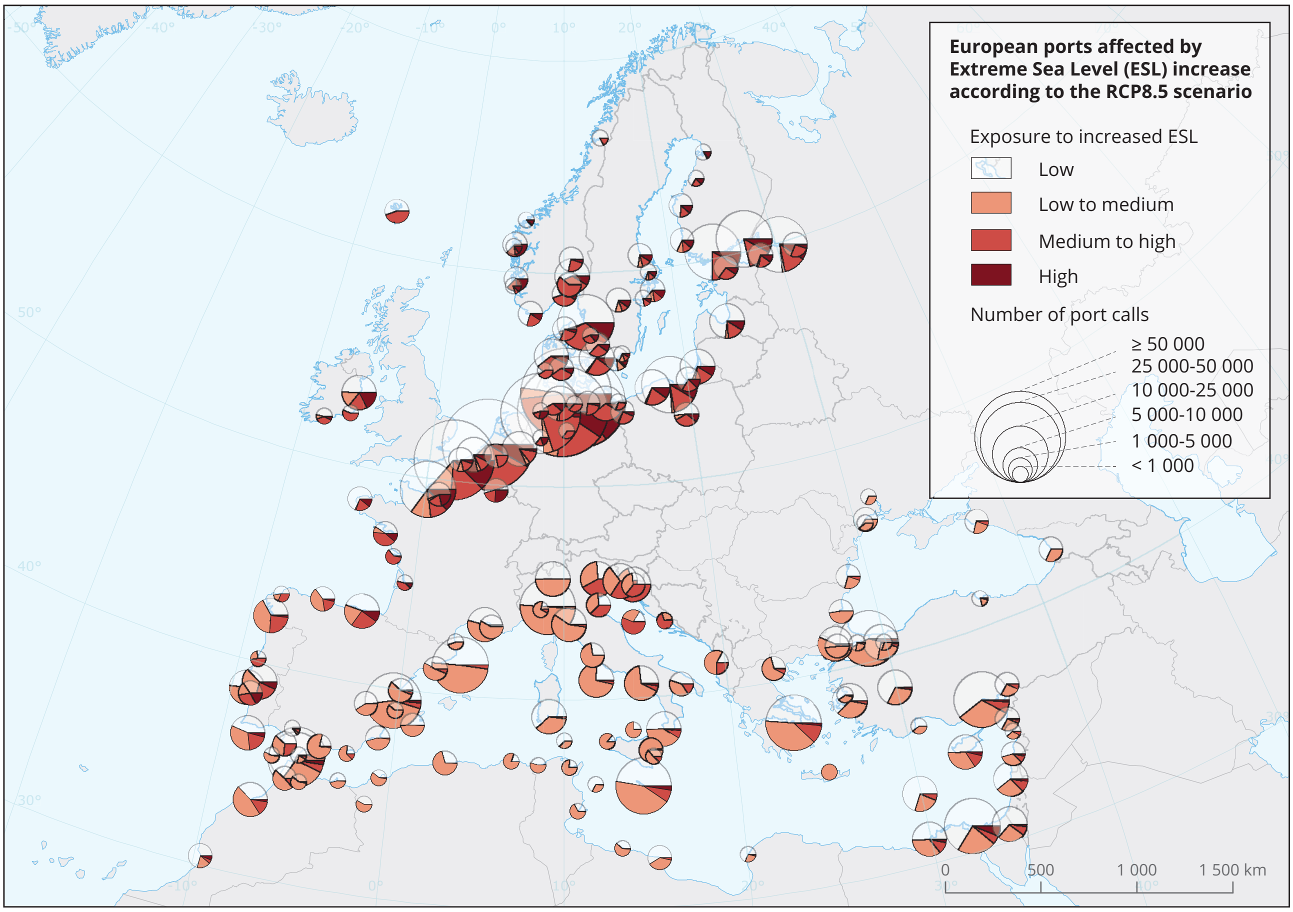
Figure 7.15 Gross weights of cargo handled in European ports affected by present-day ESL100



Note: The chart illustrates the total cargo handled in ports to be affected during a present-day 100-year Extreme Sea Level (ESL) event and indicates four categories of water levels. The figures refer to country totals.

Source: Christodoulou et al. (2019).

Map 7.1 **Links of European ports affected by an increase in ESL according to RCP 8.5**



Reference data: ©ESRI

Note: The map illustrates the secondary effects of the disruption of European port operations as a result of the projected increase of ESL until 2100. It is based on information on connections of container ports. The size of the pies represent the total number of connections or port calls and the coloured pieces of the pies represent the part of the total connections to ports exposed to different levels of ESL increases.

Source: Christodoulou et al. (2019).

8 Conclusions

Maritime transport is key for international trade and is therefore a major pillar of globalisation and economic development worldwide. It is mainly driven by consumption and production patterns. Policy changes (e.g. new environmental standards), energy use, climate change and air pollution (e.g. use of sustainable alternative fuels) or economic and technological developments (e.g. transport volumes and growth in demand) are all factors affecting the maritime transport sector. In addition, increased competition and complexity of global supply chains will play an important role in the future of maritime transport, as will changes in consumption patterns and types of goods shipped, and in the way ports operate.

8.1 Environmental pressures

Maritime transport produces significant environmental pressures on the atmosphere and the marine environment. Greenhouse gas (GHG) emissions from maritime transport represented 13.5 % of the total EU GHG emissions from transport (in 2018). Air pollutant emissions from the sector represented 24 % of nitrogen oxides (NO_x) and sulphur oxides (SO_x) combined and 9 % of fine particulate matter ($PM_{2.5}$) as proportions of EU emissions from all sectors in 2018. In 2019 emissions from ships calling at EU/European Economic Area ports represented 22 % of NO_x, 16 % of SO_x and 18 % of $PM_{2.5}$ as proportions of the overall emissions from international shipping. Water discharges from maritime transport affect the marine environment because of their hazardous nature. Leaching from anti-fouling biocides can reach concentrations that may be harmful. Although there has been a large decrease in accidental or intentional oil spills, these can have severe consequences for many different environments and habitats. Maritime transport is the main route for the introduction and spread of non-indigenous species in EU waters, some of which become invasive species (49 % of the non-indigenous species introduced into Europe's seas have arrived via shipping). Furthermore, the maritime transport sector may be a source of marine litter, with a delivery gap in ship-generated garbage estimated at between 7 % and 34 % of the total garbage generated on board. There are also indications of increasing trends in low-frequency noise energy inputs generated by ships in almost all EU seas.

All of the above pressures are described with the best available information at EU level in this report. Although these pressures are well documented, measuring their impacts on human health, the environment, climate change and the economy is challenging. This requires comprehensive, integrated and timely monitoring and outlook programmes. This effort would entail, for instance, evaluation of and insight into cases of respiratory problems that may be associated with emissions from ships. It could also involve changes in the distribution, abundance or behaviour of marine species due to continuous underwater noise. Efforts in this field could equally involve monitoring injuries or death as a result of individuals colliding with vessels, assessing organisms buried by the dumping of dredged material, identifying changes in food webs due to the introduction of non-indigenous species or poisoning and monitoring the potential death of organisms due to harmful substances. Finally, port activities, such as enlargement and developments that support a transition to a more circular blue economy, can also lead to a loss of vulnerable habitats and to hydrographical changes at the local level, which may affect coastal ecosystems.

8.2 Data and knowledge gaps

Information on actual impacts comes from data collected by EU Member States and reported to the European Commission under various laws providing guidance on achieving good status of the marine environment. Additional data are gathered from a number of specific monitoring, detection and reporting services developed by the European agencies (e.g. THETIS-MRV, THETIS-EU and CleanSeaNet). While the Marine Strategy Framework Directive can provide a picture of the status of the marine environment and the main pressures affecting it, these data might have a low temporal resolution because of the associated 6-year reporting cycle. Moreover, there are also areas where there are insufficient monitoring data available on these pressures (e.g. underwater noise), while in other instances partial information on impacts that are directly linked to shipping can be gathered from other directives, such as the Habitats Directive, where Member States have assessed species and habitats affected by maritime navigation in our seas. Similarly, the water quality monitoring in our ports is far from adequate and more efforts are needed to achieve the objectives of the Water Framework Directive. Many of the actual impacts produced by the maritime transport sector remain unknown, as they are at the local level (e.g. the impact of exhaust gas cleaning systems and water discharges). There is therefore a clear need for future research and development programmes to cover the knowledge gaps around the sector's environmental footprint and sustainability.

8.3 Measures to foster sustainability

There is currently a significant number of initiatives led by the European Commission, EU Member States and industry with the aim of navigating the maritime transport sector towards sustainability. This results from the development of new or the implementation of existing standards and from within the maritime sector itself, which is working towards its ambition to become greener. These initiatives support EU priorities (see the European Green Deal), endorsing international programmes and action plans (see the International Maritime Organization treaties and the Sustainable Development Goals) and respond to the environmental challenges mentioned above. They extend from the use of sustainable marine fuels and emission abatement technologies, to decarbonisation and measures to mitigate pressures and impacts on the marine environment and port-based solutions.

For example, as a result of legislative changes introduced by the Sulphur Directive and Annex VI of the MARPOL Convention Annex VI, discussions in recent years have focused on equivalent means and alternative fuels, as well as on the reduction of NO_x from shipping sources. The designation of emission control areas in the North and Baltic Seas has proven to be a success, resulting in a considerable reduction of SO_x and PM emissions in both areas. However, not all EU or shared seas benefit from such measures, for example the Mediterranean Sea. Bearing in mind the need to ensure continued trade and traffic, the widespread introduction of emission control areas in all EU waters will have very positive effects, improving the health of citizens and ecosystems and increasing biodiversity in coastal areas, and contributing to further developing sea-related economic activities.

