"BUSINESS CASE" FOR FURTHER ACTION ON INTERNATIONAL OCEAN GOVERNANCE

Final report

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"BUSINESS CASE" FOR FURTHER ACTION ON INTERNATIONAL OCEAN GOVERNANCE

FINAL REPORT

RAMBØLL

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"Business case" for further action on international ocean governance

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Executive summary

Introduction

A multitude of agreements and policies form the international ocean governance framework, many of which have been in place for several years. However, there are strong indications that the state of the oceans is further deteriorating. In line with international commitments, notably under the UN 2030 Agenda for Sustainable Development, and in particular its Goal 14, there is a need to significantly scale-up efforts for conserving the ocean and its ecosystems in a holistic way and urgently implement responses that can lead to transformative – and not only incremental – changes. Those responses come at a cost while at the same time they have potential to reap great benefits. However, this is linked to some challenges:

- The costs of such responses are usually easier to grasp and assess than the benefits which are often of an indirect nature;
- The benefits only manifest in the future while costs are to be borne upfront;
- The benefits may manifest outside the geographic scope of the intervention, i.e. those who pay are not necessarily the ones that benefit.

It is therefore challenging to convince decision makers, the private sector and other stakeholders to increase efforts in protecting the oceans; and hard for decision makers to convince their constituency of the benefits of such efforts.

This study

Against this backdrop, this study has three overall objectives:

- To describe and quantify the economic costs and benefits of scaling up international efforts on ocean governance;
- To estimate the economic costs in case of a no-change scenario for the oceans, i.e. pressures remain and/or increase while the ocean-related 2030 Agenda, in particular SDG 14, targets remain unfulfilled; and
- To propose actions (responses) to maximise the benefits, minimise the costs and enable the transformative changes needed to conserve and sustainably use the oceans by 2030.

Following the objectives of the study, two scenarios up to 2050 and a baseline have been defined for the project:

- A business as usual scenario (BAU): the current policy framework (policies, projects, partnerships etc.), the ambition for international ocean governance and also relevant policies for land-based activities continue in their current form;
- A scaled up efforts scenario (SUE): sufficient and, where needed, transformative efforts are made and lead to a reversal of negative trends.
- A baseline: for each pressure on the oceans, it is the point of comparison between the "business as usual" scenario and the "scaled up efforts" scenario. The study uses 2020 as the reference year. Where no data for 2020 is available, the latest available data is used.

The project uses the widely-used Driver-Pressure-State-Impact-Response (DPSIR) framework to describe links between human activities, their impacts on environment and how this is expected to change through policy interventions. This methodological framework has been adapted to meet specific challenges entailed by the topic and scope of the study.

Pressures on the oceans

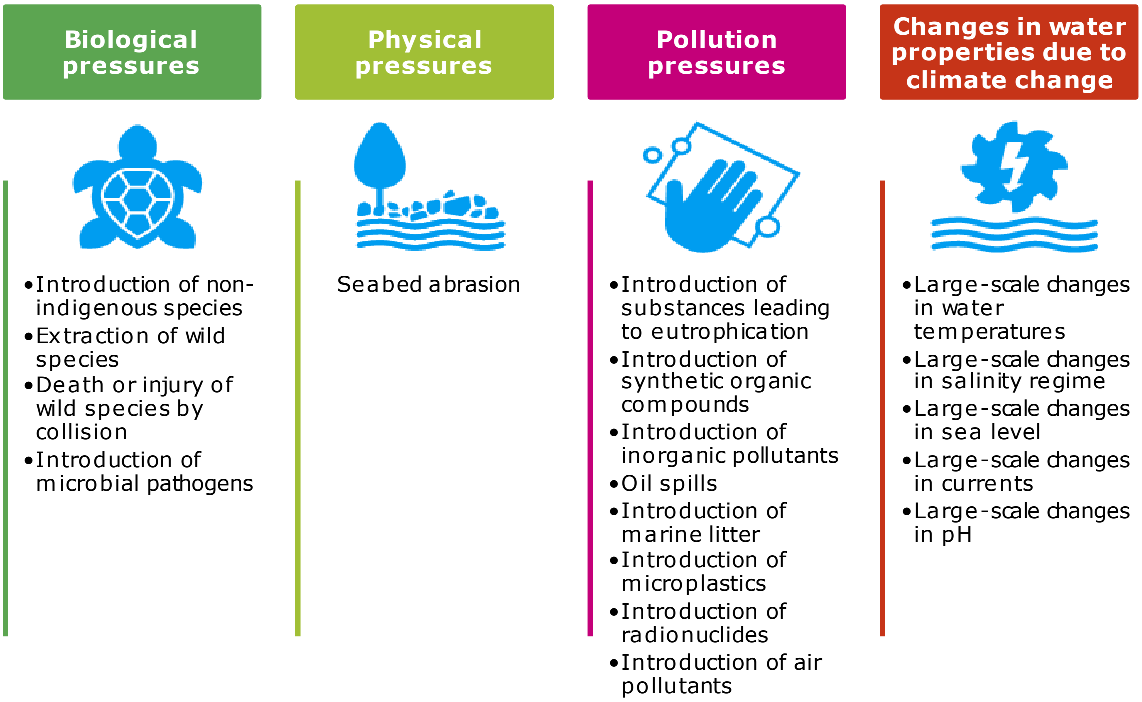
Using the DPSIR framework, the study identifies relevant pressures exerted on the oceans, i.e., the mechanisms that result from one or more human activities and impact the oceans in one way or another. The aim was to structure and map the issues the oceans face. Pressures were identified and categorised as follows:

- Biological pressures
- Physical pressures
- Pressures linked to pollution
- Changes in water properties due to climate change.

For several pressures, the main causes are land-based. Albeit those are not directly within the policy scope of international ocean governance, they were taken into consideration in the study as only a holistic approach could trigger the much-needed transformative changes.

Key pressures identified in the study are listed in the Figure below.

Figure 0.1 Overview of identified key pressures



A global ranking of the most urgent and relevant pressures has not been possible. However, some pressures seem more relevant than others and are discussed more widely in the literature or are identified as key pressures in sea-basin reports. This includes for example marine litter, the introduction of substances leading to eutrophication and the extraction of fish species.

The fact that some pressures are more widely discussed than others could help prioritise actions and investments under ocean governance, with the caveat, however, that fewer references in literature do not automatically mean less importance of the issue. Indeed, plastic litter has attracted much attention over the last decades and much literature has been produced. Other issues are less debated, for instance the introduction of harmful substances. However, this does not mean that their impacts are minor but might have other reasons, for example that those substances are harder to spot and detect than litter and that they thus are less present in the public mind.

In addition, there are often strong interactions between different pressures, some of which are yet poorly understood. An improved ocean governance should put additional emphasis on identifying and understanding those interactions in order to develop a more efficient, but also more cost-effective policy.

Where do these pressures come from

Pressures on the oceans are caused by human activities, both sea-based and land-based.

Some pressures are caused by a multitude of activities. For instance, the discharge of (not-sufficiently treated) wastewater, as well as a range of household and transport-related activities all lead to the release of microplastics into the oceans. Certain activities also contribute to causing many pressures, while others cause a specific single pressure. For instance, shipping can cause the introduction of alien invasive species and microbial pathogens, death and injury of wild species by collision, air and noise pollutions. While the introduction of radionuclides is currently mainly provoked by nuclear reprocessing and power generation (in the absence of nuclear accidents).

Some activities are concentrated in specific locations, while others have a rather global scope. For instance, activities such as oil extraction and exploration, or nuclear reprocessing and power production are taking place in rather specific places. Other activities, such as release of wastewater take place all around the globe. The pressures they cause include pollution, marine litter and introduction of microplastics, which can be found everywhere in the oceans by now. In addition to the ubiquitous introduction of those pollutants, some are also very mobile, can be transported far and cause negative impacts from their original source.

This makes it challenging to assess the sources of pressures in a local or even regional context while at the same time this is indispensable for addressing them. Also, this demonstrates the role that the local context and scope plays when monetising the cost of action / inaction. However, in general the study found that in many cases it is most cost-efficient to stop pressures at source (e.g. in case of point-source emissions) instead of trying to mitigate their impacts.

Business case for improved international ocean governance

The study presents an estimation of the current economic value of the oceans in relation to ecosystem services, abiotic flows and spatial functions they provide and support. It then compares the costs and benefits of implementing different measures under the business as usual (BAU) and scaled up efforts (SUE) scenarios. The study also estimates the minimum cost of inaction that results from comparing SUE and BAU scenarios, with a focus on ecosystem services. The findings are subject to a number of assumptions made under the System of Environmental-Economic Accounting – Ecosystem Accounting (SEEA EA) framework.

The text below provides a short summary of a series of specific economic assessments undertaken at different geographical scales and covering a wide scope of ecosystem services in the study. The summary does not include the findings for spatial functions that are considered to be less robust. It has not been possible to provide an aggregated figure for all services, flows and functions considered.

However, the findings of the study demonstrate a clear business case for an improved international ocean governance as shown by the high possible gains in case actions are scaled up (SUE scenario).

Wild fish provisioning services, i.e. services associated with commercial fisheries of specific species

Inaction and highly likely failure to achieve the maximum sustainable yield (MSY) ratio for tuna and sardine fish stocks by 2050 could result in a cost of €13.4 billion and €3.3 billion in 2050 respectively. A SUE scenario would see the MSY ratio achieved and sustained for all fish stocks by 2050, resulting in an estimated economic value of tuna and sardine fish stocks of €14.7 billion and €6.5 billion respectively in 2050. In case of a BAU scenario, it is estimated that the economic value of tuna and sardine fish stocks could reduce to €1.3 billion and €3.2 billion respectively in 2050.

Aquaculture provisioning

Under a SUE, the average consumption of seafood from mariculture in Europe could gradually replace the consumption of meat and increase to 26.03 kg / inhabitant in 2050 and have an associated economic value of €26.9 billion. This scenario would also result in an even further reduction of environmental costs associated with farming for meat production, in comparison to the BAU scenario.

Regulation and maintenance services, i.e., services resulting from the ability of the ecosystems to regulate biological processes and influence climate, hydrological and biochemical cycles)

Considering the global carbon sequestration role performed by mangroves, salt marshes and seagrass meadows only, inaction and failure to reverse historical trends of marine and coastal ecosystems loss and degradation could result in a cost of €57 billion in 2050. And if coastal protection services provided by mangroves and coral reefs worldwide are considered, the cost of inaction would add an additional €51.7 billion.

On the contrary, an increase in mangroves, salt marshes and seagrass meadows coverage, could lead to benefits with carbon sequestration services potentially reaching a value of €152 billion in 2050. Similarly, achieving pre-1980 mangrove coverage globally, and maintaining the current coverage of coral reefs as a minimum, would assist in increasing the coastal protection function that these ecosystems perform, with their associated economic value estimated at €535.2 billion in 2050.

In addition, coastal and marine ecosystems provide fundamental waste remediation services that are key to maintain a healthy ocean. Estimates indicate that the cost of inaction, should degradation rates for mangrove and saltmarsh continue, could reach an additional €415.7 billion in 2050. However, a SUE scenario that maintains their current global coverage, would also maintain the current economic value of the waste remediation services mangroves and saltmarsh provide (estimated at €3,370 billion).

Related to this, is the value biological control services can have. To illustrate its relevance, it has been assumed that under a BAU scenario, the number of human infections per year due to harmful algae blooms would lead to annual average costs potentially up to €25.7 million.

Another important role performed by coastal and marine ecosystems, and that sustains all other services and the overall ecosystem functioning, is related to nursery population and habitat maintenance services. The cost of inaction associated with mangrove and saltmarsh habitats specifically has been estimated at an additional €27.3 billion in 2050. On the contrary, a SUE scenario would maintain the current global coverage of around 192,000 km^2 of mangroves and saltmarsh in 2050, and therefore maintain their current economic value for this service (estimated at €221.4 billion).

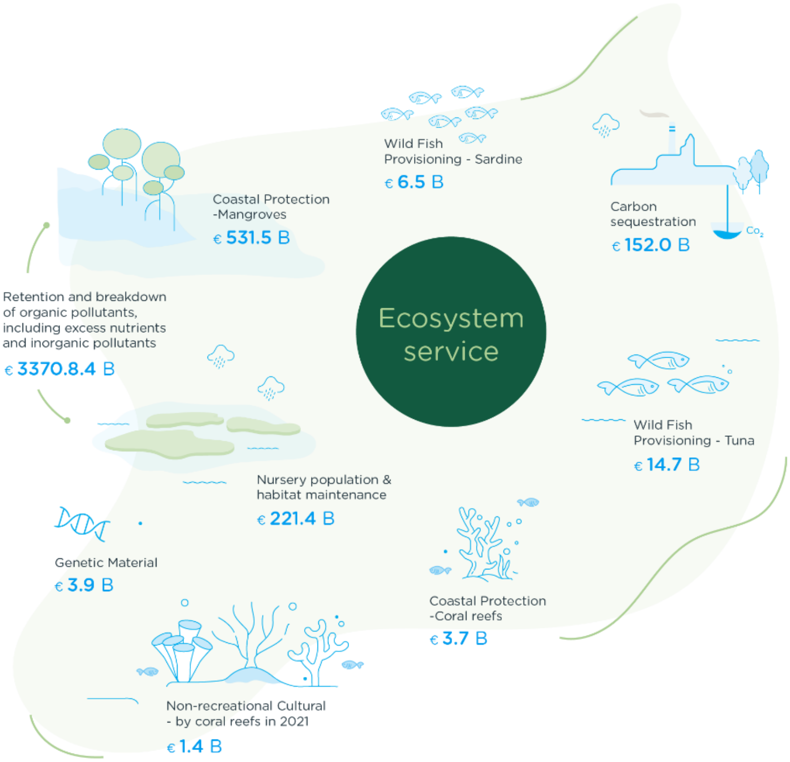
Cultural services, i.e. experiential and intangible services related to the perceived or actual qualities of the ecosystems that contribute to cultural benefits

The costs of inaction as regards plastic management due to coastal tourism could reach between €1 – €7.1 billion per year. With a SUE scenario by which coastal tourism pressures on coastal areas are alleviated, the cost of plastic management would be reduced to a range between €9 and €23 billion in 2050.

If historical coral degradation rates continue, the non-recreational cultural services they provide, like aesthetic information and knowledge development, the costs could reach €0.25 billion in 2050, while under a SUE scenario, the current coverage of coral reefs across the globe and the current value of these services estimated at €1.42 billion would be maintained as a minimum in 2050.

The figure below provides an overview of the main findings under the SUE scenario. However, it should be kept in mind that it only represents the value of a selected number of ecosystem services under a SUE scenario due to methodological challenges, and which are part of a much bigger picture that is complex to fully disentangle and monetise. Thus, it can be expected that the actual benefits are even higher than the ones presented here.

Figure 0.2 Economic value of ecosystem services under a SUE scenario



What responses could be taken

The study showed that there is a clear merit to scale up efforts to reduce the pressures on the oceans. In a business as usual scenario in which the current ambition of efforts persists, the value of several ecosystem services will continue to decline, leading to large economic damages and costs.

However, reversing negative trends requires decisive actions. However, current efforts for reducing the pressures on the oceans are not sufficient. Transformative actions are required, and they should go beyond sea-based activities, triggering large-scale changes in land-based activities, as well as in consumer attitudes and affecting society as a whole. Prevention, even though it may seem more costly at the onset, is often the most viable and cost-effective response to be given.

1. Introduction

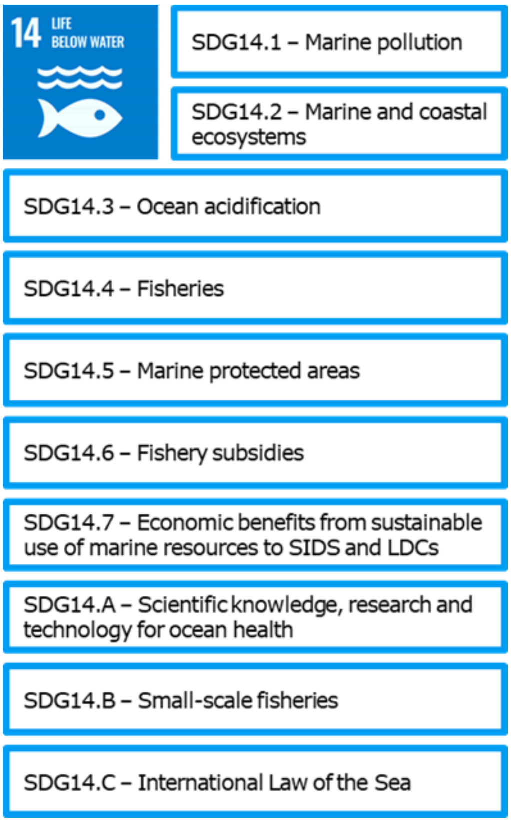
State of the oceans

The oceans cover more than 70% of the surface of the planet and their ecosystems provide significant benefits to human societies, such as climate regulation, food, coastal protection from sea action, employment, or cultural values. However, human activities continue to exert significant pressures that lead to the degradation of the marine realm and in particular of critical habitats for species such as mangroves and coral reefs. This is underpinned by social, demographic and economic developments of societies, such as population growth, the increasing demands for goods and services from the marine environment, and many more drivers. Even though those drivers and the resulting human activities are not uniformly distributed, the pressures on the oceans that result from them can be observed in almost all ocean and sea basins.

Current policy framework

In the international community, there is an increased understanding that the oceans, their ecosystems and their resources are not "endless" and need adequate conservation, that pressures/threats on them continue to increase and to have cumulative impacts, and that at the same time the current efforts by international community are not sufficient to ensure their sustainability. The obligation to protect and preserve the marine environment is a general obligation under international law as reflected in the UN Convention on the Law of the Sea (UNCLOS).

Figure 1.1 The ten SDG14 targets



At international level, this acknowledgment has also resulted in the United Nations 2030 Agenda for Sustainable Development and its Sustainable Development Goal (SDG) 14 to "Conserve and Sustainably Use the Oceans, Seas and Marine Resources for Sustainable Development"[1]. SDG 14 aims to ensure that the use of oceans, seas and their resources are protected, conserved and used sustainably in the long term by tackling some of humanity's interactions with the oceans and calling for transformative change towards more sustainable practices. SDG 14 consists of 10 targets (see Figure 1.1) which recognise the environmental, economic and social benefits that clean, healthy and productive oceans and seas provide (e.g., SDG14.7). At the same time, SDG14 recognises the human-induced pressures that the oceans are submitted to (e.g., SDG14.1), and which need to be managed through

[1] See: https://sdgs.un.org/goals/goal14

adequate responses (e.g., SDG14.6) so that the oceans continue to provide current and future generations with their invaluable ecosystem services.

Reaching those targets, however, is a major challenge. The oceans, the underlying legal governance framework and maritime policies, and the SDG14 targets themselves are highly complex and cross-sectoral. In addition, political will for implementing and further developing that framework is sometimes limited. At the same time, some of the most damaging impacts on the oceans stem from pressures that are land-based and thus fall not directly within the marine policy framework. Thus, considerable efforts are needed across almost all human activities to ensure the cleanliness, health and productivity of our oceans.

At international level and globally, numerous instruments are in place to regulate human activities and their impacts on the oceans. In particular, this includes the UN Convention on the Law of the Sea (UNCLOS)[2], which is recognised as the Constitution of the Oceans, and provides the legal framework within which all activities in the oceans and seas must be carried out. Other examples include the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing[3], the International Convention for the Prevention of Pollution from Ships (MARPOL)[4] and several others[5]. However, at a global level it is unlikely that the SDG 14 targets can be reached by their deadlines; and those for which deadlines have already passed, were not achieved.

The EU and its Member States acknowledged the need for protecting the oceans several years ago and put in place an elaborate policy framework to manage the oceans in a sustainable way, including by become party to the UNCLOS and its implementing agreements. This policy framework generally predates the 2030 Agenda (which started in 2015) but is coherent with the SDG14 targets. It is considered also to a large extent supportive of these targets – with the caveat, however, that also within EU waters, several of the SDG14 targets may not be achieved by their respective deadlines if efforts are not stepped up; and for some targets the deadline has already passed (e.g., 14.4 on sustainable fishing/maximum sustainable yield which was due in 2020).[6]

In acknowledgment that the oceans have no borders and thus that international efforts are needed to protect them, in November 2016, the European Commission and the EU's High Representative adopted a joint agenda on International Ocean Governance[7] (IOG Agenda). Following timely achievement of most deliverables of the IOG Agenda[8], the European Commission in association with the European External Relations Service also started reflecting upon strategic orientations and possible actions under a renewed IOG Agenda. This new agenda,

[2] See: https://www.un.org/depts/los/convention_agreements/texts/unclos/unclos_e.pdf

[3] FAO (2016). The FAO Agreement on Port State Measures (PSMA) to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing. See: www.fao.org/port-state-measures/en

[4] See here for more information: https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx

[5] A good and comprehensive overview can for example be found here: https://thedocs.worldbank.org/en/doc/2faa3cc2e63a83382d4ef6ca85e83fc4-0320072022/original/Ocean-Governance-Summaries-Booklet-EN-Final-Feb9.pdf

[6] EC (2021). Assessment of the existing EU policy tools in the field of Sustainable Development Goal (SDG) 14 and other ocean-related agenda 2030 targets. See: https://op.europa.eu/en/publication-detail/-/publication/1625f673-b201-11eb-8aca-01aa75ed71a1

[7] JOINT COMMUNICATION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS International Ocean Governance: an agenda for the future of our oceans. See: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52016JC0049

[8] JOINT REPORT TO THE EUROPEAN PARLIAMENT AND THE COUNCIL Improving International Ocean Governance – Two years of progress. See: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=JOIN:2019:4:FIN

titled "Setting the course for a sustainable blue planet, Joint Communication on the EU's International Ocean Governance agenda"[9] was published in 2022 and further developed the ambitions of the EU in IOG.

Future policy outlook

It is acknowledged that the current policy framework put in place at both the international and European levels to manage the oceans in sustainable way is insufficient to reach the SDG14 targets within the time given. For this reason, future policy developments are expected to increase the level of efforts to better preserve marine and coastal ecosystems.

At the European level, the European Mission "Restore our ocean and waters by 2030"[10] is part of a new instrument embedded in the Horizon Europe programme that aim to address some of the global challenges through research and innovation and with a systemic approach. It aims specifically at achieving quantifiable targets regarding the preservation and the restoration of marine ecosystems and biodiversity, the prevention and the elimination of pollution from the ocean and seas, the shift of the EU blue economy toward a circular and carbon blue neutral economy.

Along with the implementation of the European Mission, the EU is implementing the Biodiversity strategy for 2030. This comprehensive and long-term plan is the proposal for the EU's contribution to the global post-2020 biodiversity framework in the upcoming international negotiations.

The EU is also seeking to pave the way for a global agreement on plastics. Marine litter, and notably microplastics, are one of the main pressures for marine and coastal ecosystems. Nevertheless, no global agreement or legally binding instrument exist to deal with this threat and responses are fragmented.

For this reason, more than one hundred countries called to take urgent action and define a strategy under the auspices of the United Nations. In 2017, the United Nations Environment Assembly (UNEA) set up an ad-hoc open-ended expert group on marine litter (the "AHEG") in order to identify potential solutions. This process led in March 2022 to the adaption of resolution 5/14 "End Plastic Pollution: towards an international legally binding instrument" by the United Nations Environment Assembly (UNEA) which set out a mandate for negotiations for an international legally binding instrument on plastic pollution, including in the marine environment.

At the international level, the fourth session of the Intergovernmental conference to develop an international legally binding instrument under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (BBNJ) was held at the beginning of March 2022[11]. This conference aimed[12] to elaborate the text of an international legally binding instrument by addressing the topics of marine genetic resources, including questions on the sharing of benefits, measures

[9] O INT COMMUNICATION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. Setting the course for a sustainable blue planet - Joint Communication on the EU's International Ocean Governance agenda {SWD(2022) 174 final}.See: https://oceans-and-fisheries.ec.europa.eu/system/files/2022-06/join-2022-28_en.pdf

[10] See: https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe/eu-missions-horizon-europe/healthy-oceans-seas-coastal-and-inland-waters_en

[11] See the event: https://www.un.org/bbnj/content/home?Is%20Featured=0&language=en&sort_by=created&sort_order=DESC&page=1

[12] See: https://www.un.org/depts/los/biodiversity/prepcom.htm

such as area-based management tools, including marine protected areas, environmental impact assessments and capacity-building and the transfer of marine technology.

Lastly, international negotiations in line with SDG 14.6[13] regarding the prohibition of harmful fisheries subsidies[14] led in June 2022 to a WTO agreement on Fisheries Subsides with the belief that uniform and global approach would avert competition and trade distortion issues arising from differing disciplines in this area at national level. For the Agreement to become operational, two-thirds of members have to deposit their "instruments of acceptance" with the WTO

Is that sufficient?

Given the fact that despite the elaborate policy framework the oceans are still at peril it is doubtful that the current ambition suffice to maintain healthy and productive oceans in the future. It is also unclear to what extent the upcoming policies, while being highly relevant, will lead to major trend reversals.

As the remainder of this report shows, a large part of problems that the oceans face is also not predominantly caused by sea-based activities, but rather by land-based activities[15]. Those activities emit pollutants and litter which are then deposited in the oceans, cause climate change, etc. Thus, a strengthened international ocean governance alone may not be sufficient to address the issues in a comprehensive manner, and this is why the report also takes into account the land-based activities which lead to pressures at Sea. Even though also for almost all of the land-based issues there are already policy responses in place at global, regional or national levels[16], also here, a large majority of those responses are already in place for years up to decades, but nevertheless the negative trends have in most cases not been reverted.

Thus, this "business as usual", while being ambitious at times, seems to not suffice to reverse the major downward trends faced by the oceans.

What more should be done?

In view of this, it seems like efforts need to be scaled up significantly – including efforts across the whole of society, given the important role that land-based activities play in affecting the state of the oceans. Those changes cannot be to a large extent incremental but need to be transformative. However, implementing responses that lead to those changes – transformative or not – comes at a cost. At the same time, they would ensure, that the benefits provided by the oceans are maintained or even increased.

However, this is linked to some challenges:

- The costs of such responses are usually easier to grasp and assess than the benefits which are often of an indirect nature;
- The benefits only manifest in the future while costs are to be borne upfront;

[13] "By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation" See: https://sdgs.un.org/goals/goal14

[14] Harmful fisheries subsidies are understood as those that stimulate overcapacity and overfishing and illegal, unreported, or unregulated (IUU) fishing

[15] The depletion of fish stocks due to overfishing is one of the exceptions to this.

[16] It should also be pointed out, however, that also here to date there are still many policy gaps, conflicting priorities, and trade-offs.

- The benefits may manifest outside the geographic scope of the intervention, i.e., those who pay are not necessarily the ones that benefit.

Against this backdrop it is hard to convince decision makers, the private sector, and other stakeholders to increase efforts in protecting the oceans; and hard for decision makers to convince their constituency of the benefits of such efforts.

This study

This study has three overall objectives:

- To describe and quantify the economic costs and benefits of scaling up international efforts on ocean governance;
- To estimate the economic costs[17] in case of a no-change scenario for the oceans, i.e. pressures remain and/or increase while the ocean-related 2030 Agenda, in particular SDG 14, targets remain unfulfilled; and
- To propose actions (responses) to maximise the benefits, minimise the costs and enable the transformative changes needed to conserve and sustainably use the oceans by 2030.

Thus, in short, the objective of this project is to provide insights into the costs and benefits of scaling up international efforts for stopping negative effects from human activities on the oceans. This information is aimed at decision makers, the private sector and other stakeholders to better understand the added value of increasing efforts, and also to have the economic arguments needed to obtain societal buy-in necessary to support the changes and the efforts needed. To this end, the study compares this "scaled up international efforts" scenario against a "business as usual scenario". The objective is also to identify the most cost-effective (in a social, economic and environmental perspective) responses that the international community can pursue in order to achieve real and long-lasting change.

As mentioned before, for a number of pressures, the main emitters are land-based; it is important to highlight that this study also considers responses for those even though they are not directly falling under ocean governance. This is done since it is crucial to get the full picture of the reasons why the oceans are deteriorating and how to tackle this; in those cases, only focusing on sea-based emitters which fall under the direct governance of ocean policy but are fairly small compared to land-based activities would not solve the issue and would also not trigger the transformative change which is required.

The project uses a tailored Driver–Pressure–State–Impact–Response (DPSIR) framework to describe links between human activities, how they affect the oceans, and how policy interventions (responses) could be used to reduce the negative effects on the oceans, in a structured way. This is explained in more detail in Appendix 1.

The table below summarises the main structure of the report, taking into account the different objectives of the project and the DPSIR framework.

Table 1.1 Overview of the structure of the report

Chapter	Description
2 Pressures on the ocean	This chapter describes and lists the principal pressures which the oceans face due to human activities.
3 Business case for improved international ocean governance	This chapter describes the business case for an improved international ocean governance.

[17] Those are referred to as "foregone benefits" or "damages" in this study. See Appendix 1 for more detail.

Chapter	Description
4 Pathways towards improved international ocean governance	This chapter describes potential responses that could be envisaged towards improved international ocean governance.
5 Conclusions	This chapter draws main conclusions based on the information in the prior chapters.