A variety of measures is under consideration to mitigate shipping's impact on the marine environment. To reduce water pollution and introductions of non-indigenous species, they range from the installation of treatment systems for water discharges to the use of biocide-free anti-fouling paints or the use of hull cleaning systems that avoid species transfers from fouling. Impacts on the sea floor could be reduced by minimising sediment dredging and disposal and using appropriate techniques and equipment for reducing the impacts from its dumping. Similarly, the spatial delimitation of shipping-related activities could be a response to impacts caused by underwater noise (including possible re-routeing of shipping lanes to avoid biologically important areas, establishing acoustic buffer zones, or designating acoustic refuges for noise-sensitive marine life), as well as the practice of slow steaming. Lastly, the implementation of EU-wide reporting systems, for example on ship strikes, lost containers or other sea-based litter, could help the monitoring and tracking of these issues, all of which are currently not widely available.

Further to this, EU ports are currently employing a number of solutions to become greener and help the maritime transport sector further reduce its environmental impacts. These include installing onshore power supply, optimising port calls to reduce vessel waiting times, adapting and modernising port reception facilities for disposal of ship-generated waste, and adopting port fees policies and incentives to promote greener ships. Ports can also contribute to the circular economy by adhering to environmental certification and by adopting new practices.

8.4 Future prospects

The effectiveness of the responses that are being implemented is still to be measured. Meanwhile, having 17.6 % of the total world fleet, the EU faces a crucial decade in which it needs to lead the transition to a more economically, socially and environmentally sustainable maritime transport sector. The implementation of the European Green Deal's objectives, together with those of the 2030 Biodiversity Strategy, the Sustainable and Smart Mobility Strategy, the proposed European Climate Law and the Farm to Fork Strategy, will inevitably move towards a reduction in the consumption of petroleum as well as a reduction in the waste shipped out of the EU. Moreover, promoting short-sea shipping as an alternative to road transport could further reduce GHG emissions, in particular if new alternative fuel and energy solutions are used and autonomous ships are potentially introduced. In parallel, ports must prepare themselves for the potential consequences of sea level rises or extreme weather events due to climate change. Internationally, a key topic of discussion is the new routes that may open as a result of the melting of ice in the Arctic Ocean, in which case the EU would need to play a key role in guaranteeing that new routes do not pose a threat to the Arctic ecosystems.

The report has identified the need to further develop capacity in modelling and availability of observational monitoring data related to air emissions, marine litter, underwater noise and non-indigenous species at EU level. Whereas there is sporadic local data available, a more comprehensive and consistent approach should be developed to be able to calculate the relative contribution of the maritime sector to the various environmental pressures and impacts. Existing schemes and action plans (e.g. the Marine Strategy Framework Directive technical groups), as well as future European programmes and initiatives linked to the development and adoption of innovative digital technologies, may support some of these monitoring needs. Programmes such as the Copernicus Earth observation programme, and initiatives such as the EU Digital Twins/Destination Earth initiative and the Monitoring and Outlook framework under the Zero Pollution Action Plan are indeed positive and important steps in this direction. It is critical for the maritime transport sector to be an integral part of these programmes so that all sector-specific observational, modelling, monitoring and reporting needs are adequately incorporated and catered for.

The environmental challenges described in this report have fostered multiple responses, which range from reducing the pressures to mitigating the impacts. Other responses may come from external factors such as consumer preferences, which can drive the type and number of products shipped. Nevertheless, it is also important to consider these challenges in a holistic way, in line with the European Green Deal, which calls for accelerating the shift towards sustainable and smart mobility, which clearly includes the maritime transport sector. By developing new standards, fully implementing existing ones and applying bold innovative solutions, the sector can remain competitive and maintain its high-quality service and in parallel contribute to the common objective of tackling the most urgent global environmental challenges we face today.

Abbreviations and symbols

AER	Annual efficiency ratio
AFS	Anti-fouling system
AIS	Automatic identification system
AQUO	Achieve quieter oceans by shipping noise footprint reduction
BAU	Business as usual
BC	Black carbon
BIAS	Baltic Sea information on the acoustic soundscape
BPF	Blade passage frequency
BWM Convention	Ballast Water Management Convention
BWMP	Ballast water management plan
CECIS	Common Emergency Communication and Information System
CEF	Connecting European Facilities
CNG	Compressed natural gas
CO	Carbon monoxide
CO_2	Carbon dioxide
CSI	Clean Shipping Index
CSN	CleanSeaNet
DG ECHO	Directorate-General for European Civil Protection and Humanitarian Aid Operations
DPSIR	Drivers, Pressures, States, Impacts, Response
DWT	Dead weight tonnage
EAM	Emission abatement method
EASIN	European Alien Species Information Network
EC	European Commission
ECA	Emission control area
EEA	European Environment Agency
EEDI	Energy efficiency design index
EFTA	European Free Trade Association
EGCS	Exhaust gas cleaning system (scrubber)
EMCIP	European Marine Casualty Information Platform
EMSA	European Maritime Safety Agency
ERCC	Emergency Response Coordination Centre
ESL	Estimated sea level
ETS	Emissions Trading System
EU	European Union
FAME	Fatty acid methyl ester
GDP	Gross domestic product
GEF	Global Environment Facility
GES	Good environmental status
GHG	Greenhouse gas

GISIS	Global Integrated Shipping Information System of the IMO
GT	Gross tonnage
GWP	Global warming potential
HELCOM	Baltic Marine Environment Protection Commission (Helsinki Commission)
HFCs	Hydrofluorocarbons
HNS	Hazardous and noxious substances
IAS	Invasive alien species
IMO	International Maritime Organization
INEA	Innovation and Network Executive Agency
IPCC	Intergovernmental Panel on Climate Change
LBG	Liquefied biogas
LCA	Lifecycle assessment
LDT	Light displacement tonnes
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LRTAP Convention	Convention on Long-range Transboundary Air Pollution
MARPOL Convention	International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto
MEPC	IMO Marine Environment Protection Committee
MGO	Marine gas oil
m/m	Mass by mass
MoU	Memorandum of understanding
MPA	Marine protected areas
MRV Regulation	Regulation on the monitoring, reporting and verification of carbon dioxide emissions from maritime transport
MSFD	Marine Strategy Framework Directive
NEC Directive	National Emissions reduction Commitments Directive
NECA	Nitrogen oxide emission control area
NH_3	Ammonia
NIS	Non-indigenous species
NMVOC	Non-methane volatile organic compound
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
ODS	Ozone depleting substance
OPRC	International Convention on Oil Pollution Preparedness, Response and Co-operation
OPRC-HNS	Protocol on Preparedness, Response and Co-operation to Pollution Incidents by Hazardous and Noxious Substances
OPS	Onshore power supply
OSPAR Convention	Regional Sea Convention for the North-East Atlantic
PCB	Polychlorinated biphenyl
PEMFC	Proton exchange membrane fuel cell
PFCs	Perfluorocarbons
PFOS	Perfluorooctanesulphonic acid
PIAQUO	Practical Implementation of AQUO
PM	Particulate matter
PolRep	Maritime pollution report
PRF	Port waste reception facilities
REMPEC	Regional Marine Pollution Emergency Response Centre for the Mediterranean Sea

Ro-pax	Roll-on, roll-off passenger (ship)
Ro-ro	Roll-on roll-off (ship)
RPAS	Remotely piloted aircraft system
SAR	Synthetic aperture radar
SECA	Sulphur emission control area
SO_2	Sulphur dioxide
SOLAS	International Convention for the Safety of Life at Sea
SONIC	Suppression of underwater noise induced by cavitation
SO_x	Sulphur oxides
SSP	Shared Socio-economic Pathway
STEAM	Ship Traffic Emission Assessment Model
TBT	Tributyltin
TEN-T	Trans-European Transport Network
TEU	Twenty-foot equivalent unit
TG	Technical Group
UNCLOS	United Nations Convention on Law of the Sea
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNEP	United Nations Environment Programme
VOC	Volatile Organic Compounds
WFD	Water Framework Directive
WTS	Water Treatment System
WTT	Well-to-tank
WTW	Well-to-wake

Glossary

Annual efficiency ratio	Ratio between carbon dioxide (CO_2) emissions and the theoretical maximum transport work possible, i.e. cargo carrying capacity (DWT or GT as applicable — see below).
Bulk carrier	A ship generally constructed with single deck, top-side tanks and hopper side tanks in cargo spaces, and intended primarily to carry dry cargo in bulk. Bull carriers include such ore carriers and combination carriers (SOLAS Convention, 1974, SOLAS IX/1.6).
Cavitation	The rapid formation of small vapour-filled cavities called 'bubbles' in liquid in regions of very low pressure, a frequent cause of structural damage to propellers and pumps. When subjected to higher pressure, these cavities collapse and can generate a shock wave.
Chemical tanker	Cargo tankers that transport chemicals in various forms. Chemical tankers are specifically designed to maintain the consistency of the chemicals they carry aboard.
Container ship	Cargo ships that carry all of their load in lorry-sized intermodal containers, a technique called containerisation. They are a common means of commercial intermodal freight transport and now carry most seagoing non-bulk cargo.
Dead weight tonnage	Measure of how much weight a ship can carry, not its weight either, empty or in with any degree of load. DWT It is the sum of the weights of cargo, fuel, fresh water, ballast water, provisions, passengers, and crew.
Eutrophication	When a body of water becomes overly enriched with minerals and nutrients that induce excessive growth of algae (Chislock et al., 2013). This process may result in oxygen depletion of the water body (Schindler and Vallentyne, 2008).
Gas tanker	Tankers specially designed to carry different types of gas in bulk are called gas tankers (Marine Insight, 2019).
General cargo ship	A ship with a multi-deck or single-deck hull designed primarily for the carriage of general cargo (IMO, 2009).
Gross tonnage	Non-linear measure of a ship's overall internal volume.
International shipping	International shipping refers to routes between countries.
Light displacement	The weight of a ship in tonnes without cargo, fuel, lubricating oil in storage tanks, ballast water, freshwater, feedwater, consumable stores, passengers and crew and their effects. It is the sum of the weight of the hull, structure, machinery, equipment and fittings of the ship.
Light displacement tonnes	Light displacement tonnes (LDT) give an estimate of the quantity of material that may be obtained from a recycled ship. Recycling transactions are normally conducted on the basis of price per LDT. Light displacement is the mass of the ship's structure, propulsion machinery, other machinery, outfit and constants. On average about 95 % of LDT is recyclable steel.
Livestock carrier	Large ship used for the export of live sheep, cattle and goats. They can be specially built new or converted from container ships.
Mobile offshore drilling unit	Vessel capable of engaging in drilling operations for the exploration for or exploitation of resources beneath the seabed such as liquid or gaseous hydrocarbons, sulphur or salt (SOLAS Convention, 1974, SOLAS IX/1, MODU Code 2009 para. 1.3.40).
National shipping	National shipping refers to routes between ports within a country. Note that national shipping includes both maritime and inland water navigation.
Nuclear ship	Ship provided with a nuclear power plant (SOLAS Convention, 1974; SOLAS I/2).
Offshore supply ship	Ship specially designed to supply offshore oil and gas platforms.