2. Pressures on the ocean

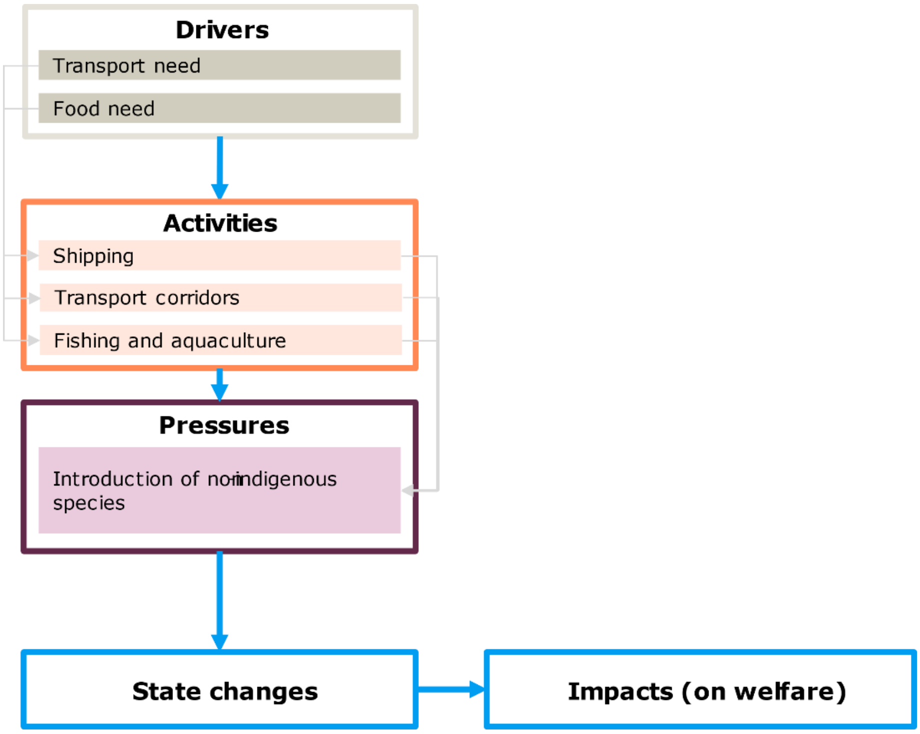
2.1 Introduction

This chapter provides insights about the pressures which affect the oceans.

First, section 2.2 provides a short summary about how the pressures have been identified and what they are. The methodology for identifying and mapping the pressures is described in more detail in Appendix 1.

Then, section 2.3 provides more details about each of those pressures. This includes information on what it is and how it affects the oceans, where it is most prominent in the world, future outlook, and, finally, which human activities lead to those pressures (including information, where available, on past trends, geographical distribution, and how different stakeholder groups are concerned). More detailed information about each of those points can be found in Appendix 2 (Detailed description of pressures) and Appendix 3 (Detailed description of activities leading to pressures). Appendix 2 also contains additional information on knowledge gaps per pressure. Appendix 3 also presents for each pressure a detailed flowchart which summarises the drivers and activities leading to the specific pressure. The Figure below is an illustration of such a flowchart, on the example of the pressure "introduction of indigenous species".

Figure 2.1 Example of a flowchart for the pressure "introduction of indigenous species"



Source: Own illustration

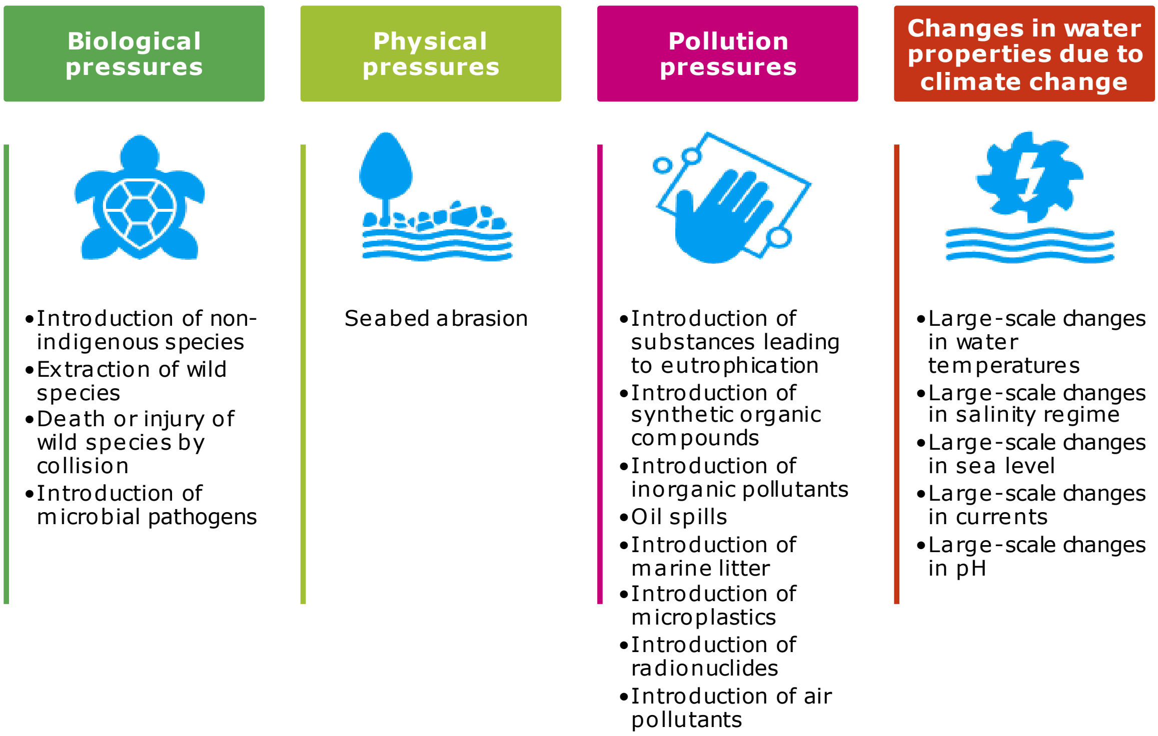
2.2 Identification of pressures

The study identified relevant pressures exerted on the oceans, i.e., mechanisms that change something in the oceans and that result from one or more human activities, in order to structure and map the issues the oceans face. Pressures have been categorised as follows:

- Biological pressures
- Physical pressures
- Pressures linked to pollution
- Changes in water properties due to climate change

Under each of the categories, different pressures have been identified which are shown in the Figure below.

Figure 2.2 Overview of identified pressures



Source: Own illustration

2.3 Mapping of pressures and main human activities leading to them

2.3.1 Biological pressures

2.3.1.1 Introduction of non-indigenous species

What is the pressure about and where is it found

The oceans are populated by different species of animals, plants and microorganisms that have evolved separated by natural barriers, in isolation – to some extent. Some of these species move, or are introduced, far beyond their natural ranges into a new biogeographical area, where they do not naturally occur. These species are called "non-indigenous species" (NIS), "introduced species" or "alien species".

When a species is established is a new environment, if it can tolerate the new conditions encountered, it may not be subjected to the natural controls, such as predators, parasites or diseases, that keep population numbers in check. As a result, the invasive species tend to increase rapidly, sometimes to the point where they take over their new environment. Such species can reduce biodiversity, alter community structure and function, diminish fisheries production and may also impact human health and well-being.

Globally, about 2,000 marine NIS have been introduced to new areas through human-mediated movements and activities[18]. Non-indigenous invasive species are thus found to be a pressure everywhere in the oceans. From our literature review it is listed as a pressure in almost all the reports covering the different sea-basins, though some areas are particularly important as vectors of NIS (e.g. Suez and Panama Canals). It is highlighted as a key pressure in the assessments of European seas (Baltic Sea[19], Mediterranean[20], North-East Atlantic[21]), Northwest Pacific[22], Arctic Ocean[23] and Pacific Islands[24]. However, the information available on NIS is variable spatially, temporally and taxonomically.

It should be noted that this phenomenon is exacerbated by climate change, including extreme events, and other human-induced disturbances[25]

Which human activities cause this pressure

Shipping

Non-indigenous species can be transported attached on ships, boats or other watercraft. This includes the unintentional transportation of species via fishing vessels or their equipment (fishing gear, anchor chains, etc), as well as species travelling into

[18] United Nations (2021) *World Ocean Assessment*, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[19] HELCOM (2018) State of the Baltic Sea – Holistic Assessment.

[20] UNEP - State of the Environment and Development in the Mediterranean.

[21] OSPAR (2016) OSPAR Coordinated Environmental Monitoring Programme.

[22] NOWPAP (2018) Assessment of Major Pressures on Marine Biodiversity in the NOWPAP Region.

[23] MARINE PROTECTED AREAS IN A CHANGING ARCTIC, PAME- Arctic Council (2021)

[24] Secretariat of the Pacific Regional Environment Programme (2020) State of Environment and Conservation in the Pacific Islands: 2020 Regional Report.

[25] Ojaveer *et al.* (2018). Historical baselines in marine bioinvasions: Implications for policy and management. See: https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0202383&type=printable

the ballast water of vessels. Long distance sport fishing can also be a source of unintentional introduction, for instance when species are transported across sea on damp angling gear[26]. A 2019 study[27] found that shipping accounts for 60 to 90 percent of the introduction of exotic species into new territories, and that given the steep increase in shipping demand, "the emerging global shipping network could yield a three-fold to 20-fold increase in global marine invasion risk between now and 2050"[28]. The study also suggests that the rising demand for shipping will promote the spread of non-native pests even more than the effects of climate change. Shipping is considered the main vector for NIS in all sea-basins[29].

Transport corridors

Non-indigenous species can be introduced into different ecosystems by travelling along artificially created infrastructure corridors such as artificial waterways/canals connecting previously unconnected water bodies, basins or seas. Shipping canals are in fact considered to pose the largest threats (e.g. Suez, Panama, Ponto-Caspian etc). In the future, the opening up of Artic transport routes, due to the reduction of sea ice, could also constitute a threat in this field.

Fishing and aquaculture

NIS can intentionally be introduced into the marine environment, for instance alien fish and especially shellfish can be introduced to increase local catches, culture or for conservation purposes. Alien species can also be introduced for the purpose of fish farming, with subsequent escape from farms, including via other animals such as cormorants. The trade in live seafood or live fish bait, as well as the use of aquariums, can also be a cause of introduction of NIS[30].

2.3.1.2 Extraction of wild fish species

What is the pressure about and where is it found

It is widely documented that large parts of the world's fisheries are not managed sustainably and that fish stocks globally are under pressure, and thus that the target calling for sustainable fisheries under SDG14 (i.e., 14.4) has not been met. This is reflected for example in the fact that around 1/3rd of assessed global marine fish stocks is fished at biologically unsustainable levels when looking at legal fishing[31], and that IUU fishing continues and fuels illicit trade in seafood while weakening fisheries governance[32].

[26] Smith et al. (2020) Recreational angling as a pathway for invasive non-native species spread: awareness of biosecurity and the risk of long distance movement into Great Britain. See: https://link.springer.com/article/10.1007/s10530-019-02169-5

[27] Nature (2019) Invasive species to surge as ship traffic soars on the high seas. See: https://www.nature.com/articles/d41586-019-00870-y

[28] Nature (2019) Invasive species to surge as ship traffic soars on the high seas. See: https://www.nature.com/articles/d41586-019-00870-y

[29] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[30] IUCN. Marine Menace: Alien invasive species in the marine environment. See: https://www.iucn.org/downloads/marine_menace_en_1.pdf

[31] FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action.

[32] Sumaila, U., et al. (2020). Illicit trade in marine fish catch and its effects on ecosystems and people worldwide. *Science Advances*, vol. 6, p. eaaz3801. https://doi.org/10.1126/sciadv.aaz3801 .

From our literature review, the extraction of species is identified as a pressure in almost all the assessments reviewed and is described as the most prominent in the Black Sea, the Mediterranean, the Baltic Sea, the Pacific and the Indian ocean.

Which human activities cause this pressure

Legal fishing

Fishing is globally an important source of food as well as an important economic sector. Annual per capita consumption of fish is around 20kg on global average, which accounts for around 17% of the consumed animal proteins with differences between world regions[33]. Global landings of marine capture fisheries increased significantly between 1950 and 1990 but has somewhat stabilised since then around 80 million tons annually; in contrast, inland captures have constantly grown from 1950 one but is only around 10 million tons annually.[34]

Fishing is conducted in all seas and oceans worldwide. However, there are differences between regions as shown in the Figure below which gives an overview of capture production per fishing area. It shows that the fishing area for which the capture production is the highest, the Pacific Northwest, fishing outputs have been relatively stable between the 2000s and now[35]. The Arctic and Antarctic Sea basins have even seen an increase of more than 100% of the production capture between 2000 and now, i.e., it more than doubled[36]. However, other sea basins have experienced a significant reduction in fisheries pressure, such as the Pacific Southeast (-40%) or the Pacific Southwest (-33%).

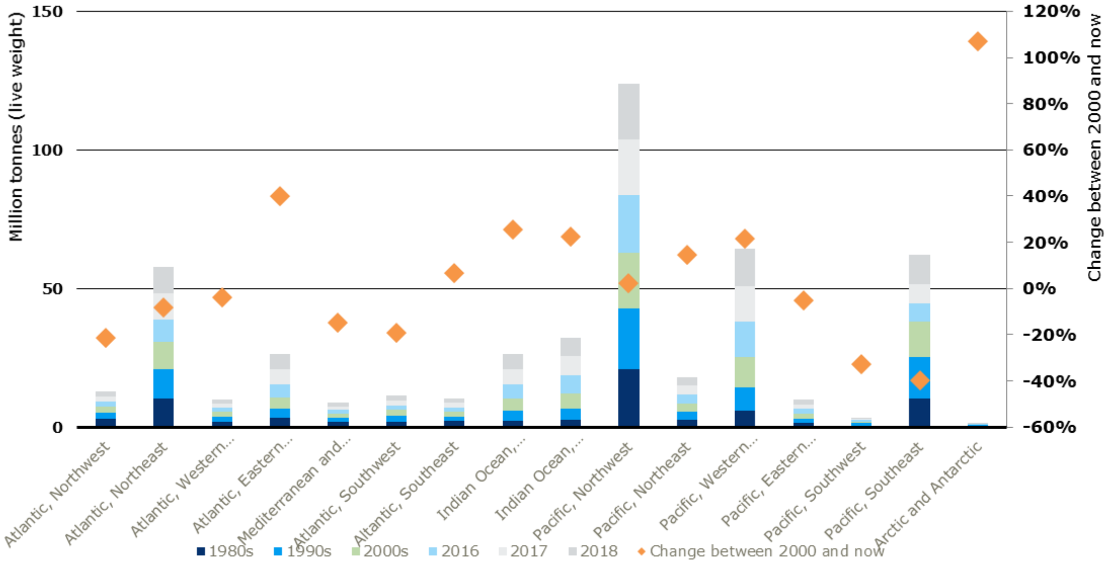
[33] FAO (2021). FAO Yearbook. Fishery and Aquaculture Statistics 2019/FAO annuaire. Statistiques des pêches et de l'aquaculture 2019/FAO anuario. Estadísticas de pesca y acuicultura 2019. See: https://www.fao.org/fishery/en/publications/287024

[34] FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

[35] This change is shown as percentage and in the orange marks. "Now" is defined as the arithmetic average of the last three years for which data is available, i.e. 2016 to 2018, to even out annual changes

[36] See footnote 512

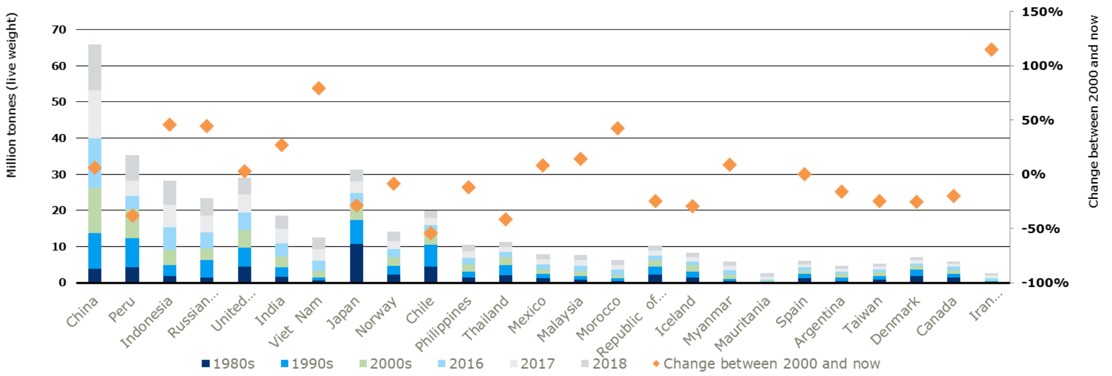
Figure 2.3 Fishing areas and capture production[37]



Source: Own illustration based on data in Table 4 in FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

It should be noted that in line with international agreements many fishing fleets operate globally and that thus the distribution above thus does not represent the fishing done by fleets of neighbouring countries to the respective fishing areas. The Figure below presents the fishing done per country for the top 25 countries in terms of marine capture production, which together account for 80% of global catches.

Figure 2.4 Marine capture production[38]



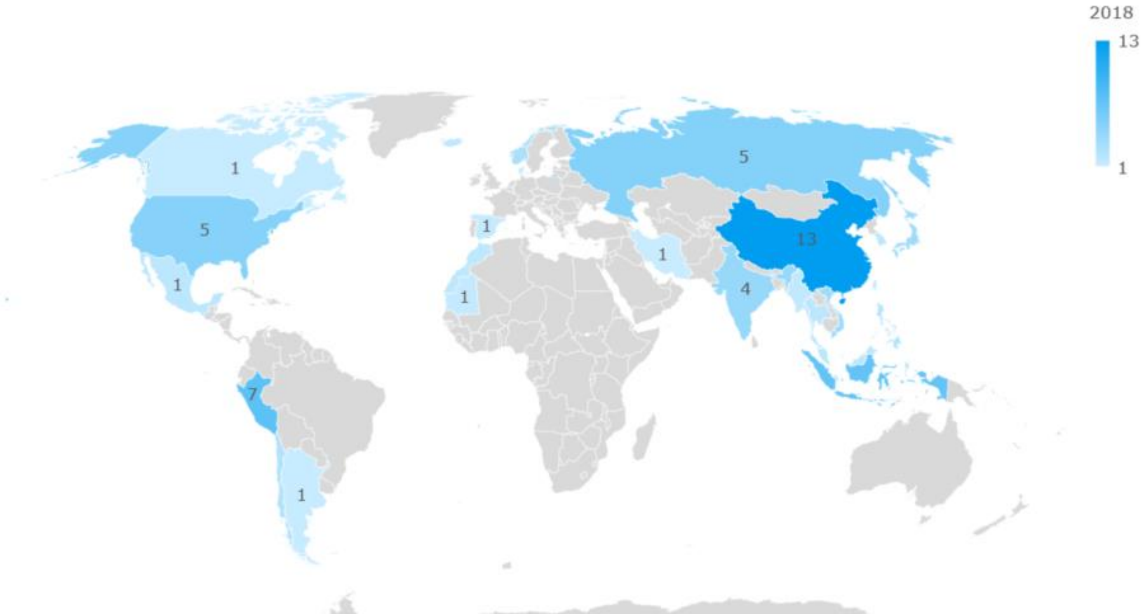
Source: Own illustration based on data in Table 2 in FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

Those 25 countries and their marine captures in the latest year for which data is available (2018) are shown in the map below.

[37] The changes between the 200s and now are plotted against the secondary vertical axis (on the right). The 2000s value is compared to the arithmetic average of the years 2016-2018 to even out annual changes.

[38] The changes between the 200s and now are plotted against the secondary vertical axis (on the right). The 2000s value is compared to the arithmetic average of the years 2016-2018 to even out annual changes. Not pictured is the change for Mauretania for which the change was more than 300%.

Figure 2.5 Map of major producing countries and their captures in 2018 (in million tons)



Source: Own illustration based on data in Table 2 in FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

Globally, there are around 39 million fishers[39] and several million more are employed in the sector. It is estimated that small-scale fisheries employ more than 90% of the people involved in capture fisheries; also, around 90% of the catches from small-scale fisheries are destined for local human consumption, thus making a sizable contribution to food security and nutrition. However, over the last 10 years or so there has been a growing globalisation trend in fishing, which increases the vulnerability of small-scale fisheries to the depletion of some locally important stocks.[40]

Illegal, unreported and unregulated (IUU) fishing

Illegal, unreported and unregulated (IUU) fishing is a broad term that captures a wide variety of fishing and fishing related activities, such as fishing without a valid license, fishing in a restricted area, or fishing in a way non-consistent with national laws or international obligations[41]. This exacerbates efforts of fishing at sustainable levels and thus can endanger stocks and ecosystems.

While exact data on this is challenging to produce, it is estimated that in 2016, IUU fishing was responsible for annual catches of up to 26 million tons[42]; this would be more than 40% of legal catches of the top 25 countries mentioned in the last section. No data is available on past trends of IUU fishing, i.e., how it developed over the years and if numbers are decreasing thanks to

[39] FAO (2021). FAO Yearbook. Fishery and Aquaculture Statistics 2019/FAO annuaire. Statistiques des pêches et de l'aquaculture 2019/FAO anuario. Estadísticas de pesca y acuicultura 2019. See: https://www.fao.org/fishery/en/publications/287024

[40] UN (2021). Chapter 15 Changes in capture fisheries and harvesting of wild marine invertebrates. In: The Second World Ocean Assessment. See: https://www.un-ilibrary.org/content/books/9789216040062

[41] A comprehensive definition of IUU fishing is provided in the FAO International Plan of Action. Available at: http://www.fao.org/3/Y3536E/y3536e04.htm

[42] FAO (2016c). The FAO Agreement on Port State Measures (PSMA) to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing. See: www.fao.org/port-state-measures/en

international and national measures being taken, such as the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (PSMA) which was adopted by the FAO Conference in 2009 and entered into force in 2016[43].

Also, regarding current prevalence of IUU fishing across the globe only very limited data is available. One data source is the "IUU Fishing Index"[44] which rates countries globally, among others, on prevalence of IUU fishing based on a wide range of indicators[45]. Based on this data, the map below presents the 25 worst rated countries globally in terms of prevalence of IUU fishing.

Figure 2.6 Prevalence of IUU fishing in 2021 based on data from the IUU Fishing Index[46]

Source: Own illustration based on data from the "IUU Fishing Index".

Regarding higher prevalence of IUU fishing in small-scale fishing on the one hand and industrial fishing on the other hand, very little information seems to exist. However, there seems to be evidence that IUU fishing is more significant in industrial fishing than in small-scale fishing.[47]

2.3.1.3 *Death or injury of wild species by collision*

What is the pressure about and where is it found

Death or injury of wild species by collision implies the impact between an object present in the marine environment, both moving and stationary, with a marine species. Most of the scientific research so far focussed on the collision between vessels and whales, in particular in the North Atlantic and North Pacific, especially

[43] See here for more information: https://www.fao.org/port-state-measures/en/

[44] See: https://www.iuufishingindex.net/

[45] For the full methodology see here: https://www.iuufishingindex.net/methodology.pdf

[46] As all indicator frameworks, the results of this index should be treated with caution. A full disclaimer for the data can be found on the following page: https://www.iuufishingindex.net/data-files

[47] FAO (2008). Small-scale capture fisheries: A global overview with emphasis on developing countries. See: http://pubs.iclarm.net/resource_centre/Big_Numbers_Project_Preliminary_Report.pdf

British Columbia. However, there is increasing evidence that this phenomenon affects more species, and in fact a recent global study[48] informs that at least 75 other marine species are affected by this phenomenon worldwide, including smaller whales, dolphins, porpoises, dugongs, manatees, whale sharks, sharks, seals, sea otters, sea turtles, penguins, and fish. Collisions with smaller species seem to be scarce, most likely because of reporting biases[49]. Besides the immediate direct consequences of the collision i.e. injury or death of the animal, there might be more long-term consequences for individual animals. These are not well-understood to date, but possible long-term consequences include long-term locomotive impairments, for instance related to injuries to fins and flippers and possible reduced fitness of the animal. For certain types of whales (e.g. North Pacific blue whales, humpback whales and fin whales, as well as Canary Island sperm whales) comprehensive studies have shown that ship strike rates may exceed population recruitment rates[50]. The risk that collision takes place varies and depends on factors such as the abundance and type of species, the season, site characteristics and conditions. Evidence of collisions is scarce, and therefore a lot remains to be revealed when it comes to the impacts and outcomes of these accidents[51].

Which human activities cause this pressure

Shipping

Shipping is the main causes of collision. Wild species might collide with vessels, most commonly with their bow or propeller, and this causes physical trauma or death of the animal. These events can cause serious damage to vessels, as well as people on board when the animal is of large size. With the increase in the use of large commercial vessels, collisions with wild species are becoming a growing concern globally[52].

Collision risk is higher in areas where high levels of marine traffic coincide with biodiversity hotspots, as well as areas where vessel speed is high. With the receding of sea ice, it is also likely that the Arctic will become a more common shipping and tourism route in the future, and therefore this risk could extend to this area[53].

A global assessment of ship strikes is only available for collisions with whales, thanks to the International Whaling Commission Ship Strike Database[54]. Based on the data collected on that database, ship strikes increased in the decade 2000-2009, but then decreased again in the past decade.

[48] Schoeman P. *et al.* (2020).A Global Review of Vessel Collisions With Marine Animal. See:https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[49] Schoeman P. *et al.* (2020).A Global Review of Vessel Collisions With Marine Animal. See:https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[50] Schoeman P. *et al.* (2020).A Global Review of Vessel Collisions With Marine Animal. See:https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[51] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[52] See: https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[53] See footnote 51

[54] Winker et al (2020) Global Numbers of Ship Strikes: An Assessment of Collisions Between Vessels and Cetaceans Using Available Data in the IWC Ship Strike Database. See: https://www.researchgate.net/publication/342734400_Global_Numbers_of_Ship_Strikes_An_Assessment_of_Collisions_Between_Vessels_and_Cetaceans_Using_Available_Data_in_the_IWC_Ship_Strike_Database_Report_to_the_International_Whaling_Commission_IWC68BSC_HI

Offshore activities

Wild species can also collide with offshore installations such as marine renewable energy installations. For instance, fish might get caught into underwater turbines, or marine birds and bats might collide with offshore wind farms. Wild species such as marine mammals might also get entangled in mooring lines, cables and anchors and get injured or die as a consequence[55]. Offshore wind is projected to "play an important role in future energy systems"[56]. Collision risk with offshore installations is poorly monitored, therefore an overview at the global level is not available. In fact, despite the potential for collisions, the frequency of occurrence of these events and their consequences are largely unknown[57].

2.3.1.4 *Introduction of microbial pathogens*

What is the pressure about and where is it found

Microbial pathogens are disease-producing agents or microorganisms[58]. They can be both of human origin, or indigenous and autochthonous marine organism that can cause disease in humans. When these bacteria and virus are transmitted to humans they can cause a wide variety of illnesses[59]. Also, fish and shellfish can suffer diseases because of the uptake of microbial pathogens. This issue is particularly concerning for the aquaculture industry – as the density of species in cultivation areas offers more opportunities for contact among animals, and therefore more opportunities for the transfer of pathogens[60].

Little is known about the many pathogens and absorption processes that occur with the myriad of species and organisms found in natural marine ecosystems, as well as the concentration levels of these pathogens worldwide. Also, no global database of outbreaks of illnesses caused by the spread of microbial pathogens exists. However, a survey of shellfish borne viral outbreaks performed for the period 1980-2012 showed that the majority of the reported outbreaks were located in East Asia, followed by Europe, Americas, Oceania and Africa[61].

Ocean warming is predicted to favour the spread of pathogens in the marine environment and might therefore influence the prevalence of microbial infections.[62].

[55] See footnote 51

[56] IEA (2019) Offshore Wind Outlook 2019. See: https://www.iea.org/reports/offshore-wind-outlook-2019

[57] Sparling et al.(2020) . Collision Risk for Animals around Turbines. See: https://tethys.pnnl.gov/sites/default/files/publications/OES-Environmental-2020-State-of-the-Science-Ch-3_final_hr.pdf

[58] Defoirdt T. (2013). Virulence mechanisms of bacterial aquaculture pathogens and antivirulence therapy for aquaculture. See: https://onlinelibrary.wiley.com/doi/abs/10.1111/raq.12030

[59] Gerba C. P. (2005) Survival of Viruses in the Marine Environment. See: https://link.springer.com/chapter/10.1007/0-387-23709-7_6

[60] Lotz et al (2006) Aquaculture and Animal Pathogens in the Marine Environment with Emphasis on Marine Shrimp Viruses. See: https://www.researchgate.net/publication/226742743_Aquaculture_and_Animal_Pathogens_in_the_Marine_Environment_with_Emphasis_on_Marine_Shrimp_Viruses

[61] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[62] United Nations (2021). World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

The role of marine plastic as a "means of transport" for microbial pathogens in the marine environment is also currently being investigated as an emerging threat[63],[64]. The potential of macro and micro plastic to be a vector for microbial pathogens is currently understudied but could pose a serious threat to both human and environment health, due to the capacity of these materials to travel across oceans, as well as their ubiquity in the global marine environment.

Which human activities cause this pressure

Wastewater discharge

Sewage water can contain microbial pathogens e.g. because of the bacteria carried into human faecal matter. When untreated sewage water (raw sewage) is discharged into the marine environment, this can lead to the dispersion of microbial pathogens[65]. This can happen in areas that do not have well-functioning sewage systems; or where the sewage system is unable to contain excess run-off in case of heavy rainfalls or flooding, untreated wastewater can end up in the marine environment[66].

Globally, around 60% of people are connected to a sewer system. High-income countries usually rely on centralised sewer systems, while developing countries mostly treat their wastewater through decentralised or self-provided services. Around 44% of household wastewater is not safely treated worldwide[67] (see map below for the geographical distribution), and over 80% of wastewater is released into the environment without adequate treatment[68]. Moreover, it appears that incomplete disinfection of faecal waters, even in effluents from wastewater treatment plants with tertiary treatment (the most advance form of treatment) is "commonplace"[69].