Oil tanker	Ship constructed or adapted primarily to carry oil in bulk in its cargo spaces, including combination carriers, any 'NLS tanker' (a ship designed to carry noxious liquid substances), as defined in Annex II of the SOLAS Convention, and any gas carrier, as defined in regulation 3.20 of chapter II-1 of SOLAS 74 (as amended), when carrying a cargo or part-cargo of oil in bulk (Marpol Annex I, regulation 1.5).
Passenger ship	Ship that carries more than 12 passengers (SOLAS Convention, 1974, SOLAS I/2).
Pleasure craft	Vessels that are not subject to the International Convention for the Safety of Life at Sea (SOLAS Convention) and do not routinely engage in commercial activities such as carrying cargo or passengers for hire. This class of vessel might also encompass vessels being used as residences provided the vessel maintains a means of propulsion. Also known as leisure craft and recreational craft.
Roll-on, roll-off	System of loading and unloading a ship in which the cargo is driven on and off ramps. Suitable for wheeled cargo such as cars, trucks and trailers. Commonly referred to as Ro-ro (Marine Insight, 2019).
Ro-pax ship	Roll-on, roll-off passenger ship/ferry. Combines the cargo capacity of Ro-ro ships with the passenger facilities of ferries (Maritime Industry Foundation, 2012-2013).
Short-sea shipping	Short-sea shipping means the movement of cargo and passengers by sea between ports situated in geographical Europe or between those ports and ports situated in non-European countries having a coastline on the enclosed seas bordering Europe. Short-sea shipping includes domestic and international maritime transport, including feeder services along the coast, to and from the islands, rivers and lakes. The concept of short-sea shipping also extends to maritime transport between the EU Member States and Norway and Iceland and other states on the Baltic Sea, the Black Sea and the Mediterranean Sea (European Shortsea Network).
Special purpose ship	Mechanically self-propelled ship, which by reason of its function carries on board more than 12 special personnel (Special Purpose Ships Code, para. 1.3.12).
Taxon (plural taxa)	Any unit used in the science of biological classification, or taxonomy. Taxa are arranged in a hierarchy from kingdom to subspecies, a given taxon ordinarily including several taxa of lower rank (Encyclopaedia Britannica).
Twenty-foot equivalent unit	Inexact unit of cargo capacity often used to describe the capacity of container ships. It is based on the volume of a 20-foot-long (6.1 m) intermodal container, a standard-sized metal box that can be easily transferred between different modes of transport, such as ships, trains and lorries. The container is defined by its length, although there is a lack of standardisation with regard to height, which ranges between 1.30 m and 2.90 m, with the most common height being 2.59 m, for a volume of 39 m^3.

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Annex 1
European policies and their focus

Directive/Regulation	Title	Policy objectives and targets	Domain
Directive (EU) 2016/802	Reduction in the sulphur content of certain liquid fuels	Reduce the emissions of sulphur dioxide resulting from the combustion of certain types of liquid fuels and reduce the harmful effects of such emissions on man and the environment. Establish limits on the sulphur content of such fuels as a condition for their use within Member States' territory, territorial seas and exclusive economic zones or pollution control zones.	Air quality/pollution
Directive 2014/94/EU	Deployment of alternative fuels infrastructure	Establishes a common framework of measures for the deployment of alternative fuels infrastructure in the EU in order to minimise dependence on oil and to mitigate the environmental impact of transport. This Directive sets out minimum requirements for the building-up of alternative fuels infrastructure to be implemented by means of Member States' national policy frameworks.	Air quality/pollution
Directive 2009/29/EC **amending Directive 2003/87/EC**	Improve and extend the greenhouse gas emission allowance trading scheme of the Community	Provides for the reductions of greenhouse gas emissions to be increased so as to contribute to the levels of reductions that are considered scientifically necessary to avoid dangerous climate change.	Climate change/ greenhouse gases
Directive (EU) 2019/883	Port reception facilities for the delivery of waste from ships	Protect the marine environment against the negative effects of discharges of waste from ships using ports located in the EU, while ensuring the smooth operation of maritime traffic, by improving the availability and use of adequate port reception facilities and the delivery of waste to those facilities.	Marine litter and ship waste
Directive (EU) 2019/904	Reduction of the impact of certain plastic products on the environment	Reduce the impact of certain plastic products on the environment, in particular the aquatic environment, and on human health, as well as to promote the transition to a circular economy with innovative and sustainable business models, products and materials.	Marine litter and ship waste
Directive 2008/98/EC	Waste Framework Directive	Measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use.	Marine litter and ship waste
Regulation (EC) No 1013/2006	Shipments of waste	Procedures and control regimes for the shipment of waste, depending on the origin, destination and route of the shipment, the type of waste shipped and the type of treatment to be applied to the waste at its destination.	Marine litter and ship waste
Regulation (EU) No 1257/2013	Ship recycling	Prevent, reduce, minimise and, to the extent practicable, eliminate accidents, injuries and other adverse effects on human health and the environment caused by ship recycling	Air quality/pollution, marine litter, water quality/pollution
Directive 2014/89/EU	Framework for maritime spatial planning	Establish a framework for maritime spatial planning aimed at promoting the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources.	Air quality/pollution, marine litter, water quality/pollution
Regulation (EC) No 782/2003	Prohibition of organotin compounds on ships	Reduce or eliminate adverse effects on the marine environment and human health caused by organotin compounds, which act as active biocides in anti-fouling systems used on ships flying the flag of, or operating under the authority of, a Member State, and on ships, regardless of the flag they fly, sailing to or from ports of the Member States.	Water quality/pollution

Regulation (EU) No 1143/2014	Prevention and management of the introduction and spread of invasive alien species	Rules to prevent, minimise and mitigate the adverse impact on biodiversity of the introduction and spread within the EU, both intentional and unintentional, of invasive alien species.	Water quality/pollution
Directive 2008/56/EC	Framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive)	Framework within which Member States are to take the necessary measures to achieve or maintain good environmental status in the marine environment by 2020 at the latest.	Water quality/pollution
Commission Decision (EU) 2017/848	Criteria and methodological standards on good environmental status of marine waters and specifications and standardised methods for monitoring and assessment	Criteria and methodological standards to be used by Member States when determining a set of characteristics for good environmental status.	Water quality/pollution
Directive 2000/60/EC	Framework for Community action in the field of water policy	Establish a framework for the protection of inland surface waters, transitional waters, coastal waters and groundwater.	Water quality/pollution
Directive 2005/35/EC	Ship-source pollution and on the introduction of penalties for infringements	Incorporate international standards for ship-source pollution into Community law and to ensure that people responsible for discharges are subject to adequate penalties, in order to improve maritime safety and to enhance protection of the marine environment from pollution by ships.	Water quality/pollution
Directive 2002/59/EC	Community vessel traffic monitoring and information system	Establish in the Community a vessel traffic monitoring and information system with a view to enhancing the safety and efficiency of maritime traffic, improving the response of authorities to incidents, accidents or potentially dangerous situations at sea, including search and rescue operations, and contributing to a better prevention and detection of pollution by ships.	Water quality/pollution
Council Directive 92/43/EEC	Conservation of natural habitats and of wild fauna and flora	Contribute towards ensuring biodiversity through the conservation of natural habitats and of wild fauna and flora in the European territory of the Member States to which the Treaty applies.	Water quality/pollution

Annex 2 Maritime transport DPSIR table

Driver	Pressures	State	Impacts	Responses (non-exhaustive list of measures tackling pressures and impacts) ([a])
Maritime transport (part of the mobility and trade systems)	Climate change induced by GHG emissions	Changes in water temperature	Changes in the distribution, metabolism, life cycle and behaviour of species	• Increase energy efficiency of equipment and engines of ships • Use of sustainable energy technologies • Use of onshore power supply • Port call optimisation • Port operations optimisation • Slow steaming • Climate adaptation plans, including restoration and conservation of marine and coastal species and habitats
		Increasing CO_2 levels and decreasing pH	Adverse effects on organisms that build calcium carbonate shells or skeletons due to acidification	
		Changes in nutrients and dissolved oxygen due to changes in circulation and stratification	Death of organisms due to hypoxia and unavailability of nutrients	
		Extreme weather events	Damage to coastal ecosystems	
		Sea level rise	Changes in habitats according to new depth zones	
	Emission of air pollutants	Increased levels of NO_x, SO_x and PM in the air	Health problems in citizens living in port cities and coastal areas (diseases such as asthma, bronchitis, emphysema, cancer)	• Adoption of new emissions control areas (e.g. Mediterranean) • Use of sustainable energy technologies • Use of low-sulphur fuels • Use of onshore power supply • Port call optimisation • Port operations optimisation • Slow steaming
		Increased levels of marine nitrogen by atmospheric deposition of NO_x	Eutrophication, proliferation of harmful algae, depletion of fish species and death of benthic organisms due to hypoxia	
		Decreasing pH, due to sulphuric or nitric acid rain from NO_x and SO_x	Adverse effects on organisms that build calcium carbonate shells or skeletons due to acidification by acid rain	
		Increased levels of contaminants in the marine environment (by atmospheric deposition)	Ecotoxic effects on organisms	
	Input of water pollutants	Increased levels of pollutants in the marine environment	Ecotoxic lethal effects: death of organisms exposed	• Ban on open-loop scrubbers • Contingency plans in place for acute pollution events • Use of biocide-free anti-fouling paints • Enhance the use of treatment systems for sewage, bilge water and tank cleaning water
			Ecotoxic sublethal effects: problems related to development and behaviour, as well as reproductive, nervous and cardiovascular systems of organisms exposed	
			Changes in distribution of individuals in a population, effective population size, mutation rate and migration rate	
			Indirect effects: organisms affected by the loss of food	