[63] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[64] Bowley (2021) Oceanic Hitchhikers – Assessing Pathogen Risks from Marine Microplastic. See: https://www.researchgate.net/publication/343635803_Oceanic_Hitchhikers_-_Assessing_Pathogen_Risks_from_Marine_Microplastic

[65] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

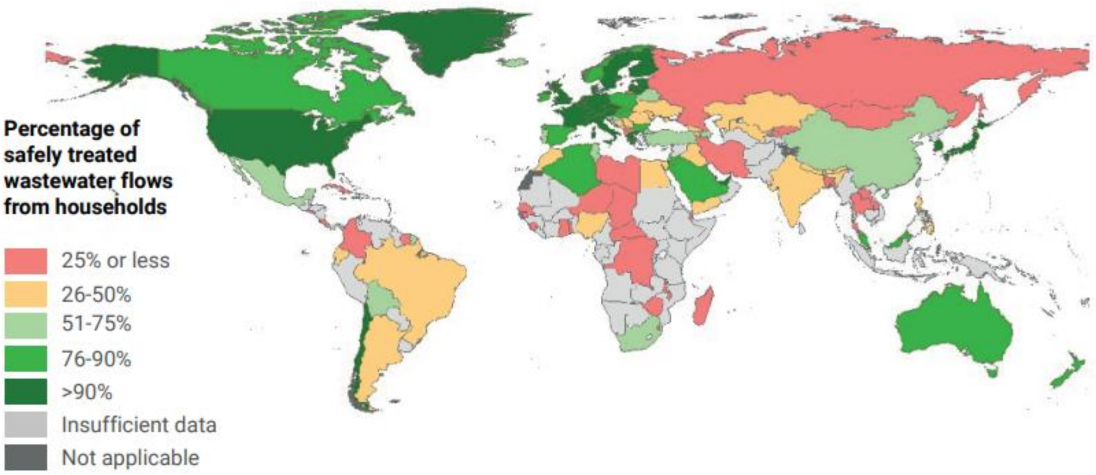
[66] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[67] United nations (2021) Summary Progress Update 2021: SDG 6 — water and sanitation for all. See: https://www.unwater.org/app/uploads/2021/12/SDG-6-Summary-Progress-Update-2021_Version-July-2021a.pdf

[68] WWAP (United Nations World Water Assessment Programme) (2017) The United Nations World Water Development Report 2017. See: http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/

[69] Beiras (2018) Chapter 4 - Microbial Pollution. See: https://www.sciencedirect.com/science/article/pii/B9780128137369000040?via%3Dihub

Figure 2.7 Estimated proportions of household wastewater safely treated (2020)



Source: UN (2021)[70]

Shipping

Microbial pathogens can be transferred by vessels via ballast water and hull fouling[71]. They can get onboard at ports, and then get discharged at other ports or in the high seas. Ports with high connectivity to other ports, can be major hotspots for the transfer of these pathogens[72].While no comprehensive monitoring of this phenomena is available, it is possible that the delivery rate of micro-organisms associated with vessel biofouling might be growing together with the increase in shipping.

Discharge of (micro)plastics

Macro and microplastics are emerging as a potential vector for microbial pathogens in the seas. In particular, microplastics found in ballast water is considered as a potential vector for the transfer of these pathogens across the globe[73].

[70] See: https://www.unwater.org/app/uploads/2021/09/SDG6_Indicator_Report_631_Progress-on-Wastewater-Treatment_2021_EN.pdf

[71] Hull fouling refers to the way organisms can attach themselves to the hull of a ship during a voyage and transport themselves long distances this way.

[72] Costello et al (2022) Assessing the potential for invasive species introductions and secondary spread using vessel movements in maritime ports. See: https://reader.elsevier.com/reader/sd/pii/S0025326X22001783?token=2461A0D8C95B515ED6B0FE7D619DF81A51660D6082E41F922D9C84FCAA9EC9549C7BE1F69967F172BAFF555F217C63B3&originRegion=eu-west-1&originCreation=20220329152546

[73] Naik et al (2019) Microplastics in ballast water as an emerging source and vector for harmful chemicals, antibiotics, metals, bacterial pathogens and HAB species: A potential risk to the marine environment and human health. See: https://pubmed.ncbi.nlm.nih.gov/31470206/

2.3.2 Physical pressures

2.3.2.1 Seabed abrasion

What is the pressure about and where is it found

Seabed abrasion refers to temporary or permanent changes to the seabed substrate or morphology, and changes to habitat and species inhabiting it[74]. When the changes are temporary and can be reverted if the activity causing the change ceases, this is called "physical disturbance". When the changes are permanent, this leads to a "physical loss" of the seabed "benthic" habitat and species[75].

Seabed abrasion can result from[76] [77] [78] the extraction of seafloor substrate and the production of "extraction and dewatering plume". It can also lead to the release of substances from sediments: when seabed sediments are disturbed, organic contaminates, heavy metals and other components can be released into the water column. These substances can be toxic, they can release nutrients into water and increase turbidity of the water column. Notably, the disturbance of the seafloor (e.g. because of trawling) has been estimated to cause the release of 1 gigaton of CO_2 every year[79].

When seabed abrasion takes place in the deep sea, this has more often "permanent" or long-term impacts. This is because deep sea habitats and fauna are in general characterised by slower growth and reproduction rate. Knowledge of deep-sea ecosystems and their response to abrasion is still scarce to this day.

It is challenging to provide an overview of the geographical distribution of seabed abrasion, as no databases on the state of the seabed are available. Some indications of where this pressure is most prominent can however be deduced from the distribution of the activities that cause it.

Which human activities cause this pressure

Seabed mining

The demand for minerals has been growing steadily in the past century. It is foreseen that this demand will continue to grow in the coming decades, in particular as minerals will play a key role in the green transition. These metals are currently sourced from land-based reserves, but this type of sourcing presents challenges. Because of this, and the

[74] HELCOM State of the Baltic Sea. See: https://helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/

[75] Idem

[76] Protecting the global ocean for biodiversity, food and climate

[77] Ecorys (2014) Study to investigate state of knowledge of Deep-Sea Mining

[78] Kaikkonen et al. (2018) Assessing the impacts of seabed mineral extraction in the deep sea and coastal marine environments: Current methods and recommendations for environmental risk assessment. Available at: https://www.researchgate.net/publication/327419232_Assessing_the_impacts_of_seabed_mineral_extraction_in_the_deep_sea_and_coastal_marine_environments_Current_methods_and_recommendations_for_environmental_risk_assessment

[79] Sala *et al.* (2021) Protecting the global ocean for biodiversity, food and climate. See: https://www.nature.com/articles/s41586-021-03371-z.epdf?sharing_token=3uCHC_BARvxR4R8PqWDCOdRgN0jAjWel9jnR3ZoTv0MwjSp_dqdYRo11ccDn9dqPW5D1xJuK8fpT__q4KFNUwr3chDwJyG9IO5W1aWFy5om4rjrtPpwoPhh8lecRX4YI2DOaZc_5Z-oJr9OWWYCQTiQu_TyleTEdjrY3qgiOqzIDG24Tb_x2iqFGHkqVdsk0hZl3ZdBIC7ovw49j6wAQhA%3D%3D&tracking_referrer=time.com

growing demand for metals, other avenues for their sourcing are being explored, including seabed mining.

This includes both nearshore mining (between 0 and 200 miles from the coast), as well as offshore mining (beyond 200 miles from the coast)[80]. Deepwater seabed mining refers to mining that takes place 200 meters below the ocean surface[81]. Offshore mining can be undertaken both within national jurisdiction and beyond. Nearshore mining is well established within the Exclusive Economic Zones of many countries worldwide. For instance, sand and gravel mining takes place in Western European countries, diamond mining in Namibia, tin mining in South-East Asian countries, iron-sand mining in New Zealand[82]. Commercial mining of the deep seabed is not currently performed, but a number of exploration licenses were granted in the last years, within national jurisdictions, and the first deep-water seabed test mining was carried out for the first time in 2017, in Japan. Pacific Island States are also working on the development of seabed mining legislation for areas within national jurisdiction[83]. It is projected that most of the deep water seabed mining activities will occur in areas beyond national jurisdiction[84].

Bottom trawling

Bottom trawling is the most widespread human activity affecting seabed habitats[85]. One-quarter of wild marine landings, around 19 million tons of fish per year, are caught through bottom trawling worldwide[86]. The extent to which bottom trawling takes places, and its geographic distribution, are often contested and poorly described – in particular at the global level. A study on the footprint of bottom trawling[87], performed on 24 selected regions of Africa, the Americas, Australasia, and Europe, showed that less than 10% of the analysed seabed areas were trawled overall. However, the situation changes when looking at specific areas. In particular, trawling takes place in around 10-30% of the analysed seabed areas in the Irish Sea, North Benguela Current, South Benguela Current, Argentina, East Agulhas Current, and west of Scotland, and between 30-81% of the analysed seabed areas were trawled in the northeast Atlantic and Mediterranean.

European seas are the most frequently trawled, among the analysed regions. More than one-half of the analysed seabed area in the Adriatic Sea is trawled at least once per year, on average, and over one-quarter of the analysed seabed area is trawled with the same frequency in five of the other eight European seas[88]

[80] Allsopp *et al.* (2013) Review of the Current State of Development and the Potential for Environmental Impacts of Seabed Mining Operations. See: https://www.greenpeace.to/greenpeace/wp-content/uploads/2013/07/seabed-mining-tech-review-2013.pdf

[81] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[82] Idem

[83] Idem

[84] Idem

[85] Hiddink *et al.* (2017) Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. See: https://www.pnas.org/doi/epdf/10.1073/pnas.1618858114

[86] Amoroso *et al.* (2018) Bottom trawl fishing footprints on the world's continental shelves. See: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6205437/

[87] The study considered bottom trawling as all towed gears making sustained contact with the seabed, including beam and otter trawls and dredges. Footprints were defined as the area of seabed trawled at least once in a specified region and time period, with area trawled determined from gear dimensions and tow locations. See: https://www.pnas.org/content/115/43/E10275#sec-1

[88] See footnote 85

2.3.3 Pollution pressures

2.3.3.1 Introduction of underwater noise

What is the pressure about and where is it found

Different human activities can produce underwater noise, either intentionally or unintentionally. Underwater noise produces a number of negative impacts on marine life. Given the growing focus on the ocean-based economy, which is projected to double its contribution to global gross domestic product by 2030[89], it is becoming more and more crucial to address this pressure.

Noise levels due to anthropogenic activities are variable across space and time. Two drivers of this variability are the level of human activity present in the environment and acoustic propagation characteristics in the region. Areas where the highest levels of anthropogenic noise are found include for instance those where industrial use of the maritime space is heavy. This is the case in the Gulf of Mexico, the North Sea and the North Atlantic Ocean. Other areas that are likely to experience increasing levels of anthropogenic noise are the Arctic where the sea is opening up to shipping, or Africa where investments and industries expand. Notably, a reduction in overall levels of anthropogenic noise have been registered because of the slow-down of shipping traffic brough by the COVID-19 pandemic[90].

From the literature review, underwater noise has been found to be a pressure listed only in a few assessments and reports with a global geographical scope, and in only one of the regional assessments (Baltic Sea).

Which human activities cause this pressure

Shipping (incl. tourism)

The most important source of sounds is marine vessels (e.g., merchant ships, fishing vessels and recreational and cruise ships), which have the most significant effect on noise. [91] The level of noise generated depends on physical variables such as ship's dimensions and design such as of propellers, tonnage, draft, load and speed, as well as wind and sea conditions[92]. A study estimated that increased shipping has contributed to a 32-fold increase in the low-frequency noise present along major shipping routes, in the past 50 years[93]. Coastal regions are the most affected, as vessel concentration increases noise considerably – despite the fact that vessel noise does not propagate far in shallow waters. Notably, vessel noise is also prominent in ocean regions that are far away from shipping lanes, because of the long-range propagation of noise at low-frequency[94], as well as the fact that noise travels much greater distances in water than in air.

[89] Ritts and Bakker (2021) Conservation acoustics: Animal sounds, audible natures, cheap nature, Geoforum, See: https://www.science.org/doi/10.1126/science.aba4658

[90] Thomson and Carclay (2020) Real-time observations of the impact of COVID-19 on underwater noise. See: https://asa.scitation.org/doi/full/10.1121/10.0001271

[91] Duarte *et al* (2021) The soundscape of the Anthropocene ocean. See: https://www.science.org/doi/10.1126/science.aba4658

[92] Richardson *et al.* (1995). *Marine Mammals and Noise*. San Diego: Academic Press. See: https://doi.org/10.1016/B978-0-08-057303-8.50003-3.

[93] See footnote 89

[94] See: https://www.science.org/doi/10.1126/science.aba4658

Resource exploration and exploitation

Resource exploration and, exploitation can generate underwater noise through a number of activities such as the oil and gas exploration and extraction (i.e. through the seismic surveys, the drilling and production phases, the generation of energy on the platforms, installation of pipelines etc.); renewable energy development and deployment (i.e. power-generating wind turbines in deeper waters including the drilling for the turbine piles, as well as other forms of ocean energy); coastal development and associated construction; shipyard and harbours functions (i.e. construction and operations); seabed mining (i.e. exploration and extraction phases); the use of sonar for mapping the ocean bottom and detecting and localizing various objects in the water column (i.e. for military use or non-military use such as fishing activities and marine research) [95]. These activities, undertaken at different levels (i.e. onshore, shoreline, nearshore or offshore) produce a compound impact that is to this day poorly understood [96].

2.3.3.2 Introduction of substances leading to eutrophication

What is the pressure about and where is it found

During the 21st century, the world's oceans have seen a sharp increase in anthropogenic inputs of nitrogen (N) and phosphorus (P) to coastal and marine ecosystems through river run-off and due to atmospheric deposition. This leads to an increase in the rate of supply of organic matter to an ecosystem [97]. It is proven that anthropogenic nutrient inputs now exceed inputs owing to natural processes [98]. Coastal eutrophication caused by anthropogenic nutrient inputs is one of the greatest threats to the health of coastal estuarine and marine ecosystems worldwide and it is estimated that globally, 24% of the anthropogenic N released in catchments is estimated to reach coastal ecosystems. [99]

This change causes consequent ecosystem degradation in the coastal oceans worldwide and is even considered today as the most widespread anthropogenic threat to the health of these ecosystems [100]. Eutrophication is today a pressure found in almost all coastal ecosystems, as it is shown in Figure below. The screening of sea basin reports showed that the "Introduction of substances leading to eutrophication" is listed as a pressure in almost all sea basins, and as a key pressure in the documents from Regional Sea Conventions of the Baltic Sea, the Mediterranean, the Black Sea, the Northwest Pacific, the Caribbean Region, the Arctic Ocean.

[95] Richardson *et al.* (1995). *Marine Mammals and Noise*. San Diego: Academic Press. See: https://doi.org/10.1016/B978-0-08-057303-8.50003-3.

[96] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

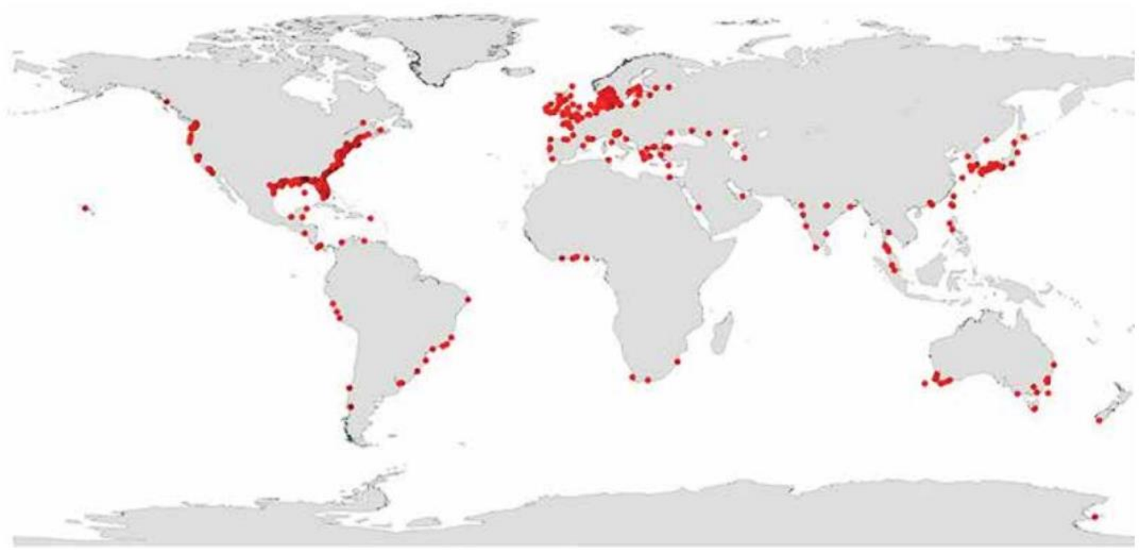
[97] Nixon, S. (1995). Coastal marine eutrophication: a definition, social causes, and future concerns. See: https://www.tandfonline.com/doi/abs/10.1080/00785236.1995.10422044

[98] UN (2021) *World Ocean Assessment*, Volume II.

[99] Malone, C., et al. (2020). The Globalization of Cultural Eutrophication in the Coastal Ocean: Causes and Consequences. See: https://www.frontiersin.org/articles/10.3389/fmars.2020.00670/full

[100] Idem

Figure 2.8 Global distribution of eutrophic coastal marine ecosystems



Source: Breitburg and others (2018) in the World Ocean Assessment (United Nations, 2021)

It can be assumed that as the anthropogenic N production will continue to increase over the course of the 21st century, the risk of coastal eutrophication will increase symmetrically in all large marine ecosystems – more specifically along the coasts of Africa, South America, South Asia and Oceania[101].

In addition, it is expected that the impact of this continued increase in N and P loadings will be reinforced by the impact of climate change on marine ecosystems and ocean hydrographical conditions such as the increase in sea temperatures, changes in rainfall patterns and changes in the flux of atmospheric CO_2 into the ocean. It is thus expected that the extent of coastal hypoxia, acidification and toxic algal events will continue to increase as well[102].

Which human activities cause this pressure

Agriculture

Agriculture is the main source of food of the global population. Fertilisers (artificial or natural) are used globally in the majority of agriculture land in order to maintain and increase the fertility of soils used for agriculture. Fertiliser use is especially high in intensive farming in order to increase crop yields/ agricultural outputs. While fertiliser use can be beneficial in increasing agricultural output, it is also one of the main sources of inputs of substances leading to eutrophication through runoff from agricultural areas; through this, agriculture is considered to be a major cause of eutrophication in many global regions.[103] The risk of fertilisers polluting water increases when there is a surplus in nutrient balances, i.e. when the quantity of nutrient inputs entering an agricultural system is higher than the quantity of nutrient outputs leaving the system; such a surplus seems to consistently occur in all

[101] United Nations. (2021) *World Ocean Assessment*, Volume II.

[102] Townhill, Bryony L., and others (2018). Harmful algal blooms and climate change: exploring future distribution changes. *ICES Journal of Marine Science*, vol. 75, No. 6, pp. 1882–1893.

[103] Withers, P., et al. (2014). Agriculture and Eutrophication: Where Do We Go from Here? See: https://www.mdpi.com/2071-1050/6/9/5853

countries where data is available (OECD countries).[104] Currently, the highest use of fertiliser[105] globally can be observed in a few global hotspots which include most parts of Europe, eastern parts of the USA, North India and Bangladesh, and eastern China.[106] [107] Mainly driven by a growing population, but also growing global GDP, agricultural production is also projected to increase in the future by around 1.4% annually (albeit that is a slowdown compared to the last decade). This production growth is expected primarily take place in emerging economies and low-income countries and to be driven by productivity-increasing investments in agricultural infrastructure, including an increase in the use of fertiliser[108].

Finfish aquaculture

Aquaculture provides important contributions for providing food security. However, finfish aquaculture is also one of the main sources of anthropogenic nutrients in the oceans with a growing trend of emissions which have increased worldwide by a factor of 6 between 1985 and 2005.[109] Over the past decades, world aquaculture production has surpassed that of capture fisheries for most categories (e.g. inland fishing); however, farming of marine fishes is unlikely to overtake marine capture production in the future. Within aquaculture, marine aquaculture accounts for approximately 40% of all production. Within marine aquaculture, finfish aquaculture accounts for around one fourth of all production, i.e., around 7.5 million tons (in 2018).[110] Marine finfish aquaculture is practiced in almost all regions in the world. By far the largest part of aquaculture production takes place in Asia (89% of global production in 2016)[111]; EU aquaculture accounts for less than 2% of global aquaculture production.[112]

Combustion of fossil fuels

Combustion of fossil fuels is done globally in order to generate electricity and the global electricity consumption has continuously grown over the last decades; between 1980 and 2019, electricity consumption tripled. This is partly due to a growing world population (which grew by 75% over the same period), but also to a large extent due to industrialisation[113]. Also, combustion of fossil fuels is among the main contributors to global marine eutrophication; this

[104] OECD (2022). Environmental performance of agriculture - nutrients balances. See: https://doi.org/10.1787/d327d2a9-en (accessed on 09 Feb 2022)

[105] Including manure

[106] Potter, P., et al. (2010). Characterizing the Spatial Patterns of Global Fertilizer Application and Manure Production. Earth Interactions. See: https://www.researchgate.net/publication/237966463_Characterizing_the_Spatial_Patterns_of_Global_Fertilizer_Application_and_Manure_Production

[107] The paper also provides evidence of close geographical overlap at global scale between areas with high use of fertilisers and marine eutrophication.

[108] OECD/FAO (2021). OECD-FAO Agricultural Outlook 2021-2030. See:

[109] Malone, C., et al. (2020). The Globalization of Cultural Eutrophication in the Coastal Ocean: Causes and Consequences. See: https://www.frontiersin.org/articles/10.3389/fmars.2020.00670/full

[110] FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. https://doi.org/10.4060/ca9229en

[111] Garlock, T., et al. (2019). A Global Blue Revolution: Aquaculture Growth Across Regions, Species, and Countries. See: https://www.researchgate.net/publication/336652599_A_Global_Blue_Revolution_Aquaculture_Growth_Across_Regions_Species_and_Countries

[112] COM/2021/236 final COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030. See: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:236:FIN

[113] Indicator "Net electricity consumption worldwide in select years from 1980 to 2019" on https://www.statista.com/statistics/280704/world-power-consumption/. Accessed on 15 December 2021

includes for power generation as well as for transport. Reduction of nitrogen oxides (NOx) which is emitted when fossil fuels are burned, would thus lead to less eutrophication. Globally, still more than 60% of electricity is generated through fossil fuel power plants[114] with regional differences. Regarding road transport, diesel cars emit considerably more NOx than petrol cars. Newer vehicle diesel standards for heavy-duty vehicles and light-duty vehicles are more effective in reducing NOx emissions than older ones, and vehicles with newer standards are more prevalent in some world regions (e.g., USA, Canada, Japan, and to some extent the EU even though to a lower degree than the others), while vehicles with older standards are more prevalent in other regions such as Mexico, India, Russia, Brazil or Australia)[115].

Discharge of wastewater

Please see discharge of wastewater in section 2.3.1.4; the information in there is also relevant for this section and is thus not repeated.

2.3.3.3 Introduction of inorganic pollutants

What is the pressure about and where is it found

There are several types of inorganic pollutants; however, regarding ocean pollution, most of the literature focuses on pollution from heavy metals. Also, those seem to be the most commonly monitored substances; a study listing more than 2,700 potential chemical contaminants in the marine environment found that three out of only four substances () which are considered under the current lists of chemicals of all European regional sea conventions are heavy metals (cadmium, lead, and mercury[116]). Heavy metals in marine ecosystems if present in too high concentrations can lead to severe effects in those ecosystems. Also, they are persistent and do not degrade, and thus once emitted, remain in the environment. Finally, they are spread among ecosystems through food chains and can accumulate in some species (bioaccumulation); consuming those can then lead to health effects in humans such as liver damange, lung injuries or cancer.

Heavy metals are introduced to the oceans through riverine and atmospheric transport and can be found in coastal areas as well as in the open ocean. This pressure has been identified in most Sea Basins around the world which can be explained by the wide range of human activities leading to this pressure as well as the emission pathways of this pressure.

Given the wide range of human activities leading to this pressure, predictions for future developments are challenging to make. Looking at past trends, there seems to be evidence that the concentration of some heavy metals has remained constant over recent years compared to the past (e.g. copper and mercury), while others have been decreasing (e.g. lead and cadmium, while Zinc has been increasing[117].

[114] See indicator "Electricity generation by source" on https://www.iea.org/fuels-and-technologies/electricity

[115] Anenberg, S., et al. (2017). Impacts and mitigation of excess diesel-related NOx emissions in 11 major vehicle markets. See: https://www.nature.com/articles/nature22086

[116] A chemical used in agricultural insecticides and as a pharmaceutical treatment for lice and scabies

[117] GESAMP (2018). Global Pollution Trends: Coastal Ecosystem Assessment for the Past Century. See: http://www.gesamp.org/publications/global-pollution-trends-coastal-ecosystem-assessment-for-the-past-century

Which human activities cause this pressure

Combustion of fossil fuels

Combustion of fossil fuels (mostly coal) is one of the global main emitters of mercury into the air (accounting for approx. 25% of global mercury air emissions[118]) and large parts of those emissions are deposited in the oceans, accounting globally for 16% of mercury emissions to water[119]. Atmospheric emissions of mercury can travel long distances; for example, mercury emissions from Asia account for more than one quarter of the mercury deposited into the Mediterranean and Black Seas every year and also have a negative impact on mercury levels in the north Pacific Ocean[120]. Combustion of coal also emits several other heavy metals, including e.g., cadmium, arsenic, zinc and others. Globally, 80 countries use coal for power generation and the practice generates nearly 40% of the global energy. The largest hotspots are China (with significant increase of coal-generated electricity capacities since 2000 and accounting today for more coal-generated electricity than all other world regions combined), USA and the EU (both with decreasing trends), India and other Asian regions[121].

Discharge of insufficiently treated wastewater

Wastewater is water which is polluted from rainwater runoff and human activities. Wastewater, both municipal and industrial, usually shows high concentrations of several heavy metals. In industrial wastewater, those include among others lead, zinc, arsenic, and mercury, stemming from a wide range of industrial activities.[122] Considerable concentrations of heavy metals can usually be found in municipal wastewater, which stem from a wide range of sources such as metal roofs, tyre and brake abrasion from cars, car washes and countless others[123]. Historically, industrial wastewater was one of the main sources of heavy metals in municipal wastewater; however, today there is evidence that diffuse sources such as the ones mentioned before are the main source of heavy metals in wastewater due to more stringent legislation.

Even though wastewater treatment cannot degrade those heavy metals, they can be removed either from final effluent or else in the sludge produced [124].

Please see discharge of wastewater in section 2.3.1.4; the information in there is also relevant for this section and is thus not repeated.

Land-based mining

Heavy metal pollution from mining activities is caused when wastewater from mining operations is discharged untreated into the environment or when heavy metals contained in excavated

[118] EEA (2018). Mercury in Europe's environment. A priority for European and global action. See: https://www.eea.europa.eu/publications/mercury-in-europe-s-environment

[119] UN (2018). Chapter 6 Anthropogenic releases of mercury to water. In: Global mercury assessment 2018. See: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment

[120] See footnote 580

[121] See: https://www.carbonbrief.org/mapped-worlds-coal-power-plants. Accessed on 11 January 2022

[122] Agarwal, R., et al. (2017). Heavy metal removal from wastewater using various adsorbents: a review. See: https://www.semanticscholar.org/paper/Heavy-metal-removal-from-wastewater-using-various-a-Renu-Agarwal/d3c924bc5d32e56a1e7d95cee9e50ca3e10e194d

[123] Sörme, L, et al. (2002). Sources of heavy metals in urban wastewater in Stockholm. See: https://www.sciencedirect.com/science/article/abs/pii/S0048969702001973#!

[124] Briffa, B., et al. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. See: https://www.sciencedirect.com/science/article/pii/S2405844020315346

rock (i.e., mining waste, which in the EU makes up approx. 30% of the total volume of waste produced in the EU) or exposed in an underground mine come in contact with water. Metals are leached out and carried downstream, including into the oceans. For example, ore mining and processing accounts for 40% of all mercury releases into water[125]. While mining is done in most regions of the world, some regional differences can be observed: for example, only five countries (China, Australia, USA, Russia, and Chile) account for half of all mining areas globally[126].

small-scale gold mining plays a special role as one of the global main sources of mercury atmospheric emissions, accounting for almost 40%[127] of atmospheric emissions which then can get deposited in oceans. The vast majority of releases from this activity occur in South America (more than 50%) and East and Southeast Asia (36%).[128]

Box 2.1 And what about deep-sea mining?

Little information seems to be available about the potential emissions of pollutants such as heavy metals from deep-sea mining activities.

Concerning the actual emissions, there could be issues with mobilising heavy metals which have been deposited in sediment before; those plumes of mobilised sediments could travel tens to hundreds of kilometres from the actual mining sites, both vertically and horizontally, and thus impact ecosystems.[129] This could introduce heavy metals in the deep sea in concentrations exceeding 4000 times the limits considered to be safe.[130]

Finally, there still seems to be little understanding on the impact on different ecosystems caused by this. While extensive data is available on toxicity of heavy metals in shallow-water ecosystems, those may be different for deep-sea ecosystems[131] as well as midwater ecosystems[132].

2.3.3.4 *Oil spills*

What is the pressure about and where is it found

An oil spill is the leakage of petroleum onto the surface of a large water body[133]. Oil can end up in the oceans either via accidental oil spills from oil-carrying tankers, as well as when produced water and drilling waste is discharged into the marine environment, usually close-by to oil extraction facilities.

[125] UN (2018). Chapter 6 Anthropogenic releases of mercury to water. In: Global mercury assessment 2018. See: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment

[126] Maus, V., et al. (2020). A global-scale data set of mining areas. See: https://www.nature.com/articles/s41597-020-00624-w

[127] UN (2018). Chapter 3 Mercury emissions to air. In: Global mercury assessment 2018. See: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment

[128] See footnote 589

[129] Drazen, J., et al. (2020). Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining. See: https://www.pnas.org/doi/10.1073/pnas.2011914117

[130] Coffey (2008). Environmental Impact Statement: Solwara 1 Project. Nautilus Minerals Niugini Limited. See : http://www.cares.nautilusminerals.com/Downloads.aspx

[131] Hauton, C., et al. (2017). Identifying Toxic Impacts of Metals Potentially Released during Deep-Sea Mining—A Synthesis of the Challenges to Quantifying Risk. See: https://web.archive.org/web/20131103175932/http://www.cares.nautilusminerals.com/Downloads.aspx

[132] See footnote 593

[133] See: https://www.britannica.com/science/oil-spill

Oil spills have proven to affect the marine ecosystems in multiple ways. Marine fauna and flora are affected through oiling: oil can directly trap animals, as well as diminish the insulating and water-repellent ability of fur-bearing mammals, thus exposing them to harsh elements and leading them to die from hypothermia[134]. When oil gets mixed with the water column, fish and other species experience reduced growth, enlarged livers, changes in heart and respiration rates, fin erosion, and reproduction impairment[135].

In terms of geographical spread of this pressure, major oil spill incidents registered in 2003-2012 took place in the Atlantic Sea[136]. Oil spills have however become less and less frequent over the years, as illustrated by the graph below. In the 1970s, there would be about 79 oil spills per year, on average. In the last decade, the annual average is 5 oil spills per year[137].

Which human activities cause this pressure

Oil exploration and extraction

Oil still occupies the largest share in total energy supply (around 32% of total energy supply), though global reliance on it dropped substantially since the 1970s (by around 16% from 1973 to 2019)[138]. The outbreak of COVID also had a significant impact on the oil demand, with 2020 demand being 9 mb/d below the level seen in 2019. This notwithstanding, the IEA foresees that global oil consumption will reach 104.1 mb/d in 2026, which is above 2019 levels, in the absence of rapid policy intervention and behavioural changes[139].

The main impact from gas and oil exploration and extraction activities is not related to oil spills, but rather to operational discharges i.e. the discharge of water produced through the exploration or extraction activity, and the disposal of drilling waste[140], as well as discharges from roads and hard standing areas. On average, three barrels of water are produced for each barrel of oil extracted.

In 2020, the major producers of crude oil were the United States, the Russian Federation, Saudi Arabia, Canada, China and Iraq (see figure below).

[134] National Ocean Service. How does oil impact marine life? Oil spills are harmful to marine birds and mammals as well as fish and shellfish. See: https://oceanservice.noaa.gov/facts/oilimpacts.html

[135] National Ocean Service. How does oil impact marine life? Oil spills are harmful to marine birds and mammals as well as fish and shellfish. See: https://oceanservice.noaa.gov/facts/oilimpacts.html

[136] See: https://ec.europa.eu/maritimeaffairs/atlas/maritime_atlas/#lang=EN;p=w;bkgd=1;theme=27:0.52,28:1,50:1;c=3005191.4096569903,627277.7517246474;z=2

[137] ITOPF (2021) Oil Tanker Spill Statistics 2021. See: https://www.itopf.org/knowledge-resources/data-statistics/statistics/

[138] See: http://energyatlas.iea.org/#!/tellmap/-1920537974

[139] IEA (2021) Oil 2021 Analysis and forecast to 2026. See: https://iea.blob.core.windows.net/assets/1fa45234-bac5-4d89-a532-768960f99d07/Oil_2021-PDF.pdf

[140] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

Oil shipping

Around 61% of the oil consumed globally, is transported via seaborne trade[141]. The main shipping routes pass through the Atlantic, as well as Indian Ocean and Mediterranean Sea, to connect exporters and importers. The largest exporters of crude oil (in terms of net trade) in 2019 were Saudi Arabia, the Russian Federation, Iraq, the United Arab Emirates and Canada. Meanwhile, the largest net importers were China, India, Japan, Korea and Germany[142].

While overall oil trade volume has increased overtime, the number of shipping accidents leading oil spills (over 7 tons) have decreased substantially since the 1970s. This is likely related to improved surveillance and action capabilities that led to an increased awareness about the issue[143]. Notably, the majority of oil spilled in the oceans is the result of a few large accidents occurred in the past decades, that had huge impacts. In the 1980s, 1990s, 2000s, 2010s, ten major oil spills in each period were responsible for around 70 to 80% of total oil spilled in the oceans for each given decade. Most major oil spill accidents happened in the Atlantic Ocean to the west of Europe[144].

2.3.3.5 *Introduction of marine litter*

What is the pressure about and where is it found

Marine litter is a significant pressure on the marine environment and its inhabitants. Marine fauna is impacted by litter mainly via entanglement and ingestion. Entanglement and ghost fishing[145] usually threatens larger marine animals, such as top predators, while ingestion affects a wider range of marine organisms. Smothering and damages to benthic organisms are also associated with marine litter.

It is estimated that 80% of marine litter originates from land-based sources, but sea-based sources also play an important role. Litter ends up in the ocean via runoff, winds, tides, gravity or via rivers[146]. Plastic is the main component of marine litter, and reportedly makes up for 80% of marine debris found in surface waters to deep-sea environment[147]. Single-use plastic items are the biggest contributors to marine litter[148]. It is estimated that between 4.8 and 12.7 Mt of plastics end up in the oceans every year, with between 0.5 and 2.7 Mt coming from rivers[149] - Asian rivers for instance are considered to be a major source of plastic pollution[150].

[141] U.S. Energy Information Administration (2017) World Oil Transit Chokepoints. See: https://www.eia.gov/international/analysis/special-topics/World_Oil_Transit_Chokepoints

[142] IEA Atlas of Energy. See: http://energyatlas.iea.org/#!/tellmap/-1920537974

[143] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[144] Chen *et al* (2019) Oil spills from global tankers: Status review and future governance. See: https://agris.fao.org/agris-search/search.do?recordID=US201900230509

[145] Ghost fishing is a term that describes what happens when derelict fishing gear 'continues to fish and trap animals' once discarded into the oceans.

[146] Chassignet et al (2021) Tracking Marine Litter with a Global Ocean Model: Where Does It Go? Where Does It Come From?

[147] IUCN. Marine plastic pollution. See: https://www.iucn.org/resources/issues-briefs/marine-plastic-pollution

[148] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[149] Chassignet *et al* (2021) Tracking Marine Litter With a Global Ocean Model: Where Does It Go? Where Does It Come From?. See: https://www.frontiersin.org/articles/10.3389/fmars.2021.667591/full

[150] See footnote 148

Overall, it is estimated that more than 150 million tonnes of plastics have accumulated in the world's oceans[151]. The annual flow of plastic waste into the ocean could almost triple by 2040 to 29 million metric tons per year, equivalent to 50 kg of plastic for every metre of coastline worldwide[152].

Which human activities cause this pressure

Waste disposal and dumping

A multitude of human activities on land generate waste, and plastics (the main component of marine litter) is now used in almost all major product categories. Plastics packaging is the largest application of plastics by weight, but they are also used widely in the textile, consumer goods, transport, and construction sectors. Most of the plastic waste generated every year is from short-lived or single use applications, such as plastic packaging or textiles[153].

Once generated, (plastics) waste is either collected through (formal or informal) waste management systems, or leaks into the natural environment (mainly through rivers, or in some case there might also be discharges from landfill sites in eroding areas). It is estimated that around 10% of global plastics waste generation (or 30 Mt) was mismanaged in 2010[154] - and that 50% of this mismanaged material comes from G20 countries[155]. In fact, many countries lack the infrastructure to prevent (plastic) pollution – or waste is directly littered into the environment. This leads to waste leakage into rivers and the ocean[156].

Illegal (plastic) waste trade

The legal and illegal global trade of plastic waste may also damage ecosystems, where waste management systems are not sufficient to contain plastic waste.[157] Where plastic waste is traded illegally, this often causes severe pressures on the environment. This waste can be exported to third countries for the purpose of disposal or recovery, in breach of existing laws[158]. Plastics are also often mixed with hazardous waste to disguise illegal shipment of the latter, and therefore can also be contaminated.

Fishing and aquaculture

Fishing can contribute to litter in the oceans. In commonly used fishing grounds, large marine litter is mostly composed of abandoned, lost or otherwise discarded fishing gear. It is estimated that around 6% of all fishing nets, 9% of all traps and almost 30% of all lines are lost around

[151] European Commission, Our Oceans, Seas and Coasts. See: https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/index_en.htm

[152] Idem

[153] OECD (2019) Issue Brief: Improving Resource Efficency to Combat Marine Plastic Litter. See: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

[154] Jambeck et al (2015) in OECD (2019) Issue Brief: Improving Resource Efficency to Combat Marine Plastic Litter. See: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

[155] OECD (2019) Issue Brief: Improving Resource Efficency to Combat Marine Plastic Litter. See: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

[156] See footnote 148

[157] IUCN Marine Plastic Pollution. See: https://www.iucn.org/resources/issues-briefs/marine-plastic-pollution

[158] Internationally, this refers to The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (1992). For the EU, this would be in breach of the Waste Shipping Regulation.

the world each year[159]. As the gear is designed to catch specific target species, its characteristics vary across regions. The frequency and magnitude of the abandonment, loss and discard of fishing gear also differs across fisheries and regions – and significant knowledge gaps remain concerning the amounts and rates of this practice[160].

Maritime transport

Marine litter can be generated by maritime transport through different avenues. However, there are little detailed studies quantifying plastic litter from shipping. Evidence is available on some types of waste; for instance, it is considered that 0.001 to 2% of cargo loads are lost annually[161].

Offshore oil and gas exploration

Activities related to the construction, operation, and maintenance of oil and gas exploration and exploitation platforms can cause the production of waste.

2.3.3.6 Introduction of microplastics

What is the pressure about and where is it found

Microplastics are a persistent pollutant that is already present in all marine habitats. Due to their size, microplastics can easily be ingested by organisms, and accumulate throughout the food chain. Microplastics have also been found in seafood, salt, honey, fruits and drinking water – and the impacts on human health are currently being investigated[162].

They are defined as plastic pieces or fragments less than 5 millimetres in diameter. The two main components of primary microplastics released into the oceans are eroded synthetic textiles (34.8%) and vehicle tyres (28.3%). The rest is attributed to "city dust"[163], rests of paint used for road markings and marine coating, among others[164]. Common sources of secondary microplastics are single-use plastics (e.g., cutlery, trays, straws, cigarette butts, caps and lids, plastic bottles and shopping bags), synthetic textiles and clothing, coatings and paints, and tyres[165]. Atmospheric transport also seems to be an additional pathway through which microplastics enter the ocean[166].

It is estimated that between 0.8 and 2.5 Mt of primary microplastics are released into the oceans every year[167], and that the concentration of oceanic microplastics could increase by four

[159] See footnote 148

[160] GESAMP (2021) Sea-based sources of marine litter. See: http://www.gesamp.org/publications/sea-based-sources-of-marine-litter

[161] Idem

[162] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[163] City Dust includes losses from the abrasion of objects (synthetic soles of footwear, synthetic cooking utensils), the abrasion of infrastructure (household dust, city dust, artificial turfs, harbours and marina, building coating) as well as from the blasting of abrasives and intentional pouring (detergents).

[164] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

[165] IUCN. Marine Plastic Pollution. See: https://www.iucn.org/resources/issues-briefs/marine-plastic-pollution

[166] See footnote 162

[167] See footnote 165

times by 2050, and by 50 times by 2100[168]. It is estimated that 98% of microplastics at sea is generated from land-based activities[169].

Which human activities cause this pressure

Passenger (and freight) transport

Road transport is a source of microplastics, via two main avenues: tyres and road markings, as well as brake linings. Microplastics are created through the abrasion of tyres, that get eroded when used. These particles consist of a mix of synthetic polymers, that turn into dust and can be spread by the wind or washed off the road by rain, and then end up in the oceans. In a similar way, the materials used for road marking (mainly paint, but also thermoplastic, preformed polymer tape and epoxy) get weathered, or abraded by vehicles, and then get spread by wind or washed off roads by rain.[170].

Household activities

Household activities, such as the laundry of synthetic textiles, and the use of personal care products, are a source of microplastics. The washing of synthetic textiles creates primary microplastics through the abrasion and shedding of fibres (e.g. polyester, polyethylene, acrylic or elastane) that are discharged in sewage water, and can then end up in the ocean[171].

Personal care and cosmetic products contain plastic microbeads that can get released into the environment, when used, through wastewater streams. The share of plastic beads can be up to 10% of total product weight, for some products[172].

Commercial activities

Commercial activities cause the release of microplastics into the (marine) environment. For instance, microplastics can be released as a consequence of the manufacturing, processing, transport and recycling of plastic pellets. The release takes place due to small or large incidents along the plastic value chain[173]. Industrial laundry of synthetic textiles is also a source of microplastics[174].

Urban life

Cities can be a source of microplastics as they produce a series of dusts that contain plastics. These include losses from the abrasion of objects (synthetic soles of footwear, synthetic cooking utensils), the abrasion of infrastructure (household dust, city dust, artificial turfs, harbours and marina, building coating) as well as from the blasting of abrasives and intentional pouring (detergents). The individual contribution of each of these sources to microplastics is mall but taken together they are estimated to constitute around 24% of all microplastics released into the oceans[175].

[168] WWF (2022) Impacts of plastic pollution in the oceans on marine species, biodiversity and ecosystem. See: https://wwfint.awsassets.panda.org/downloads/wwf_impacts_of_plastic_pollution_on_biodiversity.pdf

[169] See footnote 165

[170] See footnote 165

[171] See footnote 165

[172] See footnote 165

[173] See footnote 165

[174] See footnote 165

[175] See footnote 165

2.3.3.7 *Introduction of radionuclides*

What is the pressure about and where is it found

Radionuclides are naturally present in the environment (for example, from granite rocks), but they can also be generated by anthropogenic sources. They can be released into the marine environment directly via global atmospheric fallout (e.g. in the case of nuclear weapons tests) or from discharge into rivers (e.g. when nuclear waste is released directly into the environment), or directly into the ocean as liquid waste or from dumped solid wastes[176].

Some radionuclides stay in the water in soluble form (i.e. dissolve into water), whereas others will be insoluble or adhere to particles[177]. Ocean currents further help these radionuclides travel to other areas of the oceans – so much so that reportedly "all waters, biota and sediments of the ocean all contain radioactivity"[178].

According to available studies, both naturally occurring radioactivity in the ocean and the nuclear sources of anthropogenic inputs of radioactive material are significantly concentrated in the northern hemisphere – with the North-East Atlantic registering the highest levels of concentration of radionuclides[179]. In terms of anthropogenic inputs, this is mainly related to the deposition following the Chernobyl accident in 1986. In the years following the accident, the contamination from the Baltic and North Seas spread into the North Atlantic and Arctic Oceans. In the southern parts of the Pacific, Indian and Atlantic Oceans, the concentrations of radionuclides are about 40 times lower than those found in the North-East Atlantic[180].

However, although the ocean contains most of the anthropogenic radionuclides released into the environment, the radiological impact of this contamination is low. Radiation doses from naturally occurring radionuclides in the marine environment (e.g. 210Po), are on the average two orders of magnitude higher[181].

Which human activities cause this pressure

Nuclear weapons testing and use

Historically, the main source of input of radionuclides in the marine environment has been nuclear weapons testing[182]. However, this has significantly decreased.

Nuclear energy production and reprocessing plants

Nuclear reprocessing plants are now the dominant source of anthropogenic radioactive inputs, together with nuclear power plants. Nuclear reprocessing plants are either currently operative or expected to become operational in the near future, in China, France, India, Russia and the

[176] IAEA (2005) Worldwide marine radioactivity studies (WOMARS): Radionuclide levels in oceans and seas. See: https://www-pub.iaea.org/MTCD/Publications/PDF/TE_1429_web.pdf

[177] Idem

[178] Idem

[179] Idem

[180] IAEA (2005) Worldwide marine radioactivity studies (WOMARS): Radionuclide levels in oceans and seas. See: https://www-pub.iaea.org/MTCD/Publications/PDF/TE_1429_web.pdf

[181] Idem

[182] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

UK. The nuclear reprocessing plants at Cap de la Hague and Sellafield continue to represent the dominant source of anthropogenic radioactive inputs to the North-East Atlantic, though there have been substantial reductions in the average discharges in the last years[183].

As of 2021, there were 439 operating nuclear reactors worldwide[184]. Total electrical generating capacity is expected to increase by about 30% by 2030, and to more than double by 2050 (compared to 2020 levels). Nuclear power plants are concentrated in about 30 countries worldwide, with the highest capacity being located in the United States, Europe and Asia[185].

Up to date information concerning the discharge of radionuclides into the environment is available only for nuclear power plants in the catchments of the Baltic and North-East Atlantic, and these show continuing reductions in the discharges. Notably, "the IAEA database on discharges of radionuclides to the atmosphere and the aquatic environment (information provided by national authorities on a voluntary basis) has not been updated since 2012, and much of the data in it are substantially older than that".

Nuclear incidents taking place in nuclear power plants, are also a source of input of radionuclides into the environment. The last major nuclear incident took place in Fukushima in 2011, and although traced of radionuclides have been found in US continental waters, the levels measured in Japan in the marine environment are considered "low and relatively stable"[186].

2.3.3.8 Introduction of air pollutants

What is the pressure about and where is it found

***Note**: This section is specifically about pollutants from shipping. Other air pollutants, and specifically organic air pollutants, are discussed in section 2.3.3.2 on eutrophication.*

Air pollutants include notably sulphur dioxide (SOx), nitrogen oxides (NOx) and particulate matter[187].

Besides emissions of SOx from industrial facilities, a main relevant source of air pollution is the combustion of marine fuel, in particular that with high sulphur content. When combined with water in the atmosphere, SOx forms sulphuric acid that is the main component of acid rain[188]. SOx and NOx are also present in the wash water released into the ocean by vessels that use scrubbers to clean the exhaust gas used[189]. Air pollutants can travel for thousands of kilometres before deposition and damage occur.

The deposition of these air pollutants, which are highly soluble, can be damaging to vegetation and water bodies and marine ecosystems. The deposition of sulphuric acid can also increase

[183] Idem

[184] https://www.iea.org/fuels-and-technologies/nuclear

[185] https://www.iaea.org/newscenter/news/iaea-releases-2019-data-on-nuclear-power-plants-operating-experience

[186] See footnote 182

[187] Raut et. al (2022) Impact of shipping emissions on air pollution and pollutant deposition over the Barents Sea. See: https://www.sciencedirect.com/science/article/pii/S026974912200046X

[188] Wankhede (2021) What is Sulphur Oxides or SOx air pollution from Ships? See: https://www.marineinsight.com/maritime-law/what-is-sulphur-oxides-or-sox-air-pollution-from-ships/

[189] Duliere *et at* (2020) Potential impact of wash water effluents from scrubbers on water acidification in the southern North Sea. See: https://www.researchgate.net/publication/341642158_Potential_impact_of_wash_water_effluents_from_scrubbers_on_water_acidification_in_the_southern_North_Sea

ocean acidity locally[190]. In particular, in areas with high vessel traffic density, such as the North Sea, the decrease in ocean pH attributable to SOx deposition can be higher than that from carbon dioxide emissions[191].

Which human activities cause this pressure

Shipping

The emissions of air pollutants from shipping depend on fuel use and efficiency of the vessel: different fuels have varying CO2, SOx, NOx and methane emissions, and inefficient ships use more fuel[192]. Total global annual NOx emissions from shipping have been estimated at about 19,000 kilotons (2013–2015), of which about 91% derives from international shipping, with the rest deriving from domestic shipping and fishing vessels (6% and 3%, respectively)[193]. For SOx, it was estimated that in 2014, 43% of the total anthropogenic emissions of SOx were from power plants, followed by industry (35%) and international shipping (16%)[194]. Notably, the contribution of shipping emissions increased from 6% 249 in 1960 to 16% in 2014[195].

Currently, developing countries are the main responsible for the anthropogenic emission of SOx (83% of total emissions – from all sectors), with India being one of the major emitters[196]. It has been reported that SOx emissions decreased by approximately 6% worldwide in 2019. Importantly, this happened in all top three countries with the greatest emissions: India, Russia and China[197].

With the volume of seaborne trade projected to rise in the future, the impact of this activity on air pollution is also projected to grow – if ambitious polices are not put in place.

2.3.4 Changes in water properties due to climate change

2.3.4.1 Pressures

Large-scale changes in water temperatures

Ocean warming is now a well-documented phenomenon and has been described thoroughly in the IPCC Fifth Assessment Report (AR5)[198] as well as its Special Report on Oceans and the Cryosphere in a Changing Climate. Recent measurements over the last decade confirm the warming trend of all the layers of

[190] Raut *et al* (2022) Impact of shipping emissions on air pollution and pollutant deposition over the Barents Sea. See: https://www.sciencedirect.com/science/article/pii/S026974912200046X

[191] Duliere *et at* (2020) Potential impact of wash water effluents from scrubbers on water acidification in the southern North Sea. See: https://www.researchgate.net/publication/341642158_Potential_impact_of_wash_water_effluents_from_scrubbers_on_water_acidification_in_the_southern_North_Sea

[192] Balcombe et al (2019) How to decarbonise international shipping: Options for fuels, technologies and policies.

[193] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[194] See: https://pubs.acs.org/doi/abs/10.1021/acs.est.9b07696

[195] Idem

[196] Zhong et al (2020) Global sulfur dioxide emissions and the driving forces.

[197] https://www.greenpeace.org/static/planet4-mena-stateless/a372e5fe-so2-report-english.pdf

[198] IPCC., (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

the oceans, and in particular the top layers (0-2,000 meters). In addition, it is indicated that it is likely that the deeper layers, the abyssal and deep seas, also experience the warming, and that the rate of ocean warming increases since 1993.

Ocean warming affects marine organisms by impacting the biogeography of organisms – from phytoplankton to marine mammals. For instance, warming-induced range expansion of tropical species to higher latitudes has led to increased grazing on some coral reefs, rocky reefs, seagrass meadows and epipelagic ecosystems, leading to altered ecosystem structure. It also impacts fisheries and ultimately has implications for food production and human communities and perturbs open ocean nutrient cycles. In addition, it leads to an increase of extreme weather events, detrimental effects and several other effects.

From our literature review, large-scale change in water temperatures is very commonly listed as a key pressure. For example, the 6th Status of Coral Reefs extensively describes the impact of ocean warming on coral reef ecosystems, more specifically in East Africa, South-East Asia, Australia and Central America seas. Ocean warming is also indicated as a worrying pressure in the assessment from the Artic Council.

Large-scale changes in salinity regime

Salinity is an important factor in determining many aspects of the chemistry of water and of biological processes within it.

Salinity is an important ecological factor because it influences the types of organisms that live in the environment. A change in the salinity balance leads to ecological stress of flora and fauna. In addition, the degree of salinity is a driver of the oceans' circulation. Density changes of waters due to both salinity and temperature changes at the surface of the oceans leads to changes in buoyancy which cause the sinking and rising of water masses. Therefore, changes in salinity of the oceans can have important consequences. For instance, as CO_2 is less soluble in more saline waters, the ability of oceans to store carbon dioxide could be hindered.

Changes in salinity regime was a pressure described in global assessments such as the SROCC or the Second World Ocean Assessment. From our literature review it was however difficult to find regional assessments mentioning this as a key pressure. It was listed in the reports from the Black Sea, the Red Sea, and the Mediterranean Sea, often described as a result of climate change.

Large-scale changes in sea level

Sea level rise occurs because of global warming. First, glaciers and ice sheets are melting and add water to the oceans. Second, as oceans' water temperature rises, the volume of the oceans expands in a process called ocean thermal expansion. To a lesser extent finally, a decline in the amount of water on land (i.e., in aquifers, lakes and reservoirs, rivers) is caused a by shift of liquid water from land to ocean due to groundwater pumping.

Sea level has been monitored consistently for multiple decades now at the global and regional levels. Since 1993, the global mean sea level has been rising at a mean rate of 3.1 ± 0.3 mm per year, with a clear acceleration of approximately 0.1 mm per year[199].

[199] World Climate Research Programme Global Sea Level Budget Group, 2018

Sea level rise has severe impacts on coastal ecosystems. These ecosystems are under stress from ocean warming, more frequent and intense extreme weather events and sea-level rise. In addition, these pressures are exacerbated by non-climatic pressures from human activities on ocean and land. It is shown that global wetland area has declined by nearly 50% relative to pre-industrial level. Moreover, inundation, coastline erosion and salinisation are causing inland shifts in plant species distributions, which has been accelerating in the last decades[200]. An important effect are also impacts on coastal communities which are subject to more severe flooding risk.

Sea level rise is a pressure that we found to be mentioned frequently in both global and regional assessments during our literature review.

Large-scale changes in currents

Major ocean currents play are important contributors to regulating climate and supporting marine life by transporting heat, carbon, oxygen, and nutrients throughout the world's oceans. However, global warming affects those currents by changing their course, slowing them down and weakening them, or otherwise influencing them. While monitoring of ocean currents is challenging, there is evidence of several of the major global currents changing; also, detailed climate models predict additional changes in the future. For example, the major current around the Antarctic, the Antarctic Circumpolar Current, is expected to move closer to the pole in the future and through this will lead to increased warming in the region, which in turn has effects on the ice shelves. [201]

Large-scale changes in pH

Ocean acidification (i.e., an increasing average marine acidity) is caused by the uptake of atmospheric CO2 by the ocean, which changes the chemical composition of the seawater. It is acknowledged in the 2030 Agenda (i.e. 14.3) as well as in the 'Aichi Biodiversity Targets' in Target 10.

Ocean surface pH declined from 8.2 to below 8.1 over the industrial era as a result of an increase in atmospheric CO^2 concentrations. This decline corresponds to an increase in oceanic acidity of about 30 %. In recent decades, ocean acidification has been occurring 100 times faster than during natural events over the past 55 million years.

Acidification can lead to several problems, including creating corrosive conditions for aragonite (a mineral present in the shells and skeletons of marine organisms), which also has ripple effects in the food web since aragonites are a crucial basis for it.

Changes in pH have happened globally. However, there are regional differences, and there is evidence that changes where more strongly pronounced in the North Atlantic, North Pacific, as well as the Southern Ocean.[202]

[200] IPCC (2019). Chapter 5 Changing Ocean, Marine Ecosystems, and Dependent Communities. In: The Ocean and Cryosphere in a Changing Climate A Special Report of the Intergovernmental Panel on Climate Change. See: https://www.ipcc.ch/srocc/

[201] Delorme, B., et al. (2017). Ocean Circulation and Climate: an Overview. See: https://www.ocean-climate.org/wp-content/uploads/2017/03/ocean-circulation-climate_ScientificNotes_Oct2016_BD_ppp-3.pdf

[202] See glodap data v2 here: https://www.glodap.info/

2.3.4.2 Which human activities cause this pressure

The main human activities leading to GHG emissions include energy supply (power generation), transport, buildings, industry, AFOLU[203], and waste; however, countless other activities also emit greenhouse gases (GHGs) and thus contribute to climate change[204].

3. Business case for improved international ocean governance

3.1 Introduction

This chapter provides the "business case" for improved international ocean governance.

To this end, two scenarios are assessed and then compared:

- Business as usual scenario
- Scaled up efforts scenario.

The scenarios are explained in more detailed in Appendix 1 to this report.

The scenarios are compared to a baseline, which is described in section 3.3

In short, the chapter assesses costs and damages/forgone benefits for all relevant ecosystem services, linking in the assessment how the pressures lead to state changes and qualitatively to changes in the ecosystem services provided to society. For some ecosystem services, not enough data could be identified to quantify and monetise those impacts; in those cases, the assessments have been done qualitatively. The value of abiotic flows and spatial functions have also been considered under these two scenarios where it has been possible.

Given the importance of the methodological approach that was chosen to this end, it is explained in more detailed in the following section, section 3.2.

3.2 An Ecosystem Accounting Approach

Marine and coastal ecosystems make a significant, or even crucial, contribution to human well-being and survival, and our global economy, and their condition can determine the extent to which goods and services are delivered.

Ecosystem accounting allows the contributions of ecosystems to society to be expressed in monetary terms so those contributions to society's well-being can be more easily compared to other common goods and services[205].

[203] Agriculture, Forestry, Other Land Use

[204] Blanco, G., et al. (2014). Drivers, Trends and Mitigation. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. See: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter5.pdf

[205] United Nations Statistical Commission, 2021. System of Environmental-Economic Accounting-Ecosystem Accounting. Final Draft (Vol. 3, Issue March). Available at: https://unstats.un.org

Several concepts and classifications of ecosystem services have been developed at the national, European and international level, such as the Mapping and Assessment of Ecosystem Service (MAES)[206], the Millennium Ecosystem Assessment (MEA)[207], The Economics of Ecosystems and Biodiversity (TEEB)[208] and the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES)[209]. There is thus no standardised framework, and as a result there is a plurality of interpretations in the meaning of ecological functions and services, eventually leading to difficulties when it comes to the usages and comparability of ecosystem services assessments at national and global scales.

In this study, and within the context of the DAPSI(W)R(M) framework, the System of Environmental-Economic Accounting - Ecosystem Accounting (SEEA EA)[210] is applied, adopted by the United Nations Statistical Commission (UNSC) in 2021, in order to in order to identify the ecosystem services, abiotic flows and spatial functions that are relevant to marine and coastal environments.

The SEEA EA is a spatially based integrated statistical framework for organising biophysical information about ecosystems, including tracking changes in ecosystem extent and condition, measuring and valuing ecosystem services, and linking these with measures of economic and human activity. Within this framework, ecosystem services are defined as the contributions of ecosystems to the benefits, such as goods and services, that are ultimately used by society.