Driver	Pressures	State	Impacts	Responses (non-exhaustive list of measures tackling pressures and impacts) ([a])
Maritime transport (part of the mobility and trade systems)	Inputs of marine litter	Increasing amounts of litter in the marine environment	Entanglement of animals, which may lead to injury, illness, suffocation, starvation and death Litter ingested, which may lead to loss of nutrition, internal injury, intestinal blockage, starvation and death Damage or degradation of habitats Interference with navigational safety Economic losses in fishing and maritime industries Degradation of the quality of life in coastal communities Threat to human health and safety	• Restructuring of fees at EU ports to promote the maximum delivery of litter to EU ports • Introduction of the green-ship concept, requiring ports to reduce fees for 'green ships' engaging in waste prevention and onboard waste management • Ensure the best management of waste in ports • Implement a mandatory system for the reporting and tracking of passively fished waste, abandoned, lost or otherwise discarded fishing gear and lost containers • Reduce consumption of single use plastic • Introduce extended producer responsibility schemes
	Input or spread of NIS	Establishment and spread of NIS	Decrease in indigenous species' populations due to competition with NIS for space, food or other factors Replacement of indigenous species by NIS in the area Changes in the trophic chain (e.g. new predators) Introduction of new diseases to the local systems, to which indigenous species are not resistant	• Availability of ballast water treatment systems in ports • Enhance the dry-docking of smaller vessels for hull cleaning • Ensure the use of biofouling in-water cleaning and treatment systems that avoid NIS transfers
	Inputs of continuous anthropogenic noise	Masking of marine species' acoustic communication	Loss of hearing, reduction in communication and increase in stress levels, corresponding to behavioural changes (e.g. changes in surfacing and breathing patterns, cessation of or change in the frequency and duration of vocalisations, change in navigation patterns, avoidance of noisy areas, changing in feeding behaviour)	• Re-routeing of shipping lanes to avoid biologically important areas, or establishment of acoustic buffer zones • Slow steaming • Designation of acoustic refuges for noise-sensitive marine life • Integration of new and advancing equipment and engine technologies or vessel design solutions, specifically those that overlap with energy efficiency design index (EEDI) and GHG reduction priorities
	Disturbance of species	Ship strikes (collisions with animals)	Death or injury of animals	• Re-routeing of shipping lanes to avoid biologically important areas • Slow steaming
	Dumping of material dredged in ports and navigation canals	Burial of benthic organisms	Loss of seabed habitat	• Minimise the amount of sediment disposed • Avoid locating dumping sites close to ecologically relevant areas • Use of techniques and equipment that minimise impacts from dumping of dredged material • Use of submerged points of discharge • Lateral containment of discharges • Thin-layer placement • Contaminant control measures on the dumped dredged material
		Increased suspended matter	Decrease in the abundance of organisms and number of species in dumping sites	
		Increased levels of pollutants and micro-litter in the marine environment	Sublethal effects: problems related to development and behaviour, as well as the reproductive, nervous and cardiovascular systems of animals exposed	

Driver	Pressures	State	Impacts	Responses (non-exhaustive list of measures tackling pressures and impacts) ([a])
Maritime transport (part of the mobility and trade systems)	Wake induced turbulence	Increased suspended matter	Decrease in the abundance of organisms and number of species	• Re-routeing of shipping lanes to avoid biologically important areas • Slow steaming
	Anchoring	Abrasion	Loss of seabed habitat	• Adoption of plans for restoration and conservation of marine and coastal species and habitats (blue infrastructure) • Ensure, through the maritime spatial plans, that ecologically important areas are safeguarded
	Pressures due to port development	Change in seabed substrate and morphology by artificial infrastructure	Loss of seabed and coastal habitat	
		Permanent alteration of hydrological conditions	Habitat loss or disturbance	
		Increased levels of litter and pollutants in the marine environment	'Ecotoxic effects on organisms from pollutants. Marine litter can injure or kill marine and coastal wildlife; damage and degrade habitats; interfere with navigational safety; cause economic loss to fishing and maritime industries; degrade the quality of life in coastal communities; and threaten human health and safety' (US Fish &Wildlife, 2016)	

([a]) Responses can include technical, administrative or legal measures implemented by either public administrations from Member States or private operators, as well as strategic responses addressing the drivers at the systemic level (e.g. policies on trade or mobility).

Annex 3 Advantages and disadvantages of emission abatement methods: alternative fuels and energy technologies

	Advantages	Disadvantages
Liquefied natural gas	**Environment**. Reduction in emission of relevant substances such as NO_x, SO_x and PM. **Energy content**. Gravimetric energy density comparable to petrol and diesel fuels, extending range and reducing refuelling frequency. **Technological maturity.** Significant number of first-mover initiatives with close to 200 ships using LNG today (non-LNG carriers). Cost-effective after capital investment and better return on investment if external costs are not considered. Possibility of using liquefied biogas (LBG) as a renewal fuel, further reducing emissions. Possibility of using three different pathways to generate methane for ships using fossil fuels, biofuels or synthetic routes. Methane can be used as a hydrogen carrier, which fits both combustion engines and fuel cells, also offering a pathway for a fossil-renewable transition.	**GHG impact.** LNG is mostly composed of methane; the impact of methane on climate change is more than 30 times greater than that of CO_2 over a 100-year period. Careful consideration needs to be given to any form of methane release throughout the WTW chain of LNG (i.e. over the life cycle of the fuel, including fugitive emissions resulting during its production, distribution and combustion). Optimisation of engine performance for NO_x may compromise methane slip. Varying and low engine loads also impact methane slip. As a fossil fuel, it cannot achieve the EU's climate change objectives (even excluding methane slip). **Capital investment**. High investment costs, risk of stranded assets, as it is a transition fuel. **Bunkering.** **Loss of space** on deck due to the need sometimes to place the fuel tanks on deck for safety reasons (ventilation).
Biofuels	**Availability.** Large variety of possible sources, from crops to organic waste. **Biodegradable.** Less risk to the marine environment in the event of a spill. **Emissions.** Reduction in GHG emissions and PM compared with heavy fuel oil. **GHG impact.** Reduction in CO_2 equivalent emissions, compared with traditional oil fuels, can be up to 65 % depending on the biomass used.	**Land use.** Indicatively, the production of 300 Mt of oil equivalent (Mtoe) biodiesel based on today's technology requires about 5 % of the current agricultural land in the world. **High production cost.** The cost of producing biodiesel can be considerable. It will also depend significantly on the availability and accessibility of biomass for fuel production. **Physicochemical stability.** Concerns related to long-term storage stability of biofuels on board ships and issues with corrosion also need to be addressed. **Monoculture.** Monoculture refers to the practice of producing the same crops year after year, rather than producing various crops in a farmer's field over time. While this might be economically attractive for farmers, growing the same crop every year may deprive the soil of nutrients that are put back into the soil through crop rotation. There is a scarcity of biomass having a high potential for reducing GHG emissions due to increased competition for biomass resources between sectors.

	Advantages	Disadvantages
Ethyl and methyl alcohols	**Environment.** Emissions of SO_x are reduced by roughly 99 %, NO_x by 60 %, PM by 95 % and CO_2 by 25 % when compared with fuels currently available. **Storage.** Fuel stored in liquid form, in atmospheric tanks (particular advantage when compared with LNG). **Versatility.** Can be burned either in engines using the Otto cycle or on dual-fuel diesel engines. **Hydrogen and fuel cells.** Methanol has the potential to provide a very good stable and safe hydrogen carrier. Methanol can be used to produce hydrogen and also can be directly used in fuel cells. If produced from renewable electricity and a source of sustainable CO_2 (atmospheric or biogenic), it is almost carbon neutral.	**Energy content.** Lower heating value compared with diesel or LNG, resulting in lower performance when compared with other marine alternative fuels such as LNG. **Corrosivity.** Fuel storage tanks and fuel distribution system equipment must be corrosion and damage resistant due to the corrosive nature of ethyl/methyl alcohols. Bunkering requires use of non-corroding hoses and stainless steel fuel tanks. **Flammable characteristics.** Methyl/ethyl alcohols pose challenges for fire detection and firefighting techniques. With a flame that can hardly be seen, it is important to develop quickly available and easy-to-use thermal imagery for fire visualisation. **Toxicity.** Methyl/ethyl alcohols are toxic to humans when ingested or when their vapours are inhaled. **Low viscosity.** The viscosity of dimethyl ether is lower than that of diesel by a factor of about 20, leading to potentially increased amounts of leakage in pumps and fuel injectors.
Hydrogen	**Specific energy.** Liquid hydrogen, compressed at 700 bar (70 000 kPa), has a specific energy (kJ/m^3) more than three times that of diesel or petrol. **Availability.** Hydrogen is an element widely available in nature. It has, however, to be produced, involving significant cost. **Environment.** Liquid hydrogen generates no emissions to the atmosphere (no sulphur dioxide, CO_2 or PM). NO_x can result from the combustion of H_2 with air (O_2 + N_2) but not from fuel cells where only fresh water (H_2O) results. **Versatility.** Through different production processes hydrogen can be obtained from many different sources, making the production chain versatile, although the sustainability of hydrogen depends on the actual production process. **Non-toxic.** Unlike many other fuels, hydrogen is also non-toxic. **Sustainability**. Hydrogen, as already pointed above, is widely available in nature. It is a molecular element contained in many available sources. There is a good potential for sustainable production of hydrogen if hydrolysis is chosen as a preferred way forward, together with energy from renewable sources. **Diffusivity.** Hydrogen is lighter than air and diffuses rapidly. Hydrogen has a rapid diffusivity (3.8 times faster than natural gas), which means that when released it dilutes quickly into a non-flammable concentration.	**Energy density.** Liquefied hydrogen cooled at -253 °C has approximately one third of the energy density (kJ/m^3) of conventional fossil fuels. **Experience.** Currently there is no experience of using hydrogen for propulsion purposes on ships. **Safety.** Even though hydrogen is today largely understood and dealt with under very strict safety measures, it is still a gas with a low lower flammable limit (4 % in air) and with the largest flammability range (from 4 % lower flammable limit to around 70 % upper flammable limit). **Infrastructure.** There would be the need for a substantial hydrogen supply, distribution and bunkering infrastructure to make it viable for the marine industry. **Cost.** Production costs pose a challenge for hydrogen's viability as an alternative fuel, especially when compared with other fuels. Although widely available in nature, it nevertheless must be produced by industrial processes. Currently, most hydrogen is produced from fossil fuels by steam reforming or partial oxidation of methane and coal gasification, with only a small quantity produced by other routes such as biomass gasification or electrolysis of water. **Storage.** Hydrogen storage is today a significant area of discussion and research. A fundamental point is that while hydrogen has a high specific energy (MJ/kg), its energy density (MJ/m^3) is quite low. Thus, to carry a similar amount of energy on board to that provided by hydrocarbons would require a very large tank volume, which renders it currently not applicable to ships travelling long distances. Compression and/or liquefaction are therefore the two strategies most commonly applied to achieve a satisfactory storage of energy for mobile applications. Research is ongoing in other areas and into strategies for hydrogen storage, either chemically or physically. **Permeability and embrittlement.** Due to their small molecular size, hydrogen diatomic molecules permeate through most steel alloys and aluminium, weakening the mechanical structure of the material. Hydrogen not only is able to occupy the interstitial gaps in metallic structures, it is also able to migrate, leading to a slow, yet dangerous, potential source of explosive atmospheres. **Grey hydrogen has a larger climate footprint than the original hydrocarbon used for its production.**