These can be classified as:

- **Provisioning services**, representing the contributions to benefits that are extracted or harvested from ecosystems;
- **Regulating and maintenance services**, resulting from the ability of ecosystems to regulate biological processes and to influence climate, hydrological and biochemical cycles, and thereby maintain environmental conditions beneficial to individuals and society; and
- **Cultural services**, experiential and intangible services related to the perceived or actual qualities of ecosystems whose existence and functioning contributes to a range of cultural benefits.

There are a number of other benefits provided by marine ecosystems that are not underpinned by or reliant on ecological characteristics and processes, these are separately referred to as abiotic flows[211]. According to the United Nations (2021), abiotic flows are contributions to benefits from the environment that are not underpinned by or reliant on ecological characteristics and processes. These relate to the abstraction/extraction of abiotic resources from marine and coastal environments, for example the extraction of minerals and hydrocarbons, the generation of renewable energy, or the abstraction of water. In addition, marine ecosystems also support several spatial functions[212], also independent from ecological characteristics and processes. Spatial functions differ from ecosystem services and abiotic flows, and can be identified in three main types: i) the use of the environment (i.e. the ocean) for transportation purposes, ii) as the base for buildings and structures, and iii) as a sink for waste and pollutants.

[206] https://biodiversity.europa.eu/maes

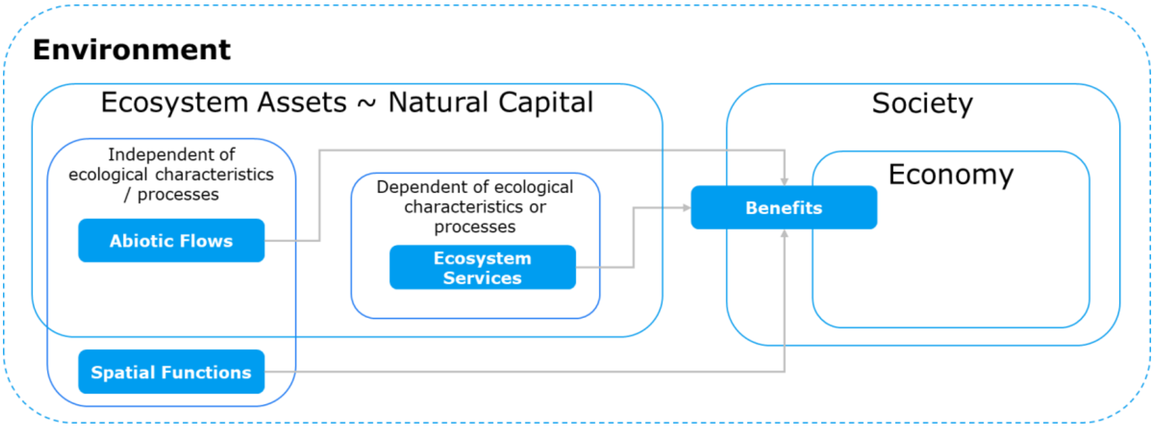
[207] https://www.millenniumassessment.org/en/index.html

[208] http://www.teebweb.org/

[209] https://www.ipbes.net/

[210] See: https://seea.un.org/ecosystem-accounting

Figure 3.1 Overview of the SEEA EA Framework



Source: Overview of concepts used in the SEEA EA framework, own illustration

As a first step to set up the framework for further analysis, the study has identified relevant ecosystem services, abiotic flows and spatial functions provided by the marine and coastal environment, using the list and associated descriptions for these provided by UNSC (2021) as a starting point.

Appendix 4 presents the list of ecosystem services, abiotic flows and spatial functions that were considered relevant for the study.

As a second step to set up the study framework, the study determined ecosystem types and/or components likely to influence the extent to which marine and coastal ecosystems can provide a given ecosystem service (note that this step is not relevant to abiotic flows or spatial functions). Ecosystem types and/or components are referred to as 'states' in the DAPSI(W)R(M) framework and are subject to changes due to the pressures described in the last chapters of the study. Changes in ecosystem services have the direct consequence of affecting, in a positive or in a negative way, the benefits that ecosystem services provide to society. This overview, together with an assessment of the nature of the interdependency between state changes and a given ecosystem service can be found in Appendix 5.

This chapter provides an overview of the current value of our oceans and how this could change under BAU and SUE scenarios, which have been quantified, where possible, to provide an indication of the minimum cost of inaction. The overview is based on individual economic assessments carried out in relation to relevant ecosystem services, abiotic flows and spatial functions identified, which use a wide range of socioeconomic and environmental indicators. Individual economic assessments are presented in Appendix 6 to this study.

It should be noted that only a selection of indicators have been used and that there are a number of intangible / non-market benefits that lack a comprehensive approach for valuation and any estimates should be considered non-exhaustive and subject to limitations and assumptions described in this section and in Appendix 6.

3.3 The Current Value of our Oceans

There are a number of studies / assessments that have attempted to estimate the value of marine and coastal ecosystems worldwide.

In 2015, WWF published a report that conservatively estimated the value of key ocean assets[213] to be at least US$24 trillion, with an annual value of goods and services estimated at US$2.5 trillion (which would have been equivalent to the 7th largest economy), noting that 70% of the annual value of ocean activity is dependent on the health of the ocean[214].

More recently, ocean-based industries were reported to contribute 3.5 – 7% of world gross domestic product[215].

The ocean also generates an increasing number of jobs. According to the World Bank, more than 350 million jobs are directly linked to marine resources such as fisheries, with ninety percent of those jobs coming from the developing world.[216]

The subsections below provide an overview of the current value of relevant ecosystem services, abiotic flows and spatial functions using a selection of monetary and non-monetary indicators reviewed as part of this study.

3.3.1 Provisioning Ecosystem Services

This study has explored three main provisioning services, i.e. wild fish provisioning (associated with commercial fisheries of specific species), aquaculture provisioning (associated with mariculture activities) and marine genetic material services.

Other provisioning services associated with marine and coastal ecosystems include those associated with subsistence fisheries or recreational fisheries; those associated with wood provisioning services, such as those provided by mangroves; and those associated with other marine organisms that also contribute to provisioning services, e.g. other fish species as well as marine algae or marine invertebrates, which are receiving increasing attention within the food industry and others. However, these were excluded due to an overall lack of appropriate data.

As further described in the Annexes, in 2019 it was estimated that the fisheries sector produced approximately 93.6 million tonnes of product, with almost half of this produced in Asia.

Two of the most commonly targeted fish species include tuna and sardine, and the 2020 economic value associated with the catches of selected subspecies of these two groups has been estimated at approximately €8.6 billion and €9.3 billion respectively.

Marine and coastal ecosystems also support the aquaculture industry, which traditionally has been developed as a land-based activity under more controlled conditions. Mariculture, i.e. aquaculture carried out in marine and coastal areas, is growing popularity to secure a source

[213] These estimates were based on direct outputs (fishing, aquaculture), services enabled (tourism, education), trade and transportation (coastal and oceanic shipping) and adjacent benefits (carbon sequestration, biotechnology), but did exclude outputs not generated by the ocean *per se*, such as offshore oil and gas or wind energy, or other more intangible / non-market outputs, such as those associated with regulatory and cultural services. In addition, less comprehensively documented economic activities, such as small-scale fisheries, which can have a significant importance to human well-being and play a key role in food security / poverty, particularly in underdeveloped coastal regions were also excluded

[214] Hoegh-Guldberg, O. et al. 2015. Reviving the Ocean Economy: the case for action - 2015. WWF International, Gland, Switzerland., Geneva, 60 pp. Available at: https://wwfint.awsassets.panda.org

[215] Konar, M., Ding, H., 2020. A sustainable ocean economy for 2050. Approximating its benefits and costs. Commissioned by High Level Panel for a Sustainable Ocean Economy.

[216] Patil, P.G., Virdin, J., Diez, S.M., Roberts, J., Singh, A. (2016). Toward A Blue Economy: A Promise for Sustainable Growth in the Caribbean; An Overview. The World Bank, Washington D.C

of protein for expanding populations[217], particularly in Asia; and produce a range of products for feed, fuel and raw material. Given that the latter applications are less common, this study has focused on mariculture dedicated to food production.

In 2020, the annual consumption of seafood from aquaculture was estimated at 9.87 kg per inhabitant on average, corresponding to approximately 18%[218] of protein-rich food consumed worldwide. The economic value of the sector globally was estimated at €245 billion globally in 2019. At European level, an average of 10.6 kg per inhabitant of seafood from aquaculture is consumed per year, and its economic value (based on its average selling price) has been estimated at €13 billion in 2020.

Regarding, marine genetic material services and their associated diversity, these do not only support the abundance and resilience of marine and coastal ecosystems and associated services, but also a number of commercial applications, including pharmaceutical, cosmeceutical and food and feed applications (other than for direct consumption). In 2020, it was estimated that approximately 24,000 marine natural products had been described to date, mainly sourced from marine invertebrates, marine algae and microorganisms.

Approximately 11% of marine genetic resources associated with patent applications are found in deep-sea and hydrothermal vent communities. The global market of marine biotechnology was estimated at €3.3 billion (approximately 1% of the wider biotechnology market), with medical and pharmaceutical applications considered to hold the largest share (approximately 25%). The benefits of marine genetic material services, however, extend beyond the successful development of a product and its economic commercialisation, as the development process leads to training opportunities promoting research and development activities, and building of biological repositories that can eventually feed into conservation policies and action, these are, however, difficult to monetise.

3.3.2 Regulation and Maintenance Ecosystem Services

This study has explored five main regulation and maintenance services, see below.

Other provisioning services associated with marine and coastal ecosystems include climate regulation services, including the influence of these environments on wind and rainfall patterns as well as local climate conditions; air filtration services, associated with the capacity of these ecosystems to filter and retain atmospheric pollutants; soil (seabed) quality and solid waste remediation regulation services associated with the role that certain organisms can have in the transformation or organic / inorganic substances in coastal soils / seabed sediments; noise attenuation services; or pollination services associated with biotic pollination (carried out by marine invertebrates, marine mammals or marine turtles among others) on which many coastal and marine ecosystems rely, such as seagrasses, see Appendix 6. However, these were excluded due to an overall lack of appropriate data and to minimise risks of double counting, as most regulation and maintenance services are closely interrelated.

Carbon sequestration services relate to the ability of coastal and marine ecosystems to capture and store carbon, also referred to as blue carbon, contributing to the mitigation of climate change effects. Capture rates depend on ecosystem type, extent and condition, and can range between 6 tg/year (deep sea) to 81 tg/year (estuaries). Based on the social cost of carbon, the

[217] Campbell, B. and Pauly, D., 2012. Mariculture: A global analysis of production trends since 1950. Marine Policy 39, 94-100. http://dx.doi.org/10.1016/j.marpol.2012.10.009

[218] 9.86 (kg / inhabitant) / 55 (kg / inhabitant)

current value of carbon sequestration services has been estimated at €115.6 billion considering both coastal and open ocean marine ecosystems.

Coastal protection services also depend on the condition and extent of certain coastal ecosystem types (namely mangroves, salt marshes and reefs) that contribute to wave and storm surge attenuation, as well as maintaining shoreline elevations, protecting human populations and associated assets. The value of coastal protection services afforded by, specifically, mangroves and coral reefs in 2018 was estimated at €500.7 billion (calculated as annual averted damages).

The role of coastal and marine ecosystems in sustaining populations of species and associated habitats, i.e. nursery populations and habitat maintenance services, has been argued to warrant separate consideration in ecosystem service assessments, although it is acknowledged that their monetisation as direct/indirect and non-use values is complex and aggregation with other service values must be carefully carried out to avoid double-counting. In 2021, the economic value of nursery services from coastal wetlands (tidal marsh, mangroves and saltwater wetlands) was estimated at €11,510 / ha / year. Of these ecosystem types, mangroves and salt marshes are the most predominant, and considering their global coverage in 2021 (approximately 192,344 km^2), their overall nursery value has been estimated at €221.4 billion.

Mangroves and salt marshes also play a key role in the retention and breakdown of organic pollutants, including excess nutrients and inorganic pollutant, i.e. waste remediation services, which have an estimated economic value of €175,250 / ha / year. Considering their current global coverage, as noted above, their overall waste remediation value has been estimated at €3,370.8 billion.

Biological control services also contribute to the maintenance of population dynamics and resilience through food web dynamics, disease and pest control. There is a significant number of examples of how different ecosystem components interact and regulate each other resulting in a number of economic and non-economic benefits / damages. For illustration purposes, in 2019 the economic damage of harmful algal blooms (HAB) on human health was estimated at €25.7 million globally.

3.3.3 Cultural Ecosystem Services

This study has explored two main cultural ecosystem services, including recreational (associated with the tourism industry) and non-recreational (associated with visual amenity services, spiritual, artistic and symbolic services, or education, scientific and research services).

Recreational cultural services are associated with ecosystem contributions that enable people to use and enjoy the environment. Coastal tourism is a component of this, associated with the ability of coastal and marine areas to attract visitors due to their beauty and recreational potential, as they support a number of activities, such as water-based sports or recreational fishing. It has been estimated that 80% of global tourism occurs in coastal areas. Within Europe, coastal tourism is the largest economic sector, employing more than 2.1 million people and being responsible for 40% of GVA in the Blue Economy. In 2020, the revenue associated with coastal tourism was estimated at €97.4 billion. Among other factors, coastal tourism is vulnerable to the condition of marine and coastal ecosystems that attract visitors, with plastic pollution considered as one of its biggest threats. In Europe, it has been estimated that the cost of plastic pollution could have reached $805.5 million in 2018, affecting a number of economic sectors, including coastal tourism.

Attempts to evaluate non-recreational cultural services from coastal and marine environments are limited and often argued to require location and context-specific assessments, challenging assessments undertaken at global level.

For illustration purposes, the economic value of non-recreational cultural services provided by coral reefs through aesthetic information and cognitive development have been estimated at €1.42 billion per year, based on the current estimated coverage of coral reefs in good condition across the globe.

3.3.4 Abiotic flows

This study has mainly explored abiotic flows associated with the extraction of minerals, abstraction of water and renewable energy generation.

Other abiotic flows associated with marine and coastal ecosystems that have not been considered in this study include the extraction of hydrocarbons.

As further described in the Annexes, the marine minerals extraction industry has historically targeted marine aggregates (estimated annual revenue of €0.9 – 2.8 billion), placer deposits, sulphur or salt (estimated annual production of 35 million tonnes) among others, with a focus on the more accessible nearshore areas (within depths of 50 m). In response to the growing demand of rare minerals, the industry is evolving into deeper areas, also referred to as deep sea mining (DSM), including within areas beyond national jurisdiction (ABNJ). However, only exploration licences have been granted to date, with no commercial activity currently ongoing.

Abstraction of water from the sea, especially for use in desalination processes, has become an essential source of freshwater / potable water in a number of coastal areas that suffer from water scarcity, or in support of a number of industrial / commercial processes. At present there are 15,906 operational desalination plants around the world with an estimated production capacity of 95.37 million m^3/day. The economic value of water abstraction from the sea is likely to differ regionally, and there are no global estimates available. For illustration purposes, the economic value of desalinated water in Israel associated with limiting water shortages was estimated at $4 per m^3.

Marine and coastal environments also offer an enormous opportunity to generate energy, particularly offshore. Marine renewable energy refers to any type of technology that uses the marine space to generate renewable energy, either from wind, wave and tidal action, or from temperature and salinity gradients. The current installed capacity of these technologies has been estimated at 23.5 GW. Employment generated by the sector was estimated at 1,255,494 jobs in 2020.

3.3.5 Spatial Functions

This study has mainly explored spatial functions associated with maritime transportation.

Other spatial functions associated with marine and coastal ecosystems that have been excluded in this study, include land reclamation from the sea, coastal developments, submarine infrastructure or use as a sink of waste.

Coastal and maritime areas are used as means of transportation and support a number of industries and activities, including maritime shipping (trade), cruise liners, military vessels, ferries, fishing boats, or recreational boats. Given the relative size of these sectors, focus has been given to maritime shipping, which is the backbone of international trade, contributing over 80% in volume of global trade (approximately 850.5 million twenty-foot equivalent unit in 2021). The sector currently generates $5.4 trillion in global economic activity but also has a significant environmental cost, including in relation to greenhouse gas (GHG) emissions that contribute to climate change effects. It has been estimated that the maritime shipping sector contributed over 0.646 GT of CO_2 in 2020 across the globe. Based on the social cost of carbon of €541.66 per tCO_2 used to estimate the economic value of carbon sequestration services (see Section 3.3.2), the current economic cost of CO_2 emissions associated with the sector could be estimated at €0.35 trillion.

3.4 The Benefits / Damages under a Business As Usual (BAU) Scenario

3.4.1 Provisioning Ecosystem Services

The three main provisioning services considered in this study directly depend on the condition (health and productivity) of marine and coastal ecosystems and the abundance of target species.

As further described in the Annexes, based on RAM Legacy Stock Assessment Database statistics, approximately 43.1% of fish stocks were overfished in 2019.

Under a BAU scenario, in which past and current trends continue into the future with no further intervention, it is estimated that the economic value of tuna and sardine fish stocks could reduce to €1.3 billion and €3.2 billion respectively in 2050. Biomass predictions also estimate that the stock of a number of sub-species could be depleted as early as 2026 (Sardine West Africa Zone C).

Regarding aquaculture provisioning, global trends indicate that consumption of seafood from mariculture has significantly increased over the last decades and would be expected to continue increasing. It has been estimated that consumption of seafood from mariculture in Europe could increase to an average of 12.43 kg / inhabitant (approximately 17% increase in comparison to 2019 estimates, see Section 3.3.1). This would not only result in an increased economic value provided by aquaculture services but also reduced reliance on other protein-rich food sources that can be considered to have higher environmental costs, including in relation to land use and carbon emissions associated with farming for meat production as well as environmental impacts from aquaculture.

Under a BAU scenario, exploitation of marine genetic resources is also anticipated to increase over time, with the global market for marine technology predicted to increase its value to €3.93 billion in 2026 (c. 20% increase in only six years). Longer-term trends are more difficult to predict, as bioprospecting for use in marine-derived products has a very low success rate. However, the exceptionally high biodiversity of coastal and marine ecosystems provides significant opportunities to discover new life forms and resources.

3.4.2 Regulation and Maintenance Ecosystem Services

Under a BAU scenario, historical trends of marine and coastal ecosystems loss and degradation would continue into the future, reducing the ability of these ecosystems to perform their carbon sequestration function. Given that degradation rates are only available for certain coastal ecosystems, i.e. mangrove, salt marshes and seagrass meadows, the social cost of carbon associated with these could reduce to €95 billion in 2050.

Similarly, should historical mangrove and coral reef loss and degradation rates continue into the future, their coastal protection function would also reduce, increasing vulnerability and exposure of coastal settlements. Accordingly, it is estimated that the value of coastal protection services provided by these two ecosystem types could reduce to €483.4 billion in 2050.

Nursery population and habitat maintenance services would also be affected by the gradual degradation and loss of coastal ecosystems, and considering the predicted global coverage of mangrove and salt marshes by 2050 (168,261 km^2), the associated value of nursery services would reduce to €194 billion in 2050. Similarly, the value of waste remediation services by these two ecosystem types would reduce to €2,995 billion in 2050.

Regarding biological control services associated with harmful algal blooms (HAB), historical trends often lack long-term observations and vary regionally so it has not been possible to predict how the economic damage of HAB on human health would evolve under a BAU scenario, other than assuming that these would, as a minimum, be maintained (€25.7 million / year).

3.4.3 Cultural Ecosystem Services

The economic value of recreational cultural services associated with coastal tourism is anticipated to grow by more than 3.5% by 2030 in Europe. The sector is expected to reach a value of between €197.9 and €321.4 billion in 2050. This would also result in increased costs associated with plastic management, estimated at a range between €10 and €30.1 billion in 2050.

Assuming coral reef coverage loss rates (6.8% per year) continue into the future, the economic value of non-recreational cultural services provided by coral reefs through aesthetic information and cognitive development could be reduced to €1.17 billion in 2050 across the globe.

3.4.4 Abiotic flows

Abiotic flows do not rely on ecological characteristics or processes, and therefore BAU scenarios can only be developed if there are historical trends of economic activity associated with them that can be used to make future predictions.

In relation to the extraction of marine minerals, there is no appropriate information at the global scale that allow for the prediction of how the economic value of marine aggregates or salt may evolve. These are activities that often take place within coastal areas / territorial sea jurisdictions and are generally managed under licences that are normally only granted if avoidance of potential significant effects on the environment can be proven. On the other hand, DSM has emerged as a potential means to meet the forecasted demand of certain minerals that are currently only sourced from land-based mining. A BAU scenario in which land-based mining is retained as the only source of certain minerals (copper, cobalt, nickel and lithium), and based on current estimates of known land reserves for these, it has been estimated that the global economy stands to lose $1.350 billion by 2040.

Abstraction of water from the sea is expected to increase in the future. No quantitative assessment could be conducted to estimate the monetary value of this service under a BAU scenario due to the lack of data. However, it has been estimated that the production capacity of desalination plants across the globe will likely reach 200 million m^3/day by 2030 and c. 285 million m^3/day by 2050.

Energy generation for marine renewable sources is expected to keep growing in the future, as barriers to technological development and consenting are overcome. The current pipeline for marine renewable projects indicates that installed capacity could reach up to 421 GW by 2050, a 17-fold increase from current capacity levels. The sector would therefore support an increased number of jobs across the globe, with estimates predicting 1.98 million jobs by 2050.

3.4.5 Spatial Functions

Under a BAU scenario, the volume of maritime trade is expected to continue growing in line with population growth and trends on consumption patterns. In 2026, this is estimated to achieve 957.7 million TEUs across the globe. GHG emissions associated with the sector are also forecasted to proportionally increase and would have reached an overall and cumulative contribution of 100 GT of CO_2 by 2075. Based on the social cost of carbon of €541.66 per tCO_2, the economic cost of CO_2 emissions associated with the sector would be estimated to increase to €54.1 trillion.

3.5 The Benefits / Damages under a Scaled Up Efforts (SUE) Scenario

3.5.1 Provisioning Ecosystem Services

As further described in the Annexes, a SUE scenario for wild fish provisioning ecosystem services would see the maximum sustainable yield (MSY) ratio achieved for all fish stocks by 2050, resulting in an estimated economic value of tuna and sardine fish stocks of €14.7 billion and €6.5 billion respectively in 2050.

Regarding aquaculture provisioning, and for illustration purposes only, a SUE scenario could see a gradual disinvestment in the meat production industry replaced by a growing mariculture industry aimed at becoming the main source of protein-rich food (e.g. replacement of protein sourced from meat by seafood from aquaculture at a 10% annual rate starting in 2025). Under this SUE scenario, the average consumption of seafood from mariculture in Europe could increase to 26.03 kg / inhabitant in 2050 and have an associated economic value of €26.9 billion. This scenario would also result in an even further reduction of environmental costs associated with farming for meat production, in comparison to the BAU scenario.

A SUE scenario for marine genetic material services would be the result of conservation measures being implemented to protect potential resources whilst reducing barriers to resource access and exploitation, e.g. through stronger partnerships and improved cooperation in ABNJ. The economic impact of this scenario is difficult to quantify, although it can be assumed that a strengthened international ocean governance that advocates for the sustainable exploitation of marine genetic material and promotes international cooperation, can only increase the potential future value of this market, not only in economic terms but in supporting a number of industries and technological advancement.

3.5.2 Regulation and Maintenance Ecosystem Services

A SUE scenario would see historical trends of marine and coastal ecosystems loss and degradation reversed. Assuming pre-1980s coverage for mangroves, salt marshes and seagrass meadows, the social cost of carbon associated with carbon sequestration services could reach €152 billion in 2050.

Similarly, achieving pre-1980 mangrove coverage globally, and maintaining the current coverage of coral reefs as a minimum, would assist in increasing the coastal protection function that these ecosystems perform, with their associated economic value estimated at €51.7 billion in 2050.

The SUE scenario defined for nursery population and habitat maintenance services would see the maintenance of existing mangrove / saltmarsh cover over time as a minimum, i.e. maintaining the current extent of 192,355 km^2 in 2050, and therefore maintaining their current value (€221.4 billion). Applying the same assumptions, the value of waste remediation services by these two ecosystem types would also maintain their current economic value of €3,370 billion in 2050.

A SUE scenario for harmful algal blooms (HAB) control, would see HAB still occurring in response to ecosystem dynamics but to a lesser extent due to water quality and ecological controls.

Accordingly, human health impacts would be avoided through improved health warning systems supported by strong international governance measures, which would reduce the economic damage of HAB on human health to €0 / year.

3.5.3 Cultural Ecosystem Services

Under a SUE in which governance measures would promote the redistribution of tourism to alleviate pressure in coastal areas, the cost associated with plastic management would be anticipated to reduce to a range between €9 and €23 billion in 2050.

A SUE scenario for coral reefs and the economic value of the non-recreational cultural services they provide through aesthetic information and cognitive development would assume that the current coverage of coral reefs across the global (and their current value €1.42 billion) is maintained as a minimum in 2050 through a number of appropriate management / governance strategies at different scales.

3.5.4 Abiotic flows

A SUE scenario would see international governance efforts dedicated to support / facilitate the sustainable development of deep-sea mining (DSM), i.e. which ensures the long-term sustain of marine environments, which could even gradually replace land-based mining for certain minerals. The economic value of this emerging sector has not been estimated by this study, but the role that DSM can play in securing certain minerals, especially rare earth elements (REE) is increasingly being recognised[219] as well as its potentially huge environmental impacts.

A SUE scenario could see both the demand of desalinated water reduced (as a result of fighting water scarcity through climate change mitigation measures) and more efficient and environment-friendly systems used in those regions that are likely to continue depending on abstraction of water from the sea. Economic estimates under a SUE scenario have not been made.

A SUE scenario could see international governance action scaling up the harnessing of marine renewable energy across the globe with the view of achieving climate neutrality goals by 2050. By 2050, marine renewable energy capacity could total 1,192 GW, dominated by offshore wind energy installed capacity (1,000 GW), an overall 51-fold increase from current capacty levels. The sector could also support approximately 3.2 million jobs worldwide.

3.5.5 Spatial Functions

Under a SUE scenario, the volume of maritime trade would be assumed to follow existing trends, as described in Section 3.4.5, but international governance efforts would focus on decarbonising the sector, aiming to reduce CO_2 emissions associated with maritime shipping by a 40% in 2030, 50% in 2050 and 100% in 2100. A maximum ambition scenario would see 100% Co2 reduction achieved by 2050. Based on the social cost of carbon of €541.66 per tCO_2, the economic cost of CO_2 emissions associated with the sector would be estimated to reduce to €15.2 and €21.6 trillion under a minimum and maximum ambition scenario respectively.

[219] Sakellariadou, F., Gonzalez, F.J., Hein, J.R., Rincón-Tomás, B., Arvanitidis, N. and Kuhn, T. 2022. Seabed mining and blue growth: exploring the potential of marine mineral deposits as a sustainable source of rare earth elements (MaREEs). IUPAC Technical Report. Pure and Applied Chemistry 94 (3). https://doi.org/10.1515/pac-2021-0325

3.6 The Cost of Inaction

The economic value of the oceans is produced by assets and services such as the generation of oxygen and the absorption of carbon, that rely directly on healthy ecosystems, where marine life can feed, grow and reproduce. Conserving habitat is crucial for the long-term viability of fish stocks and other biodiversity components which is necessary to maintain functioning ecosystems, and for much of the ocean productivity that generates economic value. [220]

International ocean governance can also play a key role in influencing / directing the way we obtain abiotic flows and use the marine space.

3.6.1 Provisioning Ecosystem Services

As further described in Appendix 6, although the SUE scenario for wild fish provisioning ecosystem services would result in reduction of the economic value of tuna and sardine subspecies stocks in the short-term, due to a reduction of fishing efforts to ensure MSY are achieved, this would also allow stocks to sustainably replenish and secure their availability in the long-term. It is estimated that the cost of inaction for selected subspecies of tuna and sardine stocks could be €13.4 billion and €3.3 billion respectively. This is based on species-specific fish stocks used directly for provisioning and does not take into account the cost of inaction that could result from imbalances in food webs and marine and coastal ecosystems resulting from fish stock depletion. The value of a sustainable fisheries sector goes beyond the economic revenue that can be secured and includes the nutritional needs that the sector helps to secure and a major source of livelihood for many Small Island Developing States (SIDS) and Coastal Least Developed Countries (CLDC)[221] (note that analysis in this study has focused on commercial fisheries only).

The cost of inaction associated with aquaculture provisioning services has not been estimated due to the complexity of defining a SUE scenario that maximises mariculture production in detriment of meat production. Although mariculture represents a number of environmental benefits in comparison to meat production, there are also a number of environmental costs associated with the sector and that would have to be factored into the comparison. Consideration of land-based aquaculture and the role it could play in helping to meet future protein demands have also been excluded from the analysis given the limited influence that ocean governance could have on this economic activity. New forms of mariculture, including integrated multi-tropic aquaculture and colocation with other marine activities, such as offshore wind farms[222] could also represent sustainable solutions for the sector that are under increasing consideration, and that international ocean governance could encourage and support.

Similarly, the cost of inaction associated with marine genetic material services has not been estimated. As noted in Section 3.5.1, without appropriate international governance actions in place, there is a risk of losing the economic benefits locked in marine genetic resources and their associated application in technological, pharmaceutical and medical industries to name a few that, overall, support advance and development across the globe.