	Advantages	Disadvantages
Ammonia	**Carbon-free fuel.** No CO_2 or soot or carbonaceous emissions derived from its combustion. **Low flammability risk.** 5-25 % present in air. Can be produced from electrical energy. Potential for use of renewables, **Can easily be converted into H_2 and N_2.** It can be stored and transported as liquid at relatively low pressure or temperature. Established as a commercial product. **Potential application in fuel cells.** Ammonia fuel cells under development.	**Toxicity.** It is classified as a hazardous substance and subject to strict reporting requirements by facilities that produce, store or use it in significant quantities. **Fuel infrastructure.** Current lack of bunkering infrastructure representing a barrier for using ammonia as an alternative marine fuel (DNV GL, 2019). **Missing regulations.** Due to its toxicity the use of ammonia as fuel on board is currently not regulated. **Technology.** Ammonia internal combustion engines still at development stage although several engine manufacturers are progressing fast towards developing such engines. **Air pollution.** Potential NO_x formation resulting in use in combination with after-treatment systems **Low energy density.** Storage tank requirements almost three times larger than for traditional conventional fuels.
Fuel cells	**Environment.** Potential of fuel cells as an environmental technology is very good, as a device that does not release the combustion products typically associated with internal combustion engines. **Noise.** Quiet, lack of vibration and noise means that they can be located close to occupied spaces, particularly for auxiliary power. Elimination of machinery component causing underwater noise. **Flexibility.** Flexible and innovative ship design is possible with fuel cells. Not only can the units be modularised, they can also be placed in different locations along the ship, contributing to possible segregated safety areas. **Efficiency.** Despite being close to the internal combustion engine in overall efficiency, fuel cells can be made more efficient through recuperation of heat. This is especially the case for high-temperature fuel cells. **Energy supply units.** Fuel cells can be deployed as auxiliary power units, to be placed anywhere in the ship, even for temporary purposes.	**Low power and power density.** Fuel cells are not yet available in the power and form needed as a main energy source. The power density of fuel cells, when compared with other energy conversion devices, is significantly lower, especially for current low-temperature proton exchange membrane technology fuel cells which are presently the most developed for the automotive market. **Cost.** Reflecting their largely experimental nature, the capital cost is still high, especially considering the lower technology readiness level of high-power higher temperature, higher efficiency fuel cells that maybe most relevant for shipping. **Safety.** The safety of hydrogen fuel cells, accounting for the presence of hydrogen in the fuel, is still a challenge to address. Installation on board ships requires particular attention to reforming of fuel, hydrogen storage (is considered) and structural fire protection. Other alternative fuels maybe less challenging in this respect. **Endurance.** Todays most developed proton exchange membrane fuel cells are yet to achieve the level of endurance required for semi-continuous operation in commercial shipping.

	Advantages	Disadvantages
Batteries	**Environment.** Batteries offer the most efficient energy conversion and storage. If charged using renewable electricity, from an operational perspective they produce no emissions. Total efficiencies exceeding 90 % are possible. Elimination of GHG, SO_x, NO_x and PM emissions in fully electric applications and improvements in internal combustion engine hybrid configurations. Hybrids are potentially able to enter port under battery power, cutting local pollution. **Fuel saving.** Even for a ship producing its own electrical power, the use of electricity from batteries has the potential to reduce the fuel consumption considerably. For propulsion, batteries as the main energy source could be used over short distances. Over long distances, batteries can be used to save waste energy. **Weight savings.** Batteries used for load levelling are typically lighter than the additional engine that they replace. **Low maintenance.** Battery electric systems have lower running costs and are more reliable. **High power.** Batteries can deliver large amounts of power and are ideal to cover large transient loads even if the total energy capacity is moderate. **Noise reduction.** A ship operating on batteries is inherently silent. Apart from the comfort of all those on board it may also represent significant operational advantages. **New battery technology.** Different battery technologies are undergoing specialised research with the objective of increasing their power density (reducing mainly volume and weight). New battery solutions include metal-sulphur, where the metal is magnesium, sodium or lithium, or metal-oxygen — also referred to as metal-air where the metal is zinc, lithium or sodium. Lithium-air batteries are today a promising area of research and development.	**Self-discharge rates.** Batteries (lead acid, zinc-carbon dry cell and nickel-cadmium) have significant challenges related to self-discharge rates and memory effect. However, waterborne batteries are used continuously. **Charging times.** Duration pf re-charging, especially if done while the ship is alongside, may present a restrictive operational condition, depending on the ship type and profile. **Cargo space.** The available cargo space on board may be reduced, especially on those vessels that adopt a hybrid solution, with fuel storage and batteries installed. The impact of voluminous and heavy batteries is still a big concern in ship design. **Unfeasible for long distance shipping if used alone**. Battery energy density is 50 times less than a conventional liquid fuel, regardless of cost, which makes them unsuitable for very large ships and very long distances due to the massive bulk of batteries required. **Lifecycle analysis and cost.** Assessing how the charging electricity is produced needs to be considered to ensure sustainability. The battery pack requires replacement when it reaches it's the end of its life as determined by the total number of charge/discharge cycles. **Safety.** Thermal runaway is still the hazard associated with lithium-ion batteries, which concern most marine battery applications. Large potential energy for fire and explosion. Toxic combustion products. **Charging infrastructure at ports**. Not harmonised, only OPS at some ports; unlike maritime fuels, electricity is taxed (ongoing revision of the Energy Taxation Directive may change this); Member States may apply for time-limited exemption from taxation of electricity used by ships. **Readiness.** There is no clear definition of OPS readiness on board ships, which may affect the implementation and use of the infrastructure.
Onshore power supply	**Environment.** Local impact from OPS is immediately positive in terms of SO_x, NO_x and PM emissions. Compensates weaknesses of NO_x reduction technologies (i.e. selective catalytic reduction) not efficient at low engine loads such as when at berth. **GHG impact.** The use of OPS reduces GHG emissions if sustainable electricity is available. The related reduction per individual ship depends on the amount of the energy used by the ship at berth. The actual impact on GHG emissions would depend on the specific CO_2 emission factor associated with the available electricity supply. **Noise reduction.** With connection to energy from the shore there would be no need to have the auxiliary engines running, leading to an immediate noise reduction on board and in the port area. **Working conditions.** Significantly improved working conditions, allowing for a more comfortable working environment on board. **IMO Guidelines for OPS.** Having been finalised in 2020, the IMO interim guidelines for safe OPS operation, once published, will constitute a global instrument for the development of shore-side electricity.	**GHG impact.** In countries with high CO_2 emission factors for their electricity supply, the use of electricity from the national grid would lead to more emissions than using the standard diesel generator on board. **Frequency.** The incompatibility between 50 Hz and 60 Hz would have to be resolved by the installation of a frequency converter. This would immediately lead to an increase in the investment cost associated with using the infrastructure. **Connectors.** Standardisation of OPS equipment can be a challenge, at the global level. Through Directive 2014/94 the standard enforced is IEC/IEEE 80051/1 (2019) — high-voltage shore connection. **Black-out.** During switch-over operations from onboard to shore power supply, there is always a very short interruption. This may have operational implications, depending on the type of ship. Electricity supplied to ships in port is routinely taxed and included within the EU ETS, but fuel for onboard generators is tax free. **Cost.** Related investments needed for establishing an effective OPS infrastructure, as well as taxation issues.
Exhaust gas cleaning systems	**Emissions.** Abatement efficiencies may reach up to 95 % or higher in the case of SO_x and a portion of PM. SO_x abatement removes a majority of PM, including black carbon, plus a portion of NO_x. **Regulatory framework.** Recognised in current regulations. **Cost-effective.** Relatively low maintenance requirements. In the case of EGCSs, their main advantage is the possibility to continue using cheaper high-sulphur fuels and therefore benefit from the cost savings resulting from the price gap between those and low-sulphur fuels or other alternative fuels.	**Weight and space.** Retrofitting may be challenging to due to lack of space and additional weight on board. **Availability.** The transition to low-sulphur fuels may pose challenged for the bunkering of high-sulphur residual fuels in some ports. **Uncertainty regarding future regulations**. Discharge waters are limited in some territorial seas in the EU (some were in place before the introduction of EGCSs) and there may be further limitations as a result of discussions at the IMO. **Price gap.** There is a price gap between high and low sulphur fuels (i.e. marine gas oils, marine diesel oil), which may reduce over time.

Annex 4
Overview of port infrastructures

Table A4.1 Overview of shore-to-ship power infrastructures in the EU

Country	Port	Category HV/LV	Power (MW)	No of berths with OPS	Types of vessel	TEN-T network
Belgium	Antwerp	High voltage	0.8	1	Container ship	Core
	Zeebrugge	High voltage	1.25	1	Ro-ro	Core
Denmark	Frederikshavn	High voltage	4.48		Navy vessels	Comprehensive
	Helsingor	High voltage	4.5	1	Ferry	Comprehensive
Finland	Helsinki	High voltage		1	Ferry, Ro-ro	Core
	Kemi	High voltage		1	Ro-pax	Comprehensive
	Oulu	High voltage		1	Ro-pax	Comprehensive
France	Antibes	High voltage	1.2	1	Maxi yacht	
	Dunkirk	High voltage	6	1	Container ship	Core
	Marseille	High voltage	1.44	3	Ferry, Ro-ro	Core
Germany	Hamburg	High voltage	9.8	1	Cruise ship	Core
	Kiel	High voltage	4.5		Ferry Oslo-Kiel, Cruise ship	Comprehensive
	Lübeck	High voltage	3.5	2	Ro-pax	Core
	Lübeck	High voltage	2	2	Container ship < 140 m	Core
	Lübeck	High voltage	9.8		Cruise ship	Core
	Lübeck	High voltage	3.5	2	Ro-ro and vehicle vessels	Core
Italy	Ancona	High voltage	1.6	2	Shipyard	
Latvia	Liepāja	High voltage	0.5	2	Ro-ro and vehicle vessels	Comprehensive
	Riga	High voltage	1.6	2	Container ship	Core
Malta	Delimara	High voltage	2.4	1	LNG to power floating storage unit	
Netherlands	Hook of Holland	High voltage	4.8		Ro-ro, ferry	
	Rotterdam	High voltage	2.8	2	Ro-pax	Core
Norway	Bergen	High voltage	12.8	3	3 cruise ships	
	Larvik	High voltage	1.8	1	Ro-ro, ferry	
	Oslo	High voltage	4.5	1	Cruise ship	
	Sandefjord	High voltage	2.75	1	Ro-ro, ferry	
Spain	Barcelona	High voltage	3.4	1	Yachts	Core
	Barcelona	High voltage	3.0	1	Yachts	Core

Table A4.1 Overview of shore-to-ship power infrastructures in the EU

Country	Port	Category HV/ LV	Power (MW)	No of berths with OPS	Types of vessel	TEN-T network
Spain	Palma	High voltage	1.6	1	Ferry	Core
Sweden	Gothenburg	High voltage	1.25-2.5	6	Ro-ro, Ro-pax	Core
	Helsingborg	High voltage	4.5	1	Ferry	Comprehensive
	Stockholm	High voltage	6 (2 × 3)	2	Ro-pax	Core
	Stockholm	High voltage	2	1	Ro-pax	Core
	Trelleborg	High voltage	0-3.2	6	Ferry	Core
	Ystad	High voltage	6.25-10	1	Cruise ship	Comprehensive
	Visby	High voltage	5	4	Ferry	Comprehensive

Note: Blank cells indicate data not available or not applicable.

Source: EAFO (2020a).

Table A4.2 Overview of LNG port infrastructure in the EU

Country	Port (city)	Type of LNG bunkering	TEN-T network
Austria	Ennshafen	Truck-to-ship	Core
Belgium	Antwerp	Terminal (port)-to-ship	Core
	Antwerp	Truck-to-ship	Core
	Zeebrugge	Ship-to-ship	Core
Bulgaria	Ruse	Terminal (port)-to-ship	
Denmark	Hirtshals	Terminal (port)-to-Ship	Comprehensive
Estonia	Tallinn	Terminal (port)-to-ship	Core
Finland	Helsinki	Truck-to-ship	Core
	Helsinki	Ship-to-ship	Core
	Pori	Terminal (port)-to-ship	Comprehensive
	Tornio	Terminal (port)-to-ship	
France	Dunkirk	Ship-to-ship	Core
	Marseilles	Ship-to-ship	Core
	Marseilles	Ship-to-ship	Core
	Montoir-de-Bretagne	Ship-to-ship	
Germany	Brunsbüttel	Truck-to-ship	Comprehensive
	Brunsbüttel	Truck-to-ship	Comprehensive
	Cologne	Terminal (port)-to-ship	
	Hamburg	Ship-to-ship	Core
	Hamburg	Terminal (port)-to-ship	Core
	Mannheim	Truck-to-ship	
	Rostock	Terminal (port)-to-ship	Core
Italy	Rome	Truck-to-ship	Comprehensive

Table A4.2 Overview of LNG port infrastructure in the EU

Country	Port (city)	Type of LNG bunkering	TEN-T network
Lithuania	Klaipėda	Terminal (port)-to-ship	Core
Netherlands	Amsterdam	Truck-to-ship	Core
	Doesburg	Terminal (port)-to-ship	
	Moerdijk	Truck-to-ship	Core
	Rotterdam	Ship-to-ship	Core
	Rotterdam	Terminal (port)-to-ship	Core
	Rotterdam Europoort	Terminal (port)-to-ship	Core
Norway	Ågotnes	Terminal (port)-to-ship	
	Avaldsnes	Terminal (port)-to-ship	
	Bergen	Ship-to-ship	
	Bjugn	Terminal (port)-to-ship	
	Bodø	Terminal (port)-to-ship	
	Florø	Terminal (port)-to-ship	
	Fredrikstad	Terminal (port)-to-ship	
	Halhjem	Terminal (port)-to-ship	
	Hammerfest	Terminal (port)-to-ship	
	Haugesund	Ship-to-ship	
	Hordvikneset	Terminal (port)-to-ship	
	Kirkenes	Terminal (port)-to-ship	
	Kollsnes	Terminal (port)-to-ship	
	Kollsnes	Terminal (port)-to-ship	
	Kristiansund	Terminal (port)-to-ship	
	Lødingen	Terminal (port)-to-ship	
	Moskenes	Terminal (port)-to-ship	
	Os	Terminal (port)-to-ship	
	Polarbase	Terminal (port)-to-ship	
	Sandnessjøen	Ship-to-ship	
	Snøvhit, Hammerfest	Terminal (port)-to-ship	
	Stavanger	Terminal (port)-to-ship	
Portugal	SInes	Ship-to-ship	Core
Spain	Algeciras	Ship-to-ship	Core
	Barcelona	Ship-to-ship	Core
	Barcelona	Ship-to-ship	Core
	Barcelona	Terminal (port)-to-ship	Core
	Bilbao	Terminal (port)-to-ship	Core
	Cartagena	Terminal (port)-to-ship	Core
	Huelva	Terminal (port)-to-ship	Core
	Huelva	Ship-to-ship	Core

Table A4.2 Overview of LNG port infrastructure in the EU

Country	Port (city)	Type of LNG bunkering	TEN-T network
Spain	Huelva	Multiple truck-to-ship	Core
	Mugardos (Ferrol)	Terminal (port)-to-ship	Comprehensive
	Sagunto	Terminal (port)-to-ship	Comprehensive
	Santander	Terminal (port)-to-ship	Comprehensive available by 2022
	Tenerife	Ship-to-ship	Core
	Valencia	Terminal (port)-to-ship	Core
	Valencia	Multiple truck-to-ship	Core
Sweden	Gothenburg	Ship-to-ship	Core
	Lysekil	Ship-to-ship	
	Stockholm	Ship-to-ship	Core
United Kingdom	Gibraltar	Ship-to-ship	

Note: Blank cells indicate data not available or not apllicable.

Source: EAFO (2020b).

Annex 5
EU projects towards achieving sustainable maritime transport

A5.1 Alternative fuels and energy technologies

A5.1.1 Liquefied natural gas

ReaLNG. *Turning LNG as marine fuel into reality in the North Sea-Baltic region (CEF Transport, EUR 12.6 million EU grant)*

This project focused on the adoption of LNG as an alternative marine fuel for the short-sea shipping sector in the North Sea-Baltic Sea basins. It covered the preparation of the design studies necessary for operating a specialised LNG bunker vessel and its subsequent construction, the upgrade of LNG-related port infrastructure and the development of training programmes and pilots in the field of LNG operations. The seagoing LNG bunker vessel (Image A5.1), named *Cardissa, is a* 6 500 m^3 ship operated by Shell sailing in the Antwerp-Rotterdam-Amsterdam area. It is equipped with an LNG bunker arm and a sub-cooling unit to keep LNG at atmospheric pressure. It can bunker ~0.4 million tonnes per annum (mtpa) of LNG to a range of vessel sizes, from small coastal and large transatlantic vessels, thanks to its cutting-edge design. It can reach a speed of 13 knots. In terms of LNG bunkering rate, it is capable of fuelling 1 000 m^3 of LNG per hour.

Image A5.1 LNG bunker vessel

Source: © Photographic Services, Shell International Limited.

EG LNG. *Bunker vessel (CEF Transport, EUR 5.4 million EU grant)*

The project finances the construction of an LNG bunker vessel by the Dutch shipyard Damen Group (Image A5.2). Expected to be delivered in Estonia in May 2021, the ship will load LNG in the Baltic Sea region terminals for its wider distribution in the Baltic Sea basin, predominantly operating in the Gulf of Finland area. Large LNG tanks have been placed under the main deck, holding a total volume of 6 000 m^3, enabling the vessel to carry out bunkering operations both in ports and at sea, at designated anchorage points. The vessel will include innovative design features, such as a low-profile, in order to be able to bunker side-by-side with passenger ships with vertical drop lifeboats. A bird's eye pilot vision safety system will be installed to increase the safety of mooring and bunkering operations in the case of low visibility and bad weather conditions. Finally, a power take-off/ power take-in shaft generator power-intake system will ensure that the shaft rotates in the event of the main engines failing.