[220] See footnote 214

[221] World Bank and United Nations Department of Economic and Social Affairs. 2017. The Potential of the Blue Economy: Increasing Long-term Benefits of the Sustainable Use of Marine Resources for Small Island Developing States and Coastal Least Developed Countries. World Bank, Washington DC

[222] Lounas, R., Kasmi, H., Chernai, S., Amarni, N., Ghebriout, L., Meslem-Haoui, N., Hamdi, B., 2020. Towards Sustainable Mariculture: some Global Trends. Thalassas: An International Journal of Marine Sciences 36 (1-4). DOI: 10.1007/s41208-020-00206-y

3.6.2 Regulation and Maintenance Ecosystem Services

The cost of inaction associated with carbon sequestration services could reach €57 billion in 2050 assuming that opportunities to restore selected coastal habitats (mangroves, salt marshes and seagrass meadows) to pre-1980s extent are missed.

Similarly, the cost of inaction from allowing historical mangrove and coral reef loss and degradation rates to continue into 2050 has been estimated at €51.7 billion, with mangrove being the main contributor to this estimate.

The cost of inaction on nursery population and habitat maintenance services associated with mangrove / salt marsh loss in extent has been estimated at €27.3 billion in 2050. Allowing mangrove and salt marsh to continue their degradation into the future would also result in a cost of inaction on waste remediation services estimated at €415.7 billion in 2050.

This is in line with other studies that analyse the benefits obtained from conserving and restoring certain coastal habitat types. For instance, it has separately been reported that for every $1 invested in mangrove conservation and restoration, a return of $3 can be secured[223].

Regarding biological control services, the cost of inaction associated with HAB control could reach €25.7 million per year, assuming that current annual costs continue at the same rate as a minimum.

3.6.3 Cultural Ecosystem Services

The cost of inaction resulting from allowing the tourism sector to continue targeting coastal areas in a non-sustainable manner could reach between € 1 – 7.1 billion only from costs associated with plastic management.

The cost of inaction affecting coral reef coverage and their role in providing non-recreational cultural services provided through aesthetic information and cognitive development has been estimated to reach up to €0.25 billion per year.

3.6.4 Abiotic flows

As noted, it has not been possible to estimate the potential future economic value of DSM or other mineral extraction activities. However, it is likely that the sector would likely continue to grow, , subject to success rates of exploration licences and international governance support. The cost of inaction associated with mineral extraction abiotic flows would be the result of missing the opportunity to sustainably exploit DSM resources, not only from a direct economic revenue perspective but also indirectly through associated technological advancement and job creation.

The cost of inaction associated with abstraction of water from the sea could see the demand and costs of freshwater / potable production growing, challenging their ongoing and increasing use across the globe with resultant consequences on agriculture and cities, particularly in underdeveloped countries. Due to an overall lack of data, no estimates for the cost of inaction have been made.

Marine renewable energy generation could play a significant role within the energy mix in the future and not only support the creation of a number of jobs worldwide, but also strengthening energy security and reducing reliance on non-renewable forms of energy generation, such as oil and gas; and therefore, contributing the reduction of the carbon and water footprint of

[223] See footnote 215

energy consumption worldwide[224]. The cost of inaction associated with allowing current trends continuing without scaling up efforts could result in missed opportunities to generate jobs, approximately 1,275,000; and missed opportunities to generate clean energy, approximately 771 GW. Given that the sector requires the use of marine space and construction of infrastructure in coastal and marine areas, appropriate site selection and environmental assessment procedures need to be fully implemented to ensure adverse effects on marine and coastal ecosystems are avoided or minimised and allow for the sustainable growth of the sector.

3.6.5 Spatial Functions

The cost of inaction associated with maintaining a maritime shipping sector that relies on traditional and non-renewable technologies would be significant in relation to the sector's contribution to CO_2 emissions across the globe which, on the basis of the social cost of carbon would be estimated at €32.5 and €39 trillion under a minimum and maximum ambition scenarios respectively. The decarbonisation of the sector would not only reduce the carbon footprint of maritime shipping activities but also help to reduce the emission of a number of other pollutants, such as NOx, PM2.5 or SO_2, contributing to the improvement of air quality from local (ports and nearby population centres) to global levels.

This is in line with separate studies that have considered the health benefits of decarbonising international shipping (with emissions reduced to net zero by 2050) estimated at $1.3 - $9.8 trillion over 30 years (2020-2050)[225].

4. Pathways towards improved international ocean governance

4.1 Introduction

This chapter proposes responses to reduce pressures.

To this end, for each human activity leading to the respective pressures, a number of responses are proposed. For each response information is provided on how it would work to address the problem, possible variations to the response (e.g., different technologies, different intensity of management), and information on the current baseline of the action.

It should be noted that no attempt was made to list the responses in order of significance, relevance, perceived effectiveness or other indicators, since in most cases such a ranking would not be feasible. As described in this section (and Appendix 7 in more detail), the right choice of response is often context-dependent and often a mix of responses would likely work best.

A more detailed description of all responses can be found in Appendix 7.

The Appendix also includes additional information per response, including on who stands to benefit and who stands to bear the cost, geographical distribution of costs and benefits, and the cost-effectiveness of each response.

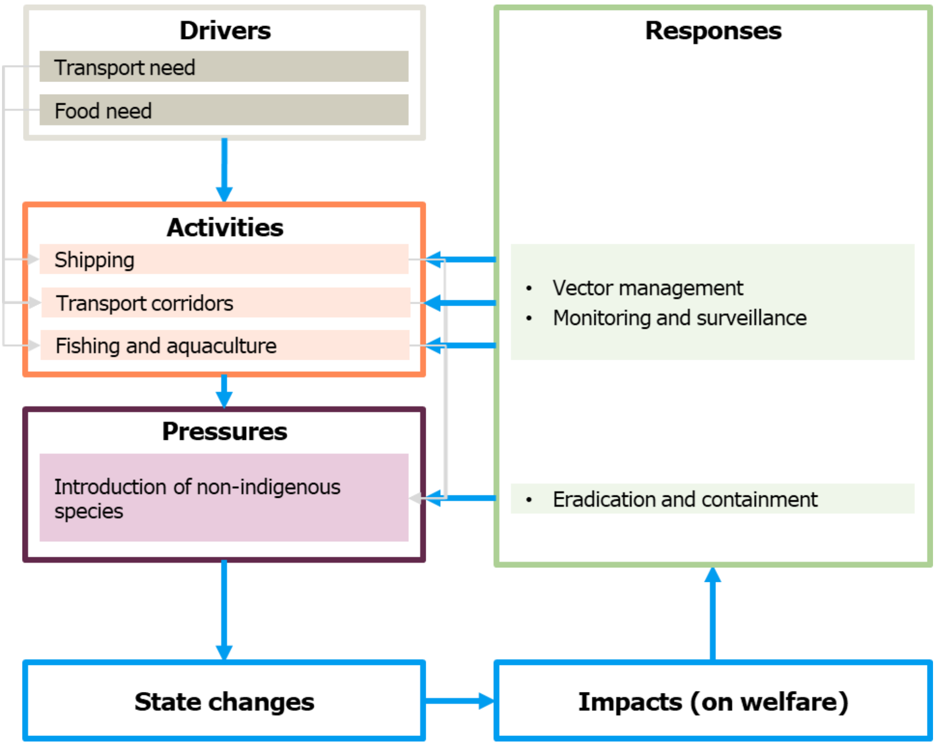
Finally, the Appendix also presents for each pressure a flowchart which summarises the human activities leading to the pressure as well as the possible responses. The Figure below is an

[224] See footnote 215

[225] See footnote 215

illustration of such a flowchart, on the example of the pressure "introduction of indigenous species".

Figure 4.1 Flowchart for the pressure including responses



Source: Own illustration

4.2 Biological pressures

4.2.1 Introduction of non-indigenous species

Vector management

Vector management is considered to be the most effective way to prevent the translocation of NIS[226], and various options are currently available. Technical measures can be applied on ships to prevent translocation through ballast water and hull fouling.

Instruments at the international level include international agreements such as the International Convention for the Control and Management of Ships' Ballast Water and Sediments[227], the Aichi Target 9[228] on putting measures in place to manage NIS pathways, as well as legally enforced measures under the Marine Strategy Framework Directive. However, besides the management of ballast water and sediments, there is an absence of a legally binding and strictly monitored framework regulating unintentional introductions from most pathways.

[226] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[227] Adopted in 1991, and entered into force in 2017.

[228] https://www.cbd.int/sp/targets/

Monitoring and surveillance

Information on non-indigenous species is "either very poorly documented or completely lacking" worldwide[229]. Since NIS can pose a significant threat for biodiversity and consequently for human well-being, there is a need to document and monitor this pressure to improve understanding of the distribution of such species and the potential mechanisms by which their range is extended, in order to propose appropriate and efficient responses. There is a need for validated, detailed georeferenced inventories of NIS accessible in searchable databases. Beyond this, improved documentation and monitoring of NIS could also facilitate early detection of introductions, which could be key to enable rapid eradication before the invasion becomes large scale.

Eradication and containment

Once the introduction of non-indigenous species has been verified, and classified as harmful, measures should be implemented to either eradicate or contain the population. "Unfortunately, these methods are often "futile" and ineffective once marine organisms becomes established[230], as these efforts are rarely successful. The economic value of damages produced by the spread of NIS has been documented in certain occasions. A study[231] found that the total invasion costs in the Mediterranean basin (particularly through the Suez Canal) amount to $27.3 billion, or $3.6 billion when only realised costs[232] were considered, and were found to have occurred over the last three decades.

Summary on costs and benefits

For all proposed responses, public authorities would face the main costs, albeit limited. For vector management, the international community could potentially bear the costs of implementing international legal instrument(s) and in those cases the industry (shipping, transport and fishing/aquaculture industries) might bear costs to implement vector management techniques and strategies.

The aquaculture and fishery industry would benefit from the reduction of NIS invasion: damages of these invasions on fisheries and aquaculture are substantial (average annual costs connected to NIS invasions have been estimated at $975.5 million for the period 1990-2017 – in the Mediterranean alone)[233].

Vector management and monitoring/surveillance can be considered fairly cost-effective; eradication and containment less so.

[229] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[230] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[231] https://neobiota.pensoft.net/article/58926/

[232] This refers to the actual occurred costs. Other costs are only potential or have not been realized yet as this would require more time.

[233] https://neobiota.pensoft.net/article/58926/

4.2.2 Extraction of wild fish species

Information campaigns to affect cultural practices

Some fish species continue to be fished due to their perceived medical properties and/or since they are considered a delicacy, such as deep sea species or shark fins, even though they are endangered.[234] One way to try and tackle ongoing illegal trade of those is to address demand through information campaigns to change cultural practices.

Such campaigns should be developed in the target regions to ensure that the respective local drivers, believes and practices are fully understood and thus can be addressed effectively.

Fishing at maximum sustainable yield

Maximum sustainable yield (MSY) is the maximum yield that may be taken year after year. It is characterized by a level of fishing mortality that will, on average, result in a stock size that produces the maximum sustainable yield over unlimited time. It is a long-term management system that focuses on obtaining the best from the productive potential of living marine resources, without compromising its use by future generations.

For an MSY to be implemented, data and models of fish stocks are needed. Also, the implementation needs to be enforced.

This response includes a) defining total allowable catch (TAC)[235] leading to MSY and monitoring for all commercially fished fish stocks (from the current 75%) and b) enforcing that TAC is followed for all fish stocks.

Reducing discards

While exact numbers are not available, it is assumed that global discard levels accounted for 11% of world catches[236]. Reducing or stopping the practice of discarding has large potential for supporting the sustainable exploitation of marine biological resources and marine ecosystems and the financial viability of fisheries: discarding is wasteful of the energy and cost used to catch the fish. It also represents a waste of wealth and resources, given the importance of fish as a source of protein[237]. Several responses (or combinations of responses) can be envisaged to reduce discards, including soft measures (e.g., awareness raising, training), technical responses (e.g. modifications to fishing gear or fishing practices), and legal responses such as

[234] Examples include Totoaba macdonaldi (Ong, E., Teng, C. (2022). A rapid assessment of online trade in sea cucumber and fish maw in Malaysia and Singapore. See: https://www.traffic.org/site/assets/files/16797/a_rapid_assessment_of_online_trade_in_sea_cucumber_and_fish_maw_in_malaysia_and_singapore_final.pdf) or different species of seahorses (see Rosa, I., et al (2013). Seahorses in Traditional Medicines: A Global Overview. See: https://www.researchgate.net/publication/278655134_Seahorses_in_Traditional_Medicines_A_Global_Overview)

[235] Total allowable catches (TACs), or fishing opportunities, are catch limits.

[236] FAO (2019). A third assessment of global marine fisheries discards. See: https://www.fao.org/responsible-fishing/resources/detail/en/c/1317018/

[237] Agnew, D. et al (2011). DRAFT FINAL REPORT Studies in the Field of the Common Fisheries Policy and Maritime Affairs. Lot 4: Impact Assessment Studies related to the CFP. Impact Assessment of Discard Reducing Policies. See: https://www.researchgate.net/profile/Sarah-Martin-73/publication/333421065_European_Commission_Studies_in_the_Field_of_the_Common_Fisheries_Policy_and_Maritime_Affairs_Lot_4_Impact_Assessment_Studies_related_to_the_CFP/links/5ced086a458515026a614845/European-Commission-Studies-in-the-Field-of-the-Common-Fisheries-Policy-and-Maritime-Affairs-Lot-4-Impact-Assessment-Studies-related-to-the-CFP.pdf?origin=publication_detail

discard bans or bycatch limits.[238] According to the World Ocean Assessment II report, at the global level progress is being made in policies and management measures for fighting discards[239].

Stop harmful subsidies

This response is in line with SDG14.6 which urges states to prohibit harmful fisheries subsidies. In 2018, annual world fishery subsidies were estimated to be around USD 35.4 billion, with a slight declining trend compared to past years[240].

Some subsidies in well-managed fisheries can be beneficial, such as investments in stock assessments. However, a major part of those subsidies are "capacity-enhancing subsidies" which are often harmful[241]. E.g., they can lead to increased- and overfishing. This, in turn, can lead to reduced profits and income for fishers and reduced amounts of fish for customers, and puts marine ecosystems at risk.[242]

The World Trade Organisation (WTO) fisheries subsidies negotiations are a lynchpin in working towards banning such capacity-enhancing subsidies. In June 2022, stemming from those negotiations, a first agreement was found which now needs to be further developed and implemented.

Fighting IUU fishing

In June 2016, the Agreement on Port State Measures to Prevent, Deter and Eliminate IUU Fishing[243], which was the first binding international agreement to target illegal, unreported or unregulated fishing specifically, entered into force. Stopping or reducing IUU fishing would contribute greatly to global efforts of maintaining fishing at sustainable levels. Currently, as of beginning of 2022, 73 countries are parties to the Agreement[244]. In some world regions there is limited progress in the implementation of international instruments aiming to combat IUU fishing and further emphasis should be put on global implementation

Summary on costs and benefits

Information campaigns can be considered very cost-effective; however, the effect is limited and thus the low cost mostly accounts for this.

For any response, more sustainable fishery management would lead in general to healthier stocks, leading ultimately to lower prices for customers because costs for fishers decrease.

National authorities would face costs for most responses, most notably for fishing at MSY level, reducing discards, and fighting IUU fishing. In the case of reducing harmful subsidies, public authorities would save the costs of providing the subsidies.

[238] UN (2021). Chapter 15 Changes in capture fisheries and harvesting of wild marine invertebrates. In: The Second World Ocean Assessment. See: https://www.un-ilibrary.org/content/books/9789216040062

[239] Idem

[240] Idem

[241] Sumaila, U., et al. (2019). Updated estimates and analysis of global fisheries subsidies. See: https://www.sciencedirect.com/science/article/pii/S0308597X19303677?via%3Dihub

[242] OECD (2018). Relative Effects of Fisheries Support Policies. See: https://www.oecd-ilibrary.org/agriculture-and-food/relative-effects-of-fisheries-support-policies_bd9b0dc3-en

[243] See: https://www.fao.org/port-state-measures/en/

[244] See https://www.fao.org/treaties/results/details/en/c/TRE-000003/ for a detailed and updated overview. Accessed on 11 Jan 2022.

The fishing industry would greatly benefit from most responses; however, this is time dependant. While it can be assumed that the introduction of the responses can lead to reduced income of the fleet in the short-term, in the mid-to long-term it is expected that they reduce costs and increase profits for the fishing industry, as the amount of effort (and associated costs, such as fuel) required per tonne of fish caught decreases. Due to this, and the general benefits for society, all measures can be considered cost-effective.

4.2.3 Death or injury of wild species by collision

Collision monitoring and awareness

Data is crucial to assess the risk of collision as well as to design appropriate mitigation measures to reduce it. Collision risk assessments require information on animal and vessel distribution patterns, installation location as well on specific vessel and installation-specific factors (e.g. size and speed) and animal-related factors (e.g., time spent at or near the surface and behavioural response to vessels)[245]. For vessels-related collisions, data and information systems can be developed to alert mariners that they are entering areas with high density of animals prone to collisions, to inform them of recent animal sightings, as well as to gather data on vessel abundance and distribution, or vessels compliance with mitigation measures. These systems include Mandatory Ship Reporting, Early Warning Systems[246]. It can take a considerable amount of time to compose and distribute internationally relevant data.

Local efforts to educate mariners on the risk of collision with a specific species or within a specific area are a faster way to create awareness and help mitigate collisions in local hotspots. Education is the fundamental basis for the implementation of mitigation measures and for compliance with regulations. Dissuasive sanctions can also be an instrument to raise awareness and attention to this issue.

Collision prevention – spatial measures

For vessel collision, re-routing measures can be implemented to avoid areas where greatest collision risk has been identified. Rerouting vessel traffic is considered to be an effective mitigation measure to reduce collision risk with whales: when compliance is high, the risk can be reduced by 60-95%[247]. Vessel traffic exclusion zones can also be established to reduce the risk of collision. This measure involves the reduction of the number of vessels in a given area[248]. Spatial measures can also be introduced to reduce collision risk with offshore installations. In particular, it is effective to avoid building offshore installations in areas of high animal abundance, especially where threatened species or species particularly prone to collision are present. Siting decisions are taken in the planning phase, and therefore do not represent a possible preventative measure in most cases[249].

[245] https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[246] https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[247] https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[248] https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[249] https://docs.wind-watch.org/marques2014.pdf

Collision prevention - speed restrictions

Vessel speed reductions can be introduced to provide animals and vessel crew with more time to detect and avoid each other, as well as to reduce the severity of the injury. Studies have found that that the probability of lethal injury decreased to <50% when vessels travelled at speeds ≤ 10 knots.

Collision prevention - technical measures

Technical measures can be applied to vessels, to reduce the risk of collision[250], including:

- Installing deterrent devices, such as devices that emit acoustic signals;
- Installing propeller guards, such as cages and ducts that act a physical boundary between the propeller blades and an animal;
- Installing systems to enable early detection of animals, such as Passive Acoustic Buoy Systems, Real Time Plotting of Cetaceans (REPCET), Mobile Phone Alerting Systems;

Early animal detection onboard the vessel can also be implemented by identifying a dedicated observer t onboard the ship hat has been trained to detect and identify marine animals.

Technical measures to reduce collision risk and impact can be taken on offshore installations.

Other measures include habitat modification techniques, such as vegetation management (i.e. the modification of underwater flora) or the creation of alternative feeding areas. The selection of the measures, as well as the resulting effectiveness in preventing or reducing collision risk, is highly dependent on the context: the type of threatened species, the location as well as the type of installation or vessel involved.

Summary on costs and benefits

Cost-effectiveness of those measures is difficult to gauge and very depended on the collision risk and is also damage dependent.

4.2.4 Introduction of microbial pathogens

Prevention is considered as the only effective measure to address the introduction of microbial pathogens in the oceans. This is because once established, the spread of these pathogens is difficult to control and eradicate, and it can have devastating effects. For instance, when pathogens are spread in aquaculture and fisheries, stock losses can be up to 100%. For example, the spread of Bonamia ostreae and Marteilia refringens drastically reduced European production of cultured flat oysters (Ostrea edulis) from 29,595 t in 1961 to 5,921 t in 2000. "Between 1980 and 1983 alone, estimated losses in France included a 20% reduction of employment within the industry, US$ 240 million turn-over, and US$ 200 million of added value"[251].

Wastewater treatment

Microbial pathogens found in wastewater generally derive from the intestinal tract in human faeces and are associated with waterborne diseases such as diarrhoea, cholera, and dysentery. Other sources are industrial waste from food production, particularly from animal processing,

[250] https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[251] Georgiades et al (2021) The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges.

that can also be a source of pathogenic microorganisms[252]. When this water is discharged untreated into water bodies, it can travel in the oceans.

Wastewater can be treated to remove pathogenic microorganisms.

No complete overview of applying standards for microbial pathogens removal from wastewater in all world regions could be identified. However, wastewater treatment in general is a challenge in certain world regions, and this can provide an indication of the magnitude of the problem. As shown in previous chapters, around 44% of household wastewater is not safely treated worldwide[253], and over 80% of wastewater is released into the environment without adequate treatment[254].

Ballast water and fouling control

Ballast water and hull fouling can be controlled or treated, to eliminate the microbial pathogens that colonise them, or to avoid colonisation in the first place.

Improve understanding of (micro)plastics as a vector

(Micro)plastics have only recently been identified as a potential vector of microbial pathogens. As such, there are critical knowledge gaps that need to be filled. For instance, research on factors that promote bacterial attachment to (micro)plastics, as well as factors that promote antibiotic resistance of pathogens found on (micro)plastics. The implications on the aquaculture sector, as well as human health and marine life in general also need to be better understood[255].

An improved understanding is the first step to developing tailor-made responses to manage this vector of microbial pathogens. The could for instance lead to the conclusion that the reduction of the use of (micro)plastics and recycling are key preventative actions to limit the introduction of microbial pathogens in the oceans.

Summary on costs and benefits

Wastewater treatment in general is expensive[256], both in terms of CAPEX (Capital Expenditure) and OPEX (Operating Expense) and it is important that locally adapted systems are selected, considering aspects such as cost-effectiveness, long-term sustainability, and availability of space. For this response the general society would bear the costs by refinancing CAPEX and OPEX through tariffs. The shipping industry would face costs for ballast water and fouling control. All responses can be considered to be very cost-effective, given the large damages that can be avoided.

[252] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7126130/

[253] https://www.unwater.org/app/uploads/2021/12/SDG-6-Summary-Progress-Update-2021_Version-July-2021a.pdf

[254] http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/

[255] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[256] For example, total annual costs for wastewater treatment in the EU are estimated at around EUR 18 billion. See: SWD(2019) 700 final PART 1/2 COMMISSION STAFF WORKING DOCUMENT EVALUATION of the Council Directive 91/271/EEC of 21 May 1991, concerning urban waste-water treatment. https://ec.europa.eu/environment/water/water-urbanwaste/pdf/UWWTD%20Evaluation%20SWD%20448-701%20web.pdf

4.3 Physical pressures

4.3.1 Seabed abrasion

Stop (deep)seabed mining

The impacts of seabed mining are not well understood to date, in particular when it comes to mining in the deep seabed. The scientific community however indicates that this activity risks to cause irreversible damage, in particular on deep-sea ecosystems[257]. An option to prevent this risk, could be to stop (deep) seabed exploration and mineral extraction. Notably, in the case of seabed mining, commercial exploitation has not started yet[258].

Enforce precaution and improve understanding

Additional research is required to better understand the extent to which deep-sea mining could lead to environmental problems and how they best could be avoided. In the waiting of evidence concerning these impacts, the precautionary principle should be widely adopted and adequately enforced when it comes to permitting of (deep)seabed mining. It has been argued[259] that the ISA has not been implementing the precautionary principle and related protective measures in practice, in that it "continued to grant exploration contracts in areas around vulnerable ecosystems without assessing the potential impacts"; that it has "not yet given effect to preservation reference zones or utilised safety margins in the form of quotas"; and that "the ISA is at present unprepared to deal with environmental emergencies". The implementation of all aspects of the precautionary principle could be further strengthened by the ISA and the members of the international community.

Ban bottom trawling in MPAs

Bottom trawling, and in particular certain techniques within it, are recognised as major pressures for the seabed, and it is also practiced within Marine Protected Areas[260]. One of the possible responses to consider addressing this issue is establishing a permanent ban on bottom trawling i.e. to prohibit all types of bottom trawling in a specific area, such as MPAs (that are established for other reasons, for instance to protect biodiversity etc.)[261]. Different NGOs in Europe have called for the ban of these practices in MPAs[262]. A study[263] showed that banning mobile bottom-contact fishing gear (trawls and dredges) across EU MPAs is cost-effective in the long term (though many uncertainties persist in the assessment). The costs of implementing the ban outweigh the benefits (e.g. in terms of ecosystem services) in terms of annual net

[257] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[258] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[259] A. L. Jaeckel (2017) The International Seabed Authority and the Precautionary Principle. Chapter 6: Implementing the Precautionary Principle: Protective Measures. See: https://brill.com/view/title/33967

[260] https://seas-at-risk.org/wp-content/uploads/2021/05/Valuing-impacts-of-potential-ban-on-bottom-contact-fishing_NEF_-FINAL-for-publication.pdf

[261] Evidence shows that 59% of the 727 EU MPAs designated in 2017 still permit trawling and that trawl fishing effort within these sites was 46% higher than outside the MPAs.

[262] https://act.wemove.eu/campaigns/bottom-trawling?utm_campaign=bottomtrawling&utm_medium=video&utm_source=partners

[263] https://seas-at-risk.org/wp-content/uploads/2021/05/Valuing-impacts-of-potential-ban-on-bottom-contact-fishing_NEF_-FINAL-for-publication.pdf

impact for the first two years but starting from year three onwards there is an annual net benefit, which rises sharply up to year 5, as the ecosystem service impacts become increasingly more pronounced. The benefits for many of the ecosystem services increase until year 13, where the habitat reaches a theoretical maximum of annual ecosystem service value. For the period between year 13 and year 20, they record an average annual cost benefit ratio for a potential ban on bottom-contact fishing in MPAs of €3.41 returned for every €1 spent[264].

Manage and restrict bottom trawling

According to ICES, "some level of bottom trawl fishing can be compatible with achieving seabed conservation objectives"[265]. For this to happen, a series of conditions need to be satisfied. For instance, it would be important to determine thresholds beyond which continued bottom trawling will have adverse effects[266].

Management of bottom trawling includes different measures, including technical measures (e.g. improved gear design and gear switching), effort and spatial control and impact quotas (i.e. establish specific maximum quotas for extraction through bottom trawling). Spatial control measures are considered to be the most effective for the biogeochemical functioning of the seabed[267] and this involves no-take zones and no-trawl zones i.e. effort and spatial controls that can involve the closing of certain areas to bottom trawling. These can be most trawled areas, as well as least trawled areas. It is considered that "intensively bottom trawled areas are where the largest impact reduction is realized when they are closed, but the cost to the fishery is often large. Closing lightly trawled areas may cost the fishery very little but can also be perceived as having little improvement because so little of the fishing effort, and the resulting impact, is removed"[268].

Summary on costs and benefits

There are large uncertainties around the response of stopping deep sea mining since this can be considered a transformative change.

For all responses public authorities and the industry would face limited costs.

Precaution and understanding can be considered highly cost-effective, despite potentially high budgets for additional research such costs are nevertheless highly cost-effective, given the novel nature of deep-sea mining activities and the major unknowns regarding effects on marine ecosystems.

[264] New Economics Foundation (2021) Valuing the impact of a potential ban on bottom-contact fishing in EU Marine Protected Areas.

[265] https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

[266] https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

[267] McConnaughey et al. (2020), cited in ICES. See: https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

[268] McConnaughey et al. (2020), cited in ICES. See: https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

4.4 Pollution pressures

4.4.1 Introduction of underwater noise

Anthropogenic underwater noise is not persistent in the marine environment and ceases once the sources that cause it are removed. For this reason, measures to stop and mitigate the production and transmission of this noise can have "near-immediate, positive effects"[269]. In general, considering the uncertainties relating to the impacts of underwater noise, the application of a precautionary approach to the management of impacts is advised[270].

Noise mitigation via technological solutions

Technological solutions can be implemented to reduce the noise produced by different human activities. In this context, it is considered easier to foster noise reduction of activities that produce sound unintentionally (e.g. shipping, construction) rather than intentionally (e.g. seismic surveys or military activities)[271].

For instance, different design features of ships can be adapted to reduce sources of underwater noise, such as propellers, hull form and on-board machinery. The implementation of such solutions can be expensive, because of high material and maintenance costs[272]. In 2014, the IMO adopted Guidelines for the reduction of underwater noise for shipping[273], which are currently under review[274].

For other sources of underwater noise (e.g. offshore energy and construction) rapid advances in noise-dampening technology have been registered[275].

For emerging activities, such as deep-seabed mining, regulators and technology developers should take underwater noise into consideration for future developments at an early stage and investigate options that would reduce noise levels stemming from this activity[276].

Temporal and spatial restrictions

Temporal and spatial restrictions to the human activities that produce underwater noise can be applied and can be particularly relevant when the mitigation of the noise source via technological means is more challenging[277].

[269] https://www.science.org/doi/10.1126/science.aba4658

[270] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[271] See: https://www.science.org/doi/10.1126/science.aba4658

[272] See: https://www.marineboard.eu/publications/addressing-underwater-noise-europe-current-state-knowledge-and-future-priorities

[273] See: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/833%20Guidance%20on%20reducing%20underwater%20noise%20from%20commercial%20shipping,.pdf

[274] See: https://www.imo.org/en/MediaCentre/HotTopics/Pages/Noise.aspx#:~:text=Noise%20on%20ships&text=IMO%20adopted%2C%20in%202012%2C%20a,noise%20levels%20on%20board%20ships.