CORE LNGas hive. *Core network corridors and liquefied natural gas (CEF Transport, EUR 15.2 million EU grant)*

This project supports the deployment of LNG infrastructure for maritime transport and port operations along the Spanish and Portuguese sections of the Atlantic and Mediterranean core network corridors in line with the corresponding corridor work plans. It includes a group of studies and real-life pilot deployments. The results will provide recommendations for the Spanish and Portuguese national policy frameworks for the alternative fuels supply infrastructure and will prepare the roll-out plan for future commercial deployment along the two corridors in the Iberian Peninsula. Moreover, a multi-product bunker vessel (MV *Oizmendi*) has been retrofitted. This 100 m length barge was installed with two 300 m^2 tanks enabling LNG bunkering. Moreover, its capacity can be further extended with the installation of extra tanks (BlueMed, 2020).

S/F SamueLNG for a blue Atlantic arch *(CEF Transport, EUR 9.9 million EU grant)*

This project had two objectives, namely piloting the first ever conversion of a dredging vessel to a dual-fuel source and preparing studies to enable the future deployment of further bunkering infrastructure in the Atlantic arch. Damen Shiprepair & Conversion was awarded the contract, following a European tender, to convert the trailing suction hopper dredger vessel named Samuel de Champlain to a dual-fuel source. This vessel was built in 2002 and, with a length of 117 m, width of 24 m and draught of 8 m, is the largest vessel of Drages-Ports and has a hopper capacity of 8 500 m^3 (Image A5.3). It is currently operational in both the Loire and Seine estuaries. As a pioneering project, significant engineering studies were completed prior to the start of work in the Damen shipyard. The existing gensets were replaced with three 3 180 kW dual-fuel gensets based on MAN 6L35/44DF engines, two type C tanks with a capacity of 153 m^3 of LNG were installed, and two refuelling stations, a nitrogen unit, a piping network and modernisation of the control/command system were implemented. This enables the vessel to operate for a week. Moreover, the project also included a risk study in the ports of Rouen, Le Havre and Nantes Saint-Nazaire, as well as training of staff in LNG operations in the ports of Nantes Saint-Nazaire and Rouen. Finally, the Port of Gijón and the Port of Vigo successfully created designs for mobile LNG bunkering devices.

Image A5.2 Construction of LNG bunker vessel by the Dutch shipyard Damen Group

Source: © INEA.

LNGHIVE2. *Green and smart links — LNG solutions for smart maritime links in Spanish core ports (CEF Transport, EUR 11.8 million EU grant)*

This project aims to create the market base for the roll-out of bunkering services by boosting LNG fuel consumption and enabling the use of LNG on shore and on board for maritime transport and port operations. It takes place in the Atlantic and Mediterranean core network corridors. The project is part of the global project LNGHIVE2, the Spanish flagship initiative for LNG maritime fuel deployment in southern Europe. The project falls within the framework of the LNG deployment strategy led by the Spanish administration and framed under the LNG section of the Spanish national policy framework for the deployment of alternative fuels in transport. It includes the retrofitting of five Ro-pax Balearic vessels to dual-fuel sources, the construction of an LNG supply station in the Port of Gijón and a multiple truck-to-ship bunker.

A5.1.2 Biofuels

EU Stakeholder initiative, MAERSK, DSGC, Lloyd's Register: *MAERSK/DSGC pilot. Second-generation biofuel deployment in large container ship*

In a pilot study between March and June 2019, a large Triple-E vessel sailed 25 000 nautical miles from Rotterdam to Shanghai and back on biofuel blends alone, using up to 20 % sustainable second-generation biofuels — a world first at this scale. The biofuel used in this pilot is second-generation biofuel, produced from waste sources, in this case used cooking oil (UCOME, or used cooking oil methyl ester).

A5.1.3 Ethyl and methyl alcohols

Methanol. *The marine fuel of the future (TEN-T programme, EUR 7.9 million EU grant)*

This pilot project aimed to test the performance of methanol on the existing passenger ferry MS *Stena Germanica* (the world's second largest Ro-pax ferry at the time of the project's initiation) operating between the ports of Gothenburg and Kiel. Running the ship on methanol allowed it to comply with the SECA regulations.

This project successfully proved the feasibility of methanol as a future fuel for shipping. It developed an engine conversion kit that can be implemented on other ships and undertook significant testing in real time, resulting in the culmination of many years of research. In addition to retrofitting the vessel, the pilot project also created the appropriate port infrastructure for the supply of methanol for bunkering: a bunker vessel and a storage tank built to carry methanol, as well as the corresponding facilities in both ports. The engine type selected for the project was a Wärtsilä-Sulzer eight-cylinder Z40S, offering a combined propulsion power output of 24 MW. The upgraded vessel was fitted with dual-fuel injection nozzles, capable of injecting both methanol and diesel. Each engine was also equipped with a high-pressure (600 bar, or 60 000 kPa) methanol pump.

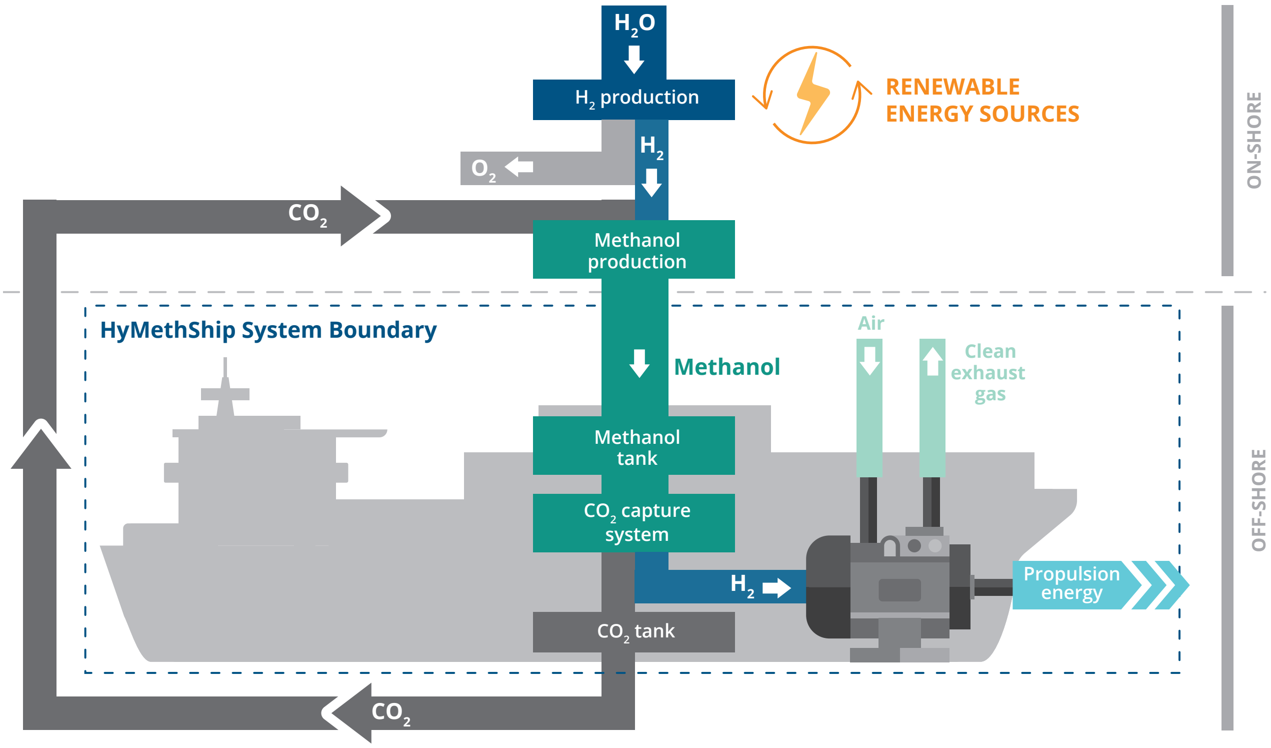
Image A5.3 The SamueLNG vessel, Samuel de Champlain: first European dual-fuel converted dredger

Source: © SamueLNG project (2015-2019).

HyMethShip: Horizon 2020 project. *Hydrogen-methanol ship propulsion system using onboard pre-combustion carbon capture*

The HyMethShip project is developing the first internal combustion engine for a marine propulsion system capable of reducing CO_2 emissions by more than 95 %. The project will achieve this goal by using renewable methanol as the energy carrier and implementing pre-combustion carbon capture. The system will be demonstrated on shore at full scale. The HyMethShip system innovatively combines a membrane reactor, a CO_2 capture system, a storage system for CO_2 and methanol, and a hydrogen-fuelled combustion engine in one system (Figure A5.1). The proposed solution reforms methanol to hydrogen, which is then burned in a reciprocating engine that has been upgraded to burn multiple fuel types and is specifically optimised for hydrogen use. The new concept allows for a closed CO_2 loop ship propulsion system while maintaining the reliability of well-established marine engine technology. The HyMethShip project will undertake risk and safety evaluations, as well as lifecycle costing and lifecycle assessment to ultimately optimise economic and environmental performance for different ship types and operating scenarios (HyMethShip project, 2018-2021).

Figure A5.1 HyMethShip system



Source: © LEC GmbH.

Image A5.4 RV Aranda: research vessel equipped with a proton exchange membrane fuel cell (PEMFC)

Source: © Ilkka Lastumäki.

A5.1.4 Hydrogen

FCH-JU — Horizon 2020 project. *Maranda: hydrogen-fuelled ship demonstrator*

In the Maranda project an emission-free hydrogen-fuelled proton exchange membrane fuel cell (PEMFC)-based hybrid powertrain system is being developed for marine applications and validated both in test benches and on board RV *Aranda*, which is one of about 300 research vessels in Europe (Image A5.4). Special emphasis is placed on air filtration and development of hydrogen ejector solutions, for both efficiency and durability reasons. In addition, full-scale freeze start testing of the system will be conducted. When research vessels are performing measurements, the main engines are turned off to minimise noise, vibration and air pollution that can disrupt the measurements. The 165 kW (2 × 82.5 kW AC) fuel cell powertrain (hybridised with a battery) will provide power to the vessel's electrical equipment as well as dynamic positioning during measurements, free from vibration, noise and air pollution. One of the major obstacles to the wider implementation of fuel cells in the marine sector is the hydrogen supply infrastructure. To alleviate this problem, a mobile hydrogen storage container, refillable in any 350 bar (35 000 kPa) hydrogen refuelling station will be developed in this project. This novel solution will increase hydrogen's availability to the marine sector as well as to many other sectors. The project consortium includes companies from the whole fuel cell value chain, from balance-of-plant component suppliers to system integrators and end users. The fuel cell system will be tested in conditions similar to arctic marine conditions before implementation in the target vessel. In addition, long-term durability testing (6 months, 4 380 operating hours) of the system will be conducted at an industrial site (Maranda project, 2017-2021).