[275] See: https://www.science.org/doi/10.1126/science.aba4658

[276] See: https://www.science.org/doi/10.1126/science.aba4658

[277] See: https://www.marineboard.eu/publications/addressing-underwater-noise-europe-current-state-knowledge-and-future-priorities

For shipping, this can entail regulating vessel speed to reduce noise, as well as re-routing, to divert impacts away from biologically sensitive areas. For instance, it has been proven that "reducing steaming speeds for noisy vessels in the major shipping route(s) in the eastern Mediterranean from 15.6 to 13.8 knots led to an estimated 50% reduction in the broadband noise from these vessels between 2007 and 2013[278].

For other sources (e.g. offshore energy and oil and gas exploration), these measure could entail the prohibition of construction or operation in areas that are deemed to be particularly sensitive to underwater noise impacts, as well as time limits for the undertaking of noisy operations as well as using techniques such as bubble curtains. Mitigation zones can also be established around sound sources.

Summary on costs and benefits

Public authorities would likely incur limited costs for the process of putting new legislation and measures into place. It is likely that the main costs would be borne by the shipping industry as well as other relevant industries (such as offshore). Both responses can be considered somewhat cost-effective.

4.4.2 Introduction of substances leading to eutrophication

It should be noted that many national and international policies[279] are in place to address the reduction of nutrient releases; however, as mentioned in the report, it appears that those efforts are not sufficient as recent trends are still increasing[280].

Reduce nutrient emissions from agriculture

Reducing nutrient runoff from agricultural areas would reduce eutrophication in coastal waters since less nutrients would be transported.

There are two main strategies that can be pursued to this end which can be understood as being at two different ends of an effort spectrum: one the one hand this includes better management of nutrients within current agricultural practices, and on the other hand a structural change of the agro-food system, limiting the use and load of fertilisers in agricultural practice.

Better nutrient management can be achieved through a number of practices, including planting of catch crops preventing bare soils outside main growing seasons, creation of buffer strips, more strategic fertilising, minimizing tillage to reduce erosion and runoff, or practices such as contour tillage. However, in areas with high use of fertilisers the application of such responses alone might not be sufficient to reduce input of nutrients into marine waters to levels that do not lead to eutrophication.[281]

Structural changes of the agro-food system include, in addition to significant changes in agricultural practices which include significant reduction of fertiliser use (e.g., turning towards de-intensified and organic farming), also changes to human diet towards more vegetal and less

[278] See: https://www.science.org/doi/10.1126/science.aba4658

[279] This includes for example in the EU the Nitrates Directive or the Marine Strategy Framework Directive, in the USA the Clean Water Act, and countless others.

[280] GESAMP (2018). Global Pollution Trends: Coastal Ecosystem Assessment for the Past Century. See: http://www.gesamp.org/publications/global-pollution-trends-coastal-ecosystem-assessment-for-the-past-century

[281] Desmit, X., et. Al (2018). Reducing marine eutrophication may require a paradigmatic change. Science of the Total Environment. See: https://www.sciencedirect.com/science/article/pii/S0048969718313603

animal-based diet (also taking into account that eutrophication is also often observed in regions with high density of animal husbandry).

Improve design and management of finfish aquaculture

Environmental impacts from aquaculture in marine waters such as eutrophication can be reduced through a wide range of techniques which can reduce the input of nutrients into water.

Those techniques could e.g., include waste recycling, biofloc technology[282], improved selection of aquaculture sites, use of use of efficient feeding systems and good quality feed types or others.[283] [284]

Despite the existence of such technologies, however, finfish aquaculture is still among the leading causes of marine eutrophication.

Reduce emissions from combustion of fossil fuels

For both power generation and transport, there are in general two main strategies for reducing the emissions which are summarised in the Table below.

Table 4.1 Overview of general responses

	Power generation	Transport
Technical solutions for reducing emissions	*Implementation of better technologies to reduce emissions from fossil fuel power plants.*	*Implementation of better technologies to reduce emissions from fossil fuel vehicles.*
Paradigm change	*Moving away from fossil fuels in power generation and fully towards other energy sources such as renewable energies.*	*Phasing out vehicles using fossil fuels and fully moving towards other technologies.*

Treatment of wastewater

Treatment of household wastewater can be highly effective in reducing nutrient discharges into the environment since it is a point-source pollution which can be relatively well contained.

Well-proven and effective technologies exist for the treatment of household wastewater which can broadly categorised as treatment plants to which wastewater is transported through sewers and/or other means, and individual and other appropriate systems (IAS), which are waste water

[282] Biofloc is suspended material in the water column, constituted by microorganisms, micro- and macroinvertebrates, filamentous organisms, exocellular polymers, faeces and uneaten feed.

[283] Braña, C., et al. (2021). Towards Environmental Sustainability in Marine Finfish Aquaculture. See: https://www.frontiersin.org/articles/10.3389/fmars.2021.666662/full

[284] Jeffrey, K., et al. (2014). Background information for sustainable aquaculture development, addressing environmental protection in particular: Sustainable Aquaculture Development in the context of the Water Framework Directive and the Marine Strategy Framework Directive. See: https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp?FormPrincipal:_idcl=FormPrincipal:_id1&FormPrincipal_SUBMIT=1&id=24623b37-8a0d-47f3-9ebb-b63dc5e37a70&javax.faces.ViewState=RczvK8qUmMBKhPYHvS%2B%2FeFl7ckXuQuFIIO1xQMh7lmKYdmD%2Fh2lMMuNAU%2FvkM904y4HNrsgdIwLqHdvfec2EeAzabEjgbYstaYMIbqQyQh6eGKExM2MbzhzoK4XnmODGMw9bo1blGm8TKRkK6v%2FWGmrlZPU%3D

treatment systems for one or a few households. Also, solutions can vary between technologically very advanced solutions (e.g. with several treatment steps) or extensive, such as pond systems or constructed wetland systems. In developing countries, extensive technologies are generating interest as they require fewer human resources and less energy consumption than intensive systems.

However, currently only 56 % of household wastewater flows are safely treated (2020 numbers). The regions with the lowest shares of safely treated household wastewater include Central and Southern Asia (25%), Sub-Saharan Africa (28%), and the regions with the highest shares Northern America and Europe (80%) and Australia and New Zealand (79%)[285].

Summary on costs and benefits

Large changes to agriculture as well as a phasing out of fossil fuels from transport and power generation would all be transformative changes for which it is challenging cost-effectiveness. However, it should be borne in mind that, besides reducing eutrophication (which is one of the key pressures that the oceans face), they would also contribute to limiting other societal challenges such as climate change and air pollution.

Improving the design and management of finish aquaculture can be considered cost-effective, given the large impact of the sector and the relatively easy implementation of such measures. Also for the treatment of wastewater, despite the high costs this can be considered very cost-effective, given that treatment is very effective in reducing pollutions from this point-source pollution. Also, other considerable benefits are attached to better wastewater treatment, such as avoiding health-issues and deaths from polluted water.

4.4.3 Introduction of inorganic pollutants

Reduce emissions from combustion of fossil fuel

The discussion on the responses is similar to the ones presented for reducing emissions from combustion of fossil fuels under the section on eutrophication (see above).

In general, there are two main pathways for reducing the emissions, technical solutions for reducing emissions from fossil fuel power plants, and a paradigm change away from fossil fuels and towards other sources of energy.

Several technologies and process optimisations are available to reduce heavy metal emissions from fossil fuel combustion power plants.[286]

For technical solutions for reducing emissions from power generation, experience has shown that a regulatory framework setting strict legally binding emission limit values can be a strong driver for reducing emissions and that the necessary technologies are available, e.g. in the EU, NOx emissions from those sources have decreased by 60% between 2004 and 2019.[287] Also

[285] UN (2020). Progress on Wastewater Treatment – 2021 Update. See: https://www.unwater.org/publications/progress-on-wastewater-treatment-631-2021-update/

[286] See e.g. chapter 10.2.1 in JRC (2017). Best Available Techniques (BAT). Reference Document for Large Combustion Plants. See: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC_107769_LCPBref_2017.pdf

[287] EEA indicator "Emissions and energy use in large combustion plants in Europe". See: https://www.eea.europa.eu/ims/emissions-and-energy-use-in

other regions implemented ambitious emission reduction strategies, such as China leading to a decrease of NOx emissions by 60% between 2014 and 2017[288].

A paradigm shift in electricity generation towards other energy sources such as renewable energies would lead to a full reduction of heavy metal reductions from this sector, besides other positive benefits (such as reduction of GHG and reduction of emission of substances leading to eutrophication).

Treatment of wastewater

Several technologies are available for removing heavy metals from wastewater during the treatment process. The effectiveness of this depends also on the treatment processes in place; e.g., there is good potential for removing heavy metals through primary[289] treatment[290] while a more complete removal can be achieved through tertiary treatment[291] which is, however, also the costliest due to the additional steps.

Heavy metals do not degrade and thus they will mostly accumulate in either the sludge (i.e., the residual material consisting of the solid residuals) or some remaining parts of it in the discharged treated water. The effectiveness of the removal of heavy metals is important since sludge is often used as fertiliser in agriculture due to its high percentage of nutrients while the most common option for reuse of water is for irrigation and landscaping[292].

Reduce emissions from land-based mining

A wide range of techniques exist that can avoid heavy metal emissions into waterbodies. This includes remediation techniques remove heavy metals from soils, from mine wastewaters (see also above), and from waterbodies. The techniques can be either physical, chemical, or biological[293].

As mentioned, small-scale gold mining plays a special role since it is one e of the global main sources of mercury atmospheric emissions. To remedy this, alternative techniques could be applied which do not rely on mercury in the process of extracting gold from ores. One technique suggested in a 2018 EEA report on mercury[294] and based on a Danish study uses borax instead of mercury, is simple and does not require specialist equipment or expertise and takes approximately the same amount of time as the mercury method, besides other benefits.[295]

[288] Tang, L., et al. (2019). Substantial emission reductions from Chinese power plants after the introduction of ultra-low emissions standards. See: https://www.nature.com/articles/s41560-019-0468-1

[289] Primary treatment removes litter and suspended solids by mechanical means; additional steps in secondary treatment degrade organic material through micro-organisms; tertiary treatment adds steps for further purification of wastewater.

[290] Sylwan, I., et al. (2021). Removal of Heavy Metals during Primary Treatment of Municipal Wastewater and Possibilities of Enhanced Removal: A Review. See: https://www.mdpi.com/2073-4441/13/8/1121

[291] Gerba, C., et al. (2019). Chapter 22 Municipal Wastewater Treatment. In: Environmental and Pollution Science (Third Edition). See: https://www.sciencedirect.com/science/article/pii/B9780128147191000227

[292] See footnote 290

[293] See e.g. here for a recent overview: Karn, R., et al. (2021). A review on heavy metal contamination at mining sites and remedial techniques. See: https://iopscience.iop.org/article/10.1088/1755-1315/796/1/012013

[294] EEA (2018). Mercury in Europe's environment. A priority for European and global action. See: https://www.eea.europa.eu/publications/mercury-in-europe-s-environment

[295] Appel, P., et al. (2014). Mercury-free gold extraction using borax for small-scale gold miners. See: https://www.researchgate.net/publication/276495769_Mercury-Free_Gold_Extraction_Using_Borax_for_Small-Scale_Gold_Miners

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Reduce dependency on land-based mining

As mentioned above, mining is done to the extract valuable materials from the Earth. Currently, several of the mined materials (e.g., metals or cement) are land-filled at the end-of-life of the products they were used in (e.g. electronic devices or houses) and thus new raw-materials need to be mined in order to manufacture new products.

Circular economy approaches have enormous potential of reducing this need for raw materials by promoting recycling and reuse of those materials instead of landfilling them.

Get better understanding about the impacts from deep-sea mining

As mentioned, there still seems to be limited understanding about the potential release of pollutants such as heavy metals from deep-sea mining activities we well as their impact on specific ecosystems.

Thus, additional research would be required to better understand the extent to which deep-sea mining could lead to environmental problems and how they best could be avoided.

Remediation of heavy metals in the oceans

If despite efforts to heavy metal stop emissions they still are transported into the oceans, there are a range of approaches that can be used to remedy those pollutants.

Those approaches, however, can only be applied effectively in heavily polluted and limited areas. Also, they should be seen as least priority solution and possibly for the remediation of legacy waste dumping sites in the marine environment. Higher priority should be given to the solutions discussed above focusing on avoiding heavy metal pollution in the first place.

Summary on costs and benefits

Also here, the cost-effectiveness of transformative approaches such as the phasing out of combustion of fossil fuels or the move towards a more circular economy are challenging to assess but there are important co=benefits besides for reduction of heavy metals which needs to be considered.

4.4.4 Oil spills

Oil phase out

Reducing reliance on oil as a fuel, or oil phase out, would reduce the likelihood of oil spills into the environment, as less oil extraction and shipping activities would be undertaken. Reducing the reliance on oil is in line with the commitments made by all signatories to the Paris Agreement as well as the subsequent Glasgow Pact, and namely the commitment to align their long-term climate change mitigation efforts with limiting global temperature increases to within 2°C of pre-industrialisation levels, pursue efforts to limit the increase to 1.5°C, and to achieve a balance between emissions of GHGs from sources and the removal of GHGs from the atmosphere by sinks by the second half of this century. It is challenging to quantify the costs and benefits of the implementation of this response. Available projections estimate that the investments needed to transform the global energy system to achieve net zero emissions in 2050 would require a large expansion in investments, as well a shift in what capital is spent on. Investments in energy could go from "USD 2 trillion globally on average over the last five years to almost USD 5 trillion by 2030 and to USD 4.5 trillion by 2050"[296], though the benefits of this are well known.

Proactive oil spill prevention

"Once oil is spilled there are no good outcomes, and every response technology involves trade-offs."[297] The most effective response to oil spills is their prevention.

The implementation of prevention legislation, including regulations regarding the use of oil tankers, has been effective in reducing the incidence of oil spills, in particular from ships, as these have substantially decreased over time, from about 79 oil spills per year, on average in the 1970s, to around 5 oil spills per year in the last decade[298].

Response preparedness

Contingency planning is crucial when it comes to oil spills. In this field, the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC)[299] provides a global framework for international co-operation in combating major incidents or threats of marine pollution related to oil. Parties to the Convention are required to establish measures for dealing with pollution incidents, either nationally or in co-operation with other countries. Although it is known that 117 states have ratified OPRC, no comprehensive overview of the national contingency plans developed worldwide by signatory countries is available[300], nor an assessment of their effectiveness for oil spill response. Obtaining an overview of the status quo could be useful to identify and address potential gaps in response preparedness.

Clean up and restoration

Clean up following an oil spill can involve both mechanical and manual techniques. The main types of clean-up techniques involve the use of booms, skimmers, sorbents, chemical dispersants, in-situ burning and bioremediation[301]. Notably, no solution completely removes the oil from the marine ecosystem, and even in the best-case scenario, only 40 per cent of oil from a spill can be cleaned up by mechanical means. Moreover, the potential negative impacts of chemical dispersants in the long-run are still being studied[302]. The ability of natural recovery to restore the environment can play an important role, and actions to enhance its effectiveness needs to be considered[303].

[296] https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

[297] https://response.restoration.noaa.gov/about/media/what-have-we-learned-about-using-dispersants-during-next-big-oil-spill.html

[298] https://www.itopf.org/knowledge-resources/data-statistics/statistics/

[299] https://www.imo.org/en/About/Conventions/Pages/International-Convention-on-Oil-Pollution-Preparedness,-Response-and-Co-operation-(OPRC).aspx

[300] A scattered overview of the adoption of National Contingency Action Plans is provided by the Global Initiative, and related regional programmes. See: https://www.ipieca.org/our-work/nature/oil-spill-preparedness-and-response/the-global-initiative/

[301] https://www.witpress.com/Secure/elibrary/papers/WRM07/WRM07049FU1.pdf

[302] https://response.restoration.noaa.gov/about/media/what-have-we-learned-about-using-dispersants-during-next-big-oil-spill.html

[303] https://www.unep.org/news-and-stories/story/how-manage-damage-oil-spills

Summary on costs and benefits

The responses can be considered cost-effective with two exceptions. The phasing-out of oil is a transformative change that is difficult to assess. On the other hand, clean up and remediation can be considered to be not cost-effective due to the limited effectiveness and the high costs.

4.4.5 Introduction of marine litter

As a general consideration, in relations to all proposed policy responses listed below, it can be said that managing marine litter requires both a local and transboundary approach and the collaboration of a broad variety of stakeholders involved in the whole value chain leading to the leakage of litter into the oceans. Multilateral cooperation is particularly needed because marine litter travels across regions.

To this end it should also be mentioned that in March 2022 resolution 5/14 "End Plastic Pollution: towards an international legally binding instrument" by the United Nations Environment Assembly was adopted which sets out a mandate for negotiations by an Intergovernmental Negotiating Committee for an international legally binding instrument on plastic pollution, including in the marine environment.

Improve resource efficiency and product design

Despite the growing attention that marine litter is gaining in the public eye, in general, plastics manufacturers, and manufacturers of products that incorporate plastics have little incentives for designing products with end-of-life management in mind. They rather focus on product performance, and in fact the number of polymer types and structures continue to grow. Also, the recyclability of plastics is sometimes hindered by factors such as the widespread use of chemical additives and the growing complexity of many plastic-containing products[304].

The improvement of resource efficiency through the plastics (and other wastes) lifecycle, including through improved product design is considered key to reduce the among of marine litter that ends up in the oceans. The reduce-recycle-reuse paradigm is key in this sense. This involves limiting the use of plastics to applications where there are few environmentally preferable alternatives, by ensuring that the plastics that are produced remain in use for as long as possible, and by recovering a greater share of plastics at their end of life – including following circular economy principles[305]. For sea-based sources of litter, this could mean designing fishing gear to reduce partial loss or producing them with bio-degradable materials, as well as designing vessels in a way that reduces discarding of gear or other marine litter[306].

Fisheries management measures

Given the diversity of sources of sea-based marine litter, as well as the nature and scale of the problem, addressing this issue demands a wide array of approaches, besides resource efficiency and product design improvements. For instance, measures aimed at regulating the way fishing and shipping activities can be implemented. For fishing gear, these measures can include: reductions in fishing effort and capacity control in specific areas, as "the less gear that is being used, the less gear there is to lose"; spatial and temporal fisheries management measures e.g. gear use limits in; fishing gear marking and tracking requirements, linked to gear loss reporting

[304] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

[305] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

[306] GESAMP (2021) Sea-Based sources of marine litter.

system to increase accountability, as well as to improve recording and reporting of gear loss; rewards for gear stewardship e.g. financial incentives for returning end-of-life gear[307]. Enforcement, including community-supported enforcement can be critical for the success of these kinds of measures.

Improve waste management (incl. port reception facilities)

To date, plastics recycling continues to be an "economically marginal activity". Recycling rates are thought to be 14–18% at the global level, with some regional variations[308]. This is substantially lower than those for other widely used materials such as steel, aluminium copper, whose recycling rate is thought to be around 50%. The remainder of plastic waste is either incinerated (24%) or disposed of in landfills or the natural environment (58–62%). In light of this, the development of better waste management systems could significantly reduce the amount of (plastic) waste that leaks into the oceans[309].

Reportedly, there are insufficient infrastructures and policies for recycling, or for wastewater and solid waste management to date[310].

Improve knowledge and monitoring

The World Ocean Assessment II highlighted that in many countries, the lack of national and regional monitoring of marine litter is a major bottleneck for addressing the issue and for assessing the effectiveness of measures already taken[311]. This concern is reflected in other publications by NGOs[312], which recall that there is no global system in place to provide independent and scientifically-based effectiveness evaluations of the numerous initiatives out there – thereby increasing uncertainty with regards to their effectiveness.

Clean up and remediation

Clean up and remediation activities include beach clean ups and the use of technology to collect plastics from oceans. Clean up and remediation activities vary in scale, going from community-led beach litter collections to larger ocean cleaning systems. These aim to remove plastics already in the natural environment, and "can be a potentially important way of addressing the legacy plastics that are already in the ocean", though their cost effectiveness and applicability to certain types of plastics remain uncertain[313]. Data and information about existing clean up technologies already on the market or in the process of being marketed is very limited, including concerning their impact on litter reduction.

[307] GESAMP (2021) Sea-Based sources of marine litter.

[308] Recycling rates in low to middle-income countries are largely unknown, but may be significant in situations where there is a well-established and effective informal sector. Data from Wilson et al. indicates that plastics recycling rates may be approaching 20 – 40% in some developing-country cities. From OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

[309] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

[310] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[311] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[312] WWF (2020) The business case for a UN treaty on plastic pollution.

[313] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

Awareness raising

The leaking of marine litter and microplastics is also linked to unstainable patterns of consumption and production. Awareness raising campaigns, implemented at different levels, could have a beneficial effect[314] in that they would foster the reduction in plastics demand (and the demand of other items that generate marine litter), and therefore a reduction in the potential waste generation. The education, awareness-raising and involvement of stakeholders across sectors is considered crucial to reduce the leakage of sea-based marine litter as well[315].

Beyond awareness raising campaigns, market signals can be effective in promoting a shift in consumer behaviour. As consumers are increasingly willing to pay more for eco-friendly products (e.g. 72% of global consumers are willing to pay up to 10% more for eco-friendly packaging)[316], these economic incentives could prove effective in fostering more sustainable forms of consumption.

Summary on costs and benefits

National authorities would likely face costs for most responses, given the legislative efforts involved. Also industries would face costs but there is potential from the "Improve resource efficiency and product design" for industries since this might reduce production cost. All responses can be considered very cost-effective expect except clean up and remediation.

4.4.6 Introduction of microplastics

Awareness raising

As for marine litter, awareness raising can be important to help reduce microplastics leakage into the environment (see related chapter under marine litter). This should tackle specifically actions to foster sustainable consumption patterns for the main sources of microplastics, e.g. textiles, care products and tyres.

Improve resource efficiency and product design

Addressing microplastics pollution requires a life-cycle approach, aimed at reducing the quantity of plastic used for producing specific commodities, as well as the amount of plastic released during their use or maintenance[317]. This also includes the use of alternative materials or recycled materials. The implementation of these measures will be particularly important in those countries where waste management adequate, but their? per-capita release of microplastics is still higher than the global average[318].

[314] UNEP, WRI (2020) Tackling plastic pollution: Legislative Guide for the Regulation of Single-Use Plastic Products

[315] GESAMP (2021) Sea-Based sources of marine litter.

[316] WWF (2020) The business case for a UN treaty on plastic pollution.

[317] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

[318] Idem

Improve waste and wastewater management

In some regions of the world, such as India and South Asia, China and Middle East, per capita losses of microplastics are lower than global average, but a larger share of microplastics is released into the environment (compared to other areas of the world, where per capita losses are larger than global average) because they have large populations – and a low percentage of this population is connected to wastewater treatment systems e.g. 6.2% of population in India and South Asia[319]. Therefore, though they produce less microplastics per se, the rate of release is higher due to the low level of connection to adequate wastewater treatment systems.

Improving waste management is key to preventing the release of microplastics into the environment, in particular in reasons where plastics releases are dominated by mismanaged wastes.

Improve knowledge and monitoring

Knowledge and monitoring of the issue of microplastics is scarce, and major gaps in knowledge still exist – in particular in relations to the fate and effects of microplastics, as well as solutions to address this pressure. According to the World Ocean Assessment II, these relate mainly to: quantification of microplastics in the marine environment, information on how plastic degrades in various components of the marine environment, presence and impact of microplastics, roles of plastic debris as a transport vector of pathogens.

Clean up and remediation

Biodegradation is currently being explored as a possible remediation measure to eliminate microplastics from the oceans. This involves the use of certain types of bacteria and microbes that can degrade certain types of plastics. These microbes can be harnessed in an environmentally safe way, and they could be applied to the treatment of sewage wastewater, as well as for the remediation of contaminated environments[320].These solutions are however at their infancy and still experimented at the laboratory scale, therefore considerable further research and development are needed to make it suitable for large scale application[321].

Summary on costs and benefits

All responses can be considered very cost-effective with two exceptions. Firstly, clean up and remediation is not considered cost-effective due to its high cost and limited effectiveness as well as potential environmental impacts. Secondly, high costs are connected to the implementation of wastewater treatment solutions that can detect microplastics and reduce their input into the environment which affects the cost-effectiveness. Thus, additional research is needed to assess cost-effectiveness of these measure – which is likely to be determined by the type of technique implemented.

4.4.7 Introduction of radionuclides

As introduction to this section, it should be mentioned that, although the ocean contains most of the anthropogenic radionuclides released into the environment, the radiological impact of

[319] Idem

[320] Auta et al (2017) Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solution.

[321] https://pubs.acs.org/doi/pdf/10.1021/acsomega.9b00222

this contamination is low. Radiation doses from naturally occurring radionuclides in the marine environment (e.g., 210Po), are on the average two orders of magnitude higher[322]

Nuclear energy phase out

Discharges from nuclear reprocessing plants as well as nuclear power plants are the main source of input of radionuclides into the environment nowadays. This includes accidental discharges due to large-scale incidents[323]. An option to significantly reduce and virtually eliminate the risk that these discharges take place is to phase out nuclear energy.

Improve compliance with international safety standards

Safety standards aimed at ensuring nuclear safety and security in all activities handling radionuclides already exist, as hosted by the International Atomic Energy Agency (IAEA)[324]. The organisations and people responsible for developing these activities have the prime responsibility for nuclear safety, and regulating safety is a national responsibility. Given that radiation risk transcends national borders, international cooperation on this matter is necessary[325]. Existing safety standards and requirements include standards on how to safely operate nuclear power plants, research reactors, fuel cycle facilities, radioactive waste disposal facilities and transport of radioactive material[326].

Given the virtually irreversible consequences of the discharge of radioactive material into the environment, global compliance with these standards is of the utmost importance. Compliance with the existing standards could be improved. As reported by the IAEA[327], 81% of Member States Agency's Radiation Safety Information Management System are making good or substantial progress in strengthening their radiation safety regulatory infrastructure, but there is still a 19% of states that are making low progress and need further technical support for establishing and developing a sustainable regulatory framework for radiation safety.

Improve monitoring

The World Ocean Assessment II indicates that the available records of level of "committed effective doses to humans of radioactivity from food from the sea are less than a quarter of the IAEA recommended annual limit for the exposure of the general public to ionizing radiation", and that there is no evidence suggesting any significant change as of today. The report informs that "provided that adequate monitoring is maintained" developments in the input of radionuclides, based on current knowledge, "are not likely to be of concern"[328].

[322] IAEA (2005) Worldwide marine radioactivity studies (WOMARS): Radionuclide levels in oceans and seas. See: https://www-pub.iaea.org/MTCD/Publications/PDF/TE_1429_web.pdf

[323] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[324] https://www.iaea.org/resources/safety-standards

[325] https://www.iaea.org/resources/safety-standards

[326] For a complete overview of existing safety standards, please visit: http://ns-files.iaea.org/standards/safety-standards-wheel-poster.pdf

[327] https://www.iaea.org/sites/default/files/gc/gc64-inf3.pdf

[328] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

Data of discharges of radionuclides into the marine environment is only publicly available for the North-East Atlantic, as monitored by OSPAR. Little to no data on such discharges in other areas of the world is available[329].

Summary on costs and benefits

The phasing out of nuclear energy would be a transformative change that is hard to assess in terms of cost effectiveness. The other two responses can be considered cost-effective. However, this should be seen in the context of how devastating one single incident in this field can be.

4.4.8 Introduction of air pollutants

Reduce emissions (shipping)

The international (and national) legislative framework regulating the emissions of air pollutants from ships aim to stimulate the adoption of less environmentally damaging practices and "encourage" either investment in innovative abatement technologies or the employment of alternative fuels in the shipping industry[330]. In particular, the international framework established by IMO, focuses on the establishment of caps for SOx, NOx and particular matter content in marine fuels, as well on the institution of minimum energy efficiency levels (in terms of grammes of CO2 per capacity mile) for different types of ships. The main pieces of legislation adopted by IMO that regulate emissions from shipping are outlined in the table below[331]. Most of the ship-owning countries, and all of the major ship-owning economies, are part to these international agreements. As some of the key requirements of these legislations have come into force only recently, their effectiveness is largely described in terms of projections.

Notably, to comply with the comply with Annex VI limits, ship operators and owners can switch to fuel oil with lower sulphur content, or they can high sulphur content by using technical means that reduce atmospheric SOx emissions to a level equivalent to the required fuel oil sulphur limit. This involves the use of "scrubbers", which clean exhaust gas of the SOx with water, and then discharge the wash water directly into the marine environment.

It is expected that the implementation of the current legislative framework will lead to a reduction of SOx emissions, but that CO2 and NOx emissions could increase if no *additional* regulations are adopted[332].

4.5 Changes in water properties due to climate change

As mentioned in the last chapter, the main human activities leading to GHG emissions include energy supply (power generation), transport, buildings, industry, AFOLU[333], and waste;

[329] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[330] https://www.emerald.com/insight/content/doi/10.1108/MABR-08-2018-0030/full/pdf?title=targeting-the-reduction-of-shipping-emissions-to-air-a-global-review-and-taxonomy-of-policies-incentives-and-measures

[331] For a comprehensive overview of other policy instruments addressing air pollution from ships, at both the global and national level, see: https://www.emerald.com/insight/content/doi/10.1108/MABR-08-2018-0030/full/pdf?title=targeting-the-reduction-of-shipping-emissions-to-air-a-global-review-and-taxonomy-of-policies-incentives-and-measures

[332] IIASA (2018) The potential for cost-effective air emission reductions from international shipping through designation of further Emission Control Areas in EU waters with focus on the Mediterranean Sea. Available at: https://previous.iiasa.ac.at/web/home/research/researchPrograms/air/Shipping_emissions_reductions_main.pdf

[333] Agriculture, Forestry, Other Land Use

however, countless other activities also emit greenhouse gases (GHGs) and thus contribute to climate change[334].