HySeas III: Horizon 2020 project. *Demonstrator for hydrogen-fuelled PEMFC*

HySeas III is the final part of a three-part research programme that began looking into the theory of hydrogen-powered vessels in 2013 (HySeas I), followed in 2014-2015 by a detailed technical and commercial study to design a hydrogen fuel cell-powered vessel (HySeas II). HySeas III builds on the first two parts by aiming to demonstrate that fuel cells may be successfully integrated with a proven marine hybrid electric drive system (electric propulsion, control gear, batteries, etc.), along with the associated hydrogen storage and bunkering arrangements. The project will do this by developing, constructing, testing and validating a full-sized drive train on land. Should this test be successful, Transport Scotland has agreed to fund the building of a Ro-pax ferry that will integrate the entire hydrogen/electric drive train and will be subject to extensive monitoring and testing. The fuel cell units to be employed are currently in service, delivering proven and reliable zero-emission road transport for over 10 years in an expanding fleet of over a hundred fuel cell buses in Europe and beyond. The PEMFC modules to be employed in HySeas III have in some cases reached over 30 000 operating hours. The route chosen as the recipient of this innovative vessel will be Kirkwall to Shapinsay, in the Orkney Islands, located off the north coast of Scotland (HySeas III project, 2018-2021).

A5.1.5 Fuel cells

EU Co-funding — 6FP (2010). *Methapu: demonstrating direct methanol fuel cell application*

The Methapu project (Methanol auxiliary power unit) was formed after the initial feasibility phase of FellowSHIP, which included a feasibility study of fuel cells for auxiliary power production for a Ro-ro car carrier. The project was a European Commission-funded research (6FP) project with the following strategic objectives: (1) assess the maturity of methanol using technology on board a commercial vessel; (2) validate marine compatible methanol running solid oxide fuel cell technology; (3) innovate the necessary technical justifications for the use of methanol on board cargo vessels involved in international trade to support the introduction of the regulations necessary to allow the use of methanol as a marine fuel; (4) assess short-term and long-term environmental impacts of the application; and (5) enable future research activities on larger marine compatible solid oxide fuel cell units and the methanol-based economy. The project consisted of various technical work packages, including the marine modification of the 250 kW solid oxide fuel cell unit and a study of its safety and reliability.

EU Co-funding — FCH-JU Horizon 2020 innovation project (2020). *ShipFC: piloting multi-MW ammonia ship fuel cells*

A maritime innovation project looking to install the world's first ammonia-powered fuel cell on a vessel has been awarded EUR 10 million EU funding. The ShipFC project is being run by a consortium of 14 European companies and institutions, co-ordinated by the Norwegian cluster organisation NCE Maritime CleanTech, and has been awarded backing from the EU's research and innovation programme Horizon 2020 under its Fuel Cells and Hydrogen Joint Undertaking (FCH JU). The project will see an offshore vessel, MS *Viking Energy*, which is owned and operated by Eidesvik and on contract to major energy company Equinor, have a large 2 MW ammonia fuel cell retrofitted, allowing it to sail solely on clean fuel for up to 3 000 hours annually (Image A5.5). In this way, the project will demonstrate that long-range zero-emission voyages by high-power larger ships are possible (ShipFC project, 2020-2025).

Image A5.5 Viking Energy: the first vessel equipped with a 2MW ammonia powered fuel cell

Source: © Eidesvik Offshore/Wärtsilä.

A5.1.6 Batteries

EU-funded CEF programme. *Zero Emission Ferries: a green link across the Öresund (CEF Transport, EUR 13.2 million EU grant)*

The project investigated the introduction and testing of new and innovative concepts and technology by converting two existing complex Ro-pax ships — originally driven by marine gas oil — to plug-in all-electric operation using batteries exclusively. Thus, the project supported the development of clean Motorways of the Sea, by testing and deploying new technological solutions in real operational conditions on a particularly busy maritime link connecting the comprehensive network TEN-T ports of Helingör (Denmark) and Helsingborg (Sweden).

The project covered the conceptual, operational and capital investment measures required to upgrade the environmental and economic performance, as well as the service quality, of four existing combined freight and passenger (Ro-pax ships) short-sea shipping services connecting Denmark with Sweden. This innovative approach eliminates exhaust gases and reduces emissions of GHGs (approx. 13 500 tonnes of CO_2 per ship per year) and also noise from the maritime/port operations. To this end, two existing complex Ro-pax ships — *Tycho Brahe* and *Aurora* — originally driven by marine gas oil, will be converted to plug-in all-electric operation using batteries, which are charged with onshore electricity (Image A5.6). Each vessel has a battery storage capacity of 4 160 kWh, corresponding to the same power as 70 electric cars. The batteries were installed in four 32-foot containers on top of the ship alongside two deckhouses, which contained transformers, converters and cooling systems for the batteries. The four diesel engines already installed on board remain on the ships and they will function as backups (Zero Emission Ferries project, 2014-2017).

Image A5.6 First automated shore-side charging stations using an ABB industrial robot

Source: ABB (2016); © ABB.

E-ferry. *Prototype and full-scale demonstration of next-generation 100 % electrically powered ferry for passengers and vehicles (Horizon 2020, EUR 15.1 million EU grant)*

The E-ferry project addresses the urgent need to reduce European CO_2 emissions and air pollution from waterborne transport by demonstrating the feasibility of a 100 % electrically powered, emission-free, medium-sized ferry for passengers and cars, lorries and cargo relevant to island communities, coastal zones and inland waterways. The vessel will be based on a newly developed, energy-efficient design concept and demonstrated in full-scale operation on longer distances than previously travelled by electric drive train ferries (> 5 nautical miles, nm), i.e. the medium-range connections Søby-Fynshav (10.7 nm) and Søby-Fåborg (9.6 nm) in the Danish part of the Baltic Sea, connecting the island of Ærø to the mainland. E-ferry builds on the Danish European Regional Development Fund-funded project Green Ferry Vision, proving the feasibility of the concept and indicating significant potential impacts compared with conventionally fuelled ferries operating on the same medium-range routes: energy savings of up to 50 %, annual emission reductions of approximately 2 000 tonnes CO_2, 41 500 kg NO_x, 1 350 kg SO_2 and 2 500 kg particulates. E-ferry is likely to the largest battery pack ever installed in a ferry, with a record-breaking high-charging power capacity of up to 4 MW, allowing for short stays in port (Image A5.7). On top of being 100 % powered by electricity, the innovativeness of the E-ferry design concept and its expected impacts addresses flaws in the state of the art by demonstrating a concept based on optimised hull shape, lightweight equipment and carbon composite materials, ensuring that the weight of parts replaced by composite elements is reduced by up to 60 %. Approval of the use of carbon fibre-reinforced composite modules in E-ferry's superstructure, in accordance with regulations on material and fire testing, is also key to the project. The ferry was successfully delivered and has been in operation since August 2019, currently making five trips daily (E-ferry project, 2015-2020).

Image A5.7 Electrically powered ferry for passengers and vehicles

Source: E-ferry project (2015-2020); © Halfdan Abrahamsen, Ærø EnergyLab.

A5.2 Exhaust gas cleaning systems

EU co-funded projects (CEF Transport) *(CEF Transport, EUR 5.6 million grant)*

Hybrid scrubber*. Back from Black — study and deployment of affordable scrubber retrofitting technology for SME shipowners*

This project financed the development of a new prototype hybrid scrubber designed to switch between open and closed loop modes, including a water treatment system cleaning unit, to enable vessels to comply with the SO_x emission limits in the Baltic Sea basin.

The hybrid scrubber (water treatment capacity 22 l/h) was successfully developed and piloted. SO_x emissions are captured and neutralised by wash water circulated through the scrubber. The scrubber tower (height 9 m, outside diameter 2.4 m, dry weight 4.5 tonnes) is a chemical absorption reactor containing a packing bed and water mixture nozzles. The wash water is introduced to the process in different stages beneath and above the packing bed. The actual SO_x neutralisation reaction takes place mainly in the packing bed. A droplet separator (demister) with a horizontal gas flow is in the upper part of the scrubber tower. The water treatment system (WTS) cleans the process water when driving in closed loop mode. It has an efficient membrane filtration system that cleans the process water beyond regulatory standards. There are no chemicals used in the filtration process and the backflush of the filter elements is automated. The WTS's sludge dewatering unit dries the sludge to the minimum volume; there is no need for a sludge tank on board, as the sludge can be stored in an intermediate bulk container or in a barrel. In the dewatering process, small amount of polymer is used. The WTS components require little space and can be in different rooms on board. The automatic control system has a graphic interface and is very easy to operate, and the data logging is tamper proof, saving values every 4 minutes and storing data for 18 months. The scrubbers have since been installed in another 12 vessels.

Closed loop scrubber. *Scrubbers: Closing the loop (CEF Transport, EUR 5.4 million EU grant)*

The project aimed to upgrade a Motorways of the Sea link in northern Europe and increase awareness of the scrubber technology in the EU. Focused on the North Sea-Mediterranean and the North Sea-Baltic core network corridors, the project focused on increasing the environmental performance of short-sea shipping routes. Closed loop scrubbers were installed on two vessels sailing between Harwich (United Kingdom) and Rotterdam/Hook of Holland terminals, i.e. the MS *Stena Britannica* (Image A5.8) and MS *Stena Hollandica*. The scrubbers were fitted with a device for continuously measuring the cleaning system's efficiency, assessing its impact on the environment.

Chemical and waste management guidelines for scrubber use were developed. Moreover, a Scrubber Observatory Platform was created, which enabled the stakeholders to exchange best practice and to share the results gathered.

Image A5.8 Closed loop scrubbers installed on a Stena ship

Source: Scrubbers: Closing the loop project (2014-2017); © INEA.

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