This in turn contributes significantly to all the pressures listed in this chapter, namely:

- Large-scale changes in water temperatures
- Large-scale changes in salinity regime
- Large-scale changes in sea level
- Large-scale changes in currents
- Large-scale changes in pH

Thus, those activities are not discussed separately for all pressures.

As can be seen, across all those sectors, wide-reaching and transformative changes are needed to reach the limits agreed on in the Paris Agreement and the Glasgow Pact. Under the Paris Agreement all countries – both developed and developing – are obliged to contribute towards the Agreement's ambitious goals to prevent of dangerous anthropogenic interference with the Earth's climate system. Consequently, all signatory Party countries are obliged to align their long-term climate change mitigation efforts with limiting global temperature increases to within 2°C of pre-industrialisation levels, pursue efforts to limit the increase to 1.5°C, and to achieve a balance between emissions of GHGs from sources and the removal of GHGs from the atmosphere by sinks by the second half of this century. This last goal is widely referred to as 'net-zero emissions' or 'carbon neutrality'.

Those required sectorial changes are well documented and not the focus of this report and thus not discussed in detail.

The costs of such required changes are very challenging to estimate. Part of the Paris Agreement was that developed countries USD 100 billion per year in climate finance by 2020 and agreed to continue mobilising finance at this level until 2025. However, it should be noted that the 2020 goal by 2020 has not been met[335] and also that according to the IPCC, several trillion USD would be needed in the energy sector alone for reaching the agreed targets[336].

5. Conclusions

This report brings together a plethora of information about the oceans. It lines out the pressures faced by the oceans, the activities leading to them, their effects on the health and productivity of the oceans, responses on how to alleviate the pressures – and, how society stands to benefit from those responses.

[334] Blanco, G., et al. (2014). Drivers, Trends and Mitigation. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. See: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter5.pdf

[335] UN (2020). DELIVERING ON THE $100 BILLION CLIMATE FINANCE COMMITMENT AND TRANSFORMING CLIMATE FINANCE. INDEPENDENT EXPERT GROUP ON CLIMATE FINANCE. See: https://www.un.org/sites/un2.un.org/files/100_billion_climate_finance_report.pdf

[336] Coninck, E., et al. (2018): Strengthening and Implementing the Global Response. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]

Each of those different discussions entails considerable complexities which make general findings challenging to reach. However, several key conclusions can nevertheless be drawn.

Pressures

Ranking

In terms of pressures, it does not seem to be possible to do a global ranking of the most urgent and relevant pressures since each pressure has its local dimensions. However, some pressures seem more relevant than others and are discussed more widely in the literature. This includes for example marine litter, introduction of substances leading to eutrophication, and extraction of fish species. Those three pressures were the ones most frequently discussed in the assessed sea-basin reports as well as very frequently in other literature. Also, those topics are very much present in the public consciousness. The two least mentioned pressures, on the other hand, are "death and injury of wild species by collision" as well as "introduction of microbial pathogens".

While this seems to point that at a stronger relevance of some pressures, it should be also kept in mind that those with fewer mentions are harder to measure or to see which can by itself create dynamics. For example, inorganic pollutants (or heavy metal pollutants in the case of this report) seem to be a major problem in several sea basins while at the same time there is less awareness in the general population about this than for example marine litter which is highly visible. This could potentially lead to an over-prioritisation of the topic of marine litter in mead and public perception compared to heavy metals, which in turn might influence policy making and research.

Comparability

While this should not be understood as argument that heavy metal pollution is more urgent than introduction of marine litter, it could maybe point at a benefit if international ocean governance defines key pressures. In the case of the sea-basin assessment reports such a top-down overview could then be used to assess the prevalence of those pressures in a targeted way, instead of a bottom-up approach in which sea-basins identify pressures to further assess. Such a way forward could in the long run also potentially lead to a better global comparable overview of key pressures which, in turn, could influence policy making. It could also lead to better comparable data. Also in general, without building on different sea-basin studies, global studies of pressures would be beneficial, for example for benchmarking of different world regions and prioritising action, or for the better identification of key human activities leading to the pressure at a global scale since, to date, for several pressures (e.g. heavy metal pollution or eutrophication) global studies are few and far between.

Interaction

Scientific literature often highlights potential interaction of pressures.

For example, it is assumed that climate change contributes to the spread of pathogens in the marine environment and might therefore influence the prevalence of microbial infections; while at the same time marine plastic as a "means of transport" for microbial pathogens in the marine environment is also currently being investigated as an emerging threat and also increasing aquaculture has been identified as a potential intensifier of this.

Another example is eutrophication, which can hamper the sequestration of atmospheric CO_2 and thus increase the severity of climate change, while at the same time eutrophication is expected to increase through the impact of climate change on marine ecosystems and ocean hydrographical conditions such as the increase in sea temperatures.

Finally, in another example which shows more of a trade-off, it is assumed that in order to meet the Paris Agreement goals, the demand for certain metals will increase significantly and it is uncertain to what extent land-based mining can cover this demand. Seabed mining could thus be seen as an option here; however, there are still strong uncertainties about its environmental impact, may it be in terms of abrasion, or pollution through inorganic pollutants.

While those interactions are often pointed out, it seems that this knowledge is to date not sufficiently aggregated in global ocean assessments and thus there may be a risk of underestimating future trends due to multiplier effects from other pressures. International ocean governance could play an important role here be assessing those factors in a structured way and then by ensuring, that the findings are accounted for in policy making.

The poles require special attention

Arctic and Antarctic are undergoing major changes and are subject to a wide range of developing pressures which may require even more attention from international ocean governance. For example, they are the regions with the highest increase in capture production over the last 20 years. Also, they will face increased risk of collisions, introduction of non-ingenious species, anthropogenic noise, and introduction of microbial pathogens due to increased shipping following the opening of shipping routes due to the receding ice. At the same time, the local ecosystems are already under major pressure from climate change.

Activities and responses

The important of land-based activities

It has been shown that for several of the pressures, land-based activities are one of the main causes and that thus land-based responses need to be taken in order to alleviate the pressures on the oceans – international ocean governance can play a role here by ensuring that those issues remain high on the policy agenda but needs to rely on actors in land-based activities to make changes.

The diverse toolbox of ocean governance

However, the study also clearly shows the diversity and potency of sea-based responses for several pressures – mostly those, which are not related to pollution and to climate change. Here, there seems to be great potential especially for increased cooperation on and enforcement of international policies (e.g. for IUU prevention) or technical advancements (e.g. for reducing ship pollution, collision with ships, technical measures supporting sustainable fishing).

The need for transformative changes

Reversing negative trends requires in most cases decisive actions and responses by society. It has been shown, that for a range of key pressures, the current efforts for reducing the pressure are not sufficient. In fact, in several of the assessments of adequate responses for reducing the pressures it has been shown that transformative actions would be required which in most cases go beyond the change of sea-based activities and indeed would require large-scale changes in land-based activities, as well as in consumer attitudes and affecting society as a whole.

One example for this is the introduction of substances to the oceans leading to eutrophication, one of the largest and most widespread pressures identified in the oceans. This pressure is almost entirely caused by land-based human activities, the largest of which include use of fertilisers in agriculture as well as combustion vehicles/cars and fossil-fuel based energy production. While all of those activities and their emissions have already been subject to a wide field of policy actions, eutrophication continues to spread and to worsen across the globe. Thus, more decisive and in fact transformative action would be required to reduce this pressure, which, however, does not traditionally fall under the umbrella of ocean governance.

At the same time, pursuing the most transformative responses such as a switch away from intensive agriculture and considerable reduction of fertilisers, or the phasing out of fossil fuel combustion cars and power generation, also each have a wide range of considerable co-benefits which go beyond the oceans.

Prevention is often the most viable response option

In several cases – e.g. oil spills, introduction of inorganic pollutants – prevention is the most effective response. Thus, international ocean governance should ensure to prioritise such responses, even if they seem more costly at the onset (e.g. improved technical standards for ships). In the same vein, for pollution pressures, tackling point-source discharges is often easier and more effective than diffuse sources.

Often, the choice of the best response is context-dependent

It is shown that in many cases, there is no single-best-solution but that this should be rather decided depending on the context. To this end it was also not attempted to list the responses in order of significance, relevance, perceived effectiveness or other indicators, since in most cases such a ranking would not be feasible.

However, it is considered relevant for international ocean governance to work towards making the different options more visible and accessible to international, national, and regional decision makers. During the research for this study, in many cases a complex literature review was required to identify and compare different options. Having this information more easily accessible would potentially help stakeholders to better assess their options and take informed decisions when designing their local, regional, or national responses.

Nevertheless, global action is needed

While not a surprise, it should nevertheless be pointed out that there is dire need for global action for global responses to most of the problems. Pollutants are mobile, so is the ocean flora and fauna, and the inaction of one country or region can have severe global effects. This has been shown for several of the pressures and the activities and provides a clear need – and mandate – for international ocean governance. Again, it should be noted in this context though that "global" also very much includes land-based activities and

The business case for international ocean governance

It should be noted that, due to their context-dependency and wide diversity, this study faced major challenges in assessing the costs of those responses at an aggregated level. While examples were identified and presented, this nevertheless hampers the ability of the study to compare the costs with the benefits.

The study shows however that there is a clear merit to reduce the pressures. In the business as usual scenario, it can be seen that several ecosystem services would continue to decline which would lead to large economic damages worldwide. Other ecosystem services under this scenario would remain stable or even slightly increase; however, also in those cases an improved international ocean governance would lead to innumerable benefits.

In general, the scenario which assumes an improved international ocean governance, shows that the benefits that could be gained by "getting rid" of the pressures are considerable. A wide range of economic sectors which depend on the ecosystem services that the ocean provide would benefit immensely. Also the general society would benefit enormously, be it from a reduction of GHG in the atmosphere or from reduced presence of coastal disasters.

APPENDIX 1. – METHODOLOGICAL FRAMEWORK OF THE STUDY

Overall framework - the DSPIR framework

Introduction

This project is conducted against the backdrop of the deteriorating status, health and productivity of oceans due to a wide range of human activities, including in-situ activities happening in and on the oceans as well as land-based activities indirectly affecting the oceans. Those activities could be grouped into activities taking something out of the oceans; putting something into the oceans; and disturbing something within the oceans.

This in turn affects the oceans, its chemistry and physical properties, biodiversity and ecosystems/habitats, and its ability to provide ecosystem services, and related socio-economic benefits, that society can benefit from.

For this project to reach its objectives, those complex relationships need to be structured in a meaningful way. In addition, the structure also needs to reflect human interventions, both, as a "problem" (i.e., the human activities mentioned above), but also as "solutions" to those problems through appropriate responses (projects, programmes, policies, actions etc.).

The approach for structuring this complexity is to use a Driver–Pressure–State–Impact–Response framework as a tool.

A way of structuring complexity –DPSIR framework

A Driver–Pressure–State–Impact–Response (DPSIR) framework describes links between human activities, their impacts on the environment, and how this is expected to change through policy interventions. Through this, it helps assessing complex cycles of feedback loops and interactions within a system in a structured way. The aim is then to identify means for improving the system through appropriate policy interventions. The framework has been originally developed by the OECD[337] and is today widely used, e.g., by the European Environment Agency[338], the UNEP as part of their Global Environment Outlook reports[339], the International Council for the Exploration of the Sea (ICES)[340], in scientific literature [341], in Horizon 2020 projects[342], and many others.

The Figure overleaf depicts a "generic" DPSIR framework.

[337] See e.g. Lewison, R. L., et al (2015): How the DPSIR framework can be used for structuring problems and facilitating empirical research in coastal systems. Environmental Science & Policy. See: https://www.sciencedirect.com/science/article/abs/pii/S1462901115301027

[338] See e.g. here: https://www.eea.europa.eu/help/glossary/eea-glossary/dpsir

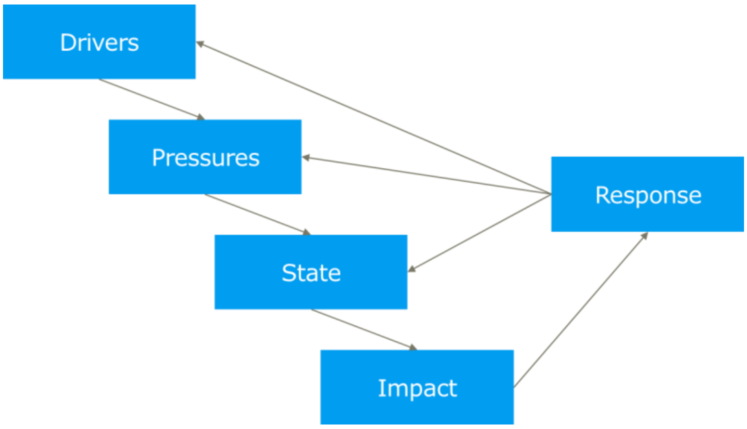
[339] See e.g. here for the latest report: https://www.unep.org/resources/global-environment-outlook-6?_ga=2.145407924.1871730340.1634729426-1688743821.1627367473

[340] See e.g. here: https://www.ices.dk/sites/pub/Publication%20Reports/Cooperative%20Research%20Report%20(CRR)/CRR317.pdf

[341] See footnote 337

[342] See e.g. https://www.lars-project.eu/assets/14/Newsletter/LARS-newsletter-5-May-2020.pdf

Figure: The DPSIR framework



Source: Own illustration

However, the DPSIR is not a tightly defined tool. It rather allows researchers to structure and focus their assessment depending on the research question and can e.g. be extended to include further subcategories which are deemed necessary. Also, no clear definitions exist for the different steps, and they are interpreted differently from study to study.

During the inception phase of the project, the project team has aimed to operationalise the DPSIR framework for this project, which included the following:

- Identify/develop clear definitions for the different steps;
- Identify the relevant topics for the different steps;
- Confirm, based on the first two points, if the framework in its generic form is fit for this project.

As a result, the team found that, while the overall DPSIR framework is fit for purpose, it would need to be refined to address the following challenges:

- Most of the studies using the framework only have somewhat unclear definitions for the different steps and use them inconsistently;
- The "drivers" step is challenging to define and there seems to be confusion on what it should include, e.g. if it includes societal changes (e.g. population growth), or sectorial activities (e.g. fishing), or human needs (such as food) which in turn lead to sectorial activities, or a mix. Furthermore, certain drivers can also reinforce other drivers, for instance when population growth has an impact on the increased demand for food and raw materials. Eventually, it seemed that this step would need to be further split up in order to make it useful, given that the project needs to assess the activities leading to pressure, while also taking long-term trends into consideration;
- Given that the project needs to assess in monetary terms the social (e.g. jobs) and economic (e.g. gross value added) impacts on the one hand, but importantly also the environmental impacts and costs (through ecosystem services and their loss) the step "impacts" quickly becomes overloaded with many intermediate steps since, for example, environmental impacts also can have economic impacts[343].

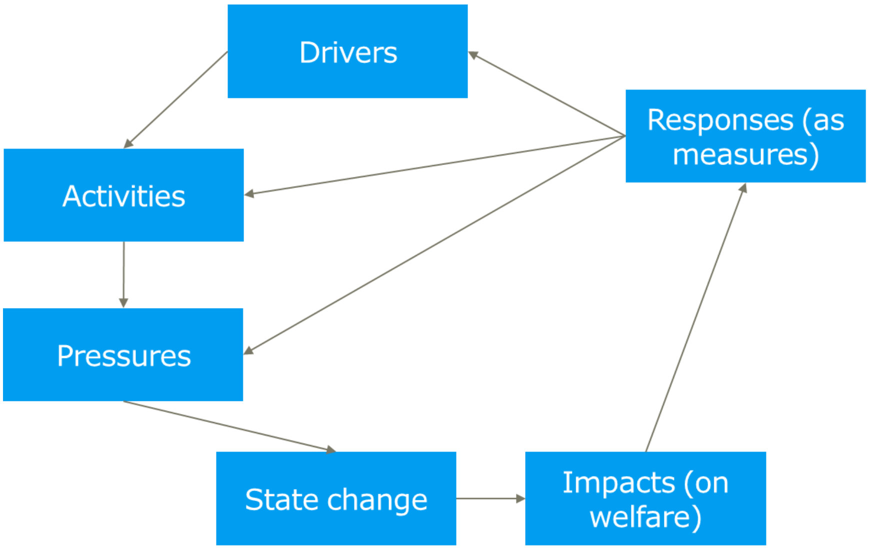
[343] As an example, an increase of pollutants can lead to decrease in fish stocks which in turn can lead to reduced income for the fishing industry and higher costs to find and catch the fish; at the same time, an increase in pollutants can also lead to the accumulation of these pollutants in fish, potentially resulting in human health implications – that could perhaps also result in a reduced demand for fish and therefore reduced income for the industry

As part of a literature review, a derivative of the DPSIR has been identified which addresses those main issues – the so-called "DAPSI(W)R(M)".

A useful derivative of the DPSIR framework - the DAPSI(W)R(M)

The main steps of the DAPSI(W)R(M) are shown in the Figure below.

Figure: The DAPSI(W)R(M) framework



Source: Own illustration based on Borja, A. (2016): Overview of Integrative Assessment of Marine Systems: The Ecosystem Approach in Practice. Frontiers in Marine Science.[344]

As can be seen, compared to the generic DPSIR framework, additional steps are added in this derivative which address the identified key challenges, namely:

- Clear definition of "drivers"
- Addition of step "activities" for clear distinction;
- Separate steps for state changes (environmental component) and impacts on welfare (socio-economic component)

In addition, the steps are exhaustingly defined in the paper introducing the framework[345]. Short summaries of the definitions from the paper are presented in the table below. The full definitions can be found in the paper.

Table: Summary of the definitions of the steps of the DAPSI(W)R(M)

Sep	Short definition
Drivers	Basic human needs such as biological needs (e.g. food, drink), self-actualisation (e.g. seeking experiences), or satisfaction (e.g. economic income or growth). The drivers are the reasons for why society does something (i.e., why we "do" the activities"); e.g., fishing to provide food, or tourism on cruise ships to seek experiences.

[344] See: https://www.frontiersin.org/articles/10.3389/fmars.2016.00020/full

[345] Elliott, M., et al (2017): "And DPSIR begat DAPSI(W)R(M)!" - A unifying framework for marine environmental management. Marine Pollution Bulletin. See: https://www.sciencedirect.com/science/article/pii/S0025326X17302692

Sep	Short definition
Activities	Activities are the things that society "does". This includes activities happening directly in and on the oceans (e.g., shipping) as well as land-based activities indirectly affecting the oceans (e.g. agricultural activities which then affect the oceans because soil is getting washed off into rivers which in turn transport the pollutants from the soil into the oceans). Activities do not necessarily automatically lead to Pressures, however. For example, if shipping follows corridors which have been shown to not affect ecosystems through noise, and there are no discharges from the ship because all waste is kept on board for later treatment, this does not lead to noise Pressure or pollution Pressure.
Pressures	Pressures are resulting from one or more activities. They are the mechanisms that change something in the ocean, including through: • Taking something out of the ocean (e.g., fishing activities at unsustainable levels lead to decrease of fish) • Putting something into the ocean (e.g., introduction of high levels of phosphorus into the ocean which leads to eutrophication) • Disturbing something within the ocean (e.g., changes in major currents due to climate change)
State change	State changes relate to changes in the natural environment as a result of a single or multiple Pressures.
Impacts (on welfare)	Those changes in the natural environment then change how much society can benefit from the ocean and the many services it provides.
Responses (as measures)	Those are the policy responses that can be put in place to address harmful Drivers, Activities, Pressures, and/or State Changes.

Source: Own compilation based on Elliott, M., et al (2017): "And DPSIR begat DAPSI(W)R(M)!" - A unifying framework for marine environmental management. Marine Pollution Bulletin.

Mapping of pressures

Introduction

As a starting point for identifying and structuring the issues faced by the oceans the study first identified the relevant "pressures" through a structured literature review.

For the identification of literature, the following criteria have been used:

- Grey literature is accepted but must be from a reputable and trustworthy institution;[346]
- The literature cannot be focused on specific sectors but must take a comprehensive view on the seas and oceans;
- The geographic scope of the literature as a whole should cover all oceans.

Where available, environmental monitoring programmes or state of the environment reports of Regional Sea Conventions have also been identified as key source for the identification of relevant pressures.

[346] While there is no fix definition the project team has based this assessment on experience.

Finally, relevant policies and policy papers have been used as key sources, such as the Maritime Strategy Framework Directive and the Agenda 2030 (the targets of the Sustainable Development Goal 14).

It should be noted that the paper which presents the DAPSI(W)R(M)[347] actually suggests mapping activities as a starting point and to derive the other steps of the framework from there.

The present study nevertheless took mapping of pressures as a starting point, given that it also takes into account pressures from land-based activities which account for a large part of the problems that the oceans face; the cited paper, on the other hand, focuses preliminarily on sea-based activities.

To exemplify the above, one could look at the pressure "Introduction of non-synthetic compounds (heavy metals)". The introduction of heavy metals into the oceans is identified throughout a wide range of literature as a threat to marine ecosystems due to their toxicity. In this study, this Pressure is identified through a structured literature review. Following from this, the study identified the main human activates leading to heavy metal input into the oceans. If in turn the activities are taken as a starting point, first, all relevant human activities emitting pollutants would have to be identified and then, in a second step, the pressures they produce would have to be mapped. While this is a practical approach when mostly looking at sea-based activities[348], it becomes unpractical when also taking land-based activities into account.

Overview of literature

The following documents have been screened for the identification of pressures.

Table: List of key literature to be screened

Report	Institution	Year	Geographic scope
Reports			
Ocean State Report 5th issue[349]	Copernicus Marine Service	2021	European Seas
Special Report on the Ocean and Cryosphere in a Changing Climate[350]	IPCC	2019	Global
Second World Ocean Assessment[351]	United Nations	2021	Global
Global ocean science report 2020: charting capacity for ocean sustainability[352]	Intergovernmental Oceanographic Commission	2020	Global

[347] Elliott, M., et al (2017): "And DPSIR begat DAPSI(W)R(M)!" - A unifying framework for marine environmental management. Marine Pollution Bulletin

[348] Such as aquaculture, transport and shipping, or tourism.

[349] See: https://marine.copernicus.eu/access-data/ocean-state-report/ocean-state-report-5

[350] See: https://www.ipcc.ch/srocc/

[351] See: https://www.un.org/regularprocess/woa2launch

[352] See: https://en.unesco.org/gosr

Report	Institution	Year	Geographic scope
6th Status of Corals of the World: 2020 report[353]	GCRMN / ICRI	2020	Global
Marine messages II – Navigating the course towards clean, healthy and productive seas through implementation of an ecosystem-based approach[354]	EEA	2019	European Seas
Documents from Regional Sea Conventions[355]			
State of the Baltic Sea – Holistic Assessment[356]	HELCOM	2018	Baltic Sea
State of the Environment and Development in the Mediterranean	UNEP (Barcelona Convention)[357]	/	Mediterranean Sea
OSPAR Coordinated Environmental Monitoring Programme[358]	OSPAR	2016	North-East Atlantic
Black Sea Integrated Monitoring and Assessment Program[359]	Bucharest Convention	2017	Black Sea
Secretariat of the Pacific Regional Environment Programme (SPREP) State of Environment and Conservation in the Pacific Islands: 2020 Regional Report[360]	SPREP	2020	Pacific Islands
COBSEA Strategic Directions 2018-2022[361]	Coordinating Body on the Seas of East Asia (COBSEA)	2018	East Asian Seas

[353] See: https://gcrmn.net/2020-report/

[354] See: https://www.eea.europa.eu/publications/marine-messages-2

[355] No information was found for the Abidjan Convention (West and Central Africa), the Tehran convention (Caspian Sea), South East Asia Action Plan, Permanent Commission of South Pacific, Artic, Antarctic

[356] See: http://stateofthebalticsea.helcom.fi/in-brief/

[357] See: https://www.unep.org/unepmap/resources/2020-edition-state-environment-and-development-mediterranean-soed

[358] See: https://www.ospar.org/work-areas/cross-cutting-issues/cemp

[359] See: https://ec.europa.eu/environment/marine/international-cooperation/regional-sea-conventions/bucharest/pdf/BSIMAP_2017_to_2022_en.pdf

[360] See: https://soec.sprep.org/

[361] See: https://www.unep.org/cobsea/resources/policy-and-strategy/cobsea-strategic-directions-2018-2022

It should be noted that no recent "state of the environment" report could be identified for this region and thus the strategy has been selected instead under the assumption that the strategy will focus on most relevant pressures in the region

Report	Institution	Year	Geographic scope
Regional State of the Coast Report Western Indian Ocean[362]	Nairobi Convention	2015	Western Indian Ocean
Assessment of Major Pressures on Marine Biodiversity in the NOWPAP Region[363]	Northwest Pacific Action Plan (NOWPAP)	2018	Northwest Pacific
State Of The Marine Environment Report – THE RED SEA AND GULF OF ADEN	The Regional Organization for the Conservation of the Environment of the Red Sea and Gulf of Aden (PERSGA)	2020	Red Sea and Gulf of Aden
State of the Marine Environment Report[364]	Regional Organization for the Protection of the Marine Environment (ROPME)	2013	Coastal Areas of Bahrain, I.R.Iran, Iraq, Kuwait, Oman, Qatar, Saudi Arabia and the United Arab Emirates
[Five state of the Environment reports for Cook Islands, Niue, Papua New Guinea, Solomon Islands and Tonga.]	Secretariat of the Pacific Environment Programme - The SPREP Convention	2020	Pacific islands
State of the Cartagena Convention Area report[365]	UNEP / Cartagena Convection	2020	Wider Caribbean Region (Cartagena Convection Area)
Relevant policies and policy papers			
Marine Strategy Framework Directive; Relevant GES Indicators[366]	EC	2008	European Seas
SDG14 targets	UN	2015	Global

Overview of pressures

Based on a preliminary screening, the pressures which are commonly mentioned in the literature have been identified. Then, all documents from Regional Sea Conventions (See Table above) have been reassessed to identify the pressures mentioned in each of those documents as being an issue in the region. Through this, a structured identification of key pressures per sea basin has been developed which is presented below.

Table: List of pressures

Pressure name	Group
Introduction of non-indigenous species	Biological pressures

[362] See: https://nairobiconvention.org/clearinghouse/node/150

[363] See: https://www.unep.org/nowpap/resources/report/assessment-major-pressures-marine-biodiversity-nowpap-region-2018

[364] See: http://ropme.org/411_SOMER_REPORTS_EN.clx

[365] See: https://wedocs.unep.org/handle/20.500.11822/36346

[366] See e.g.: https://ec.europa.eu/environment/marine/good-environmental-status/index_en.htm

Pressure name	Group
Extraction of wild species	
Death or injury of wild species by collision	
Introduction of microbial pathogens	
Seabed abrasion	Physical pressures
Introduction of underwater noise	Pollution
Introduction of substances leading to eutrophication	
Introduction of synthetic organic compounds	
Introduction of inorganic pollutants	
Oil spills	
Introduction of marine litter	
Introduction of microplastics	
Introduction of radionuclides	
Introduction of air pollutants	
Large-scale changes in water temperatures	Changes in water properties due to climate change
Large-scale changes in salinity regime	
Large-scale changes in sea level	
Large-scale changes in currents	
Large-scale changes in pH	

Source: Own compilation

Definition of scenarios

Introduction

Following the objectives of the study (see section 1), two scenarios and a baseline have been defined for the project which are described in the Table below.

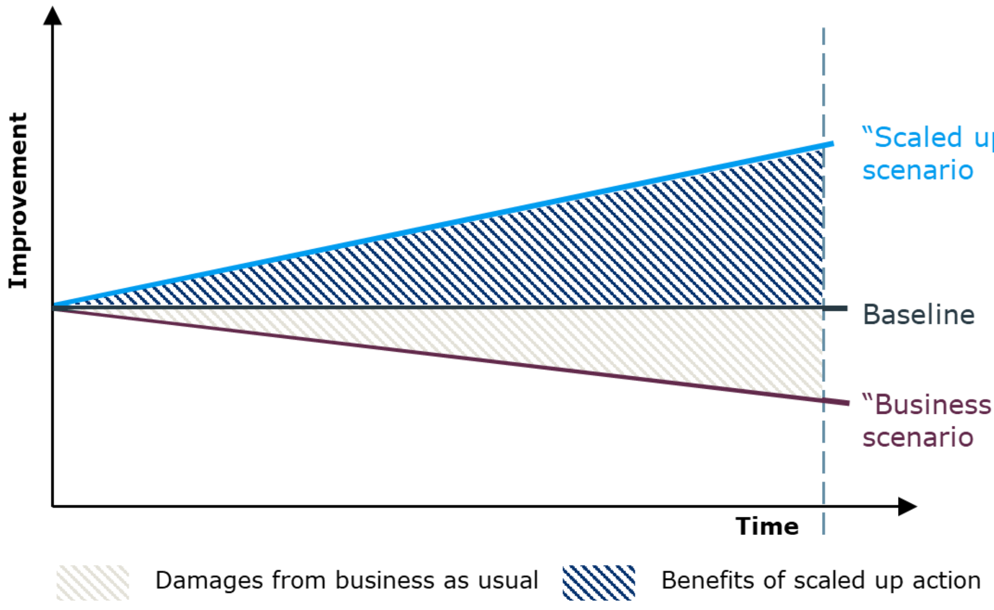
Table: Overview of scenarios

Name	Definition
Business as usual scenario	Under this scenario the current policy framework (policies, projects, partnerships etc.) for international ocean governance but also relevant policies for land-based activities will continue in their current form. In addition, policy developments such as the post-2020 global biodiversity framework, UNFCCC COP26 outcomes, international legally binding instrument on the conservation and sustainable use of biodiversity beyond national jurisdiction (BBNJ) etc are considered to be implemented. However, the effectiveness of those is uncertain and thus they have not been factored in in the calculations but rather mentioned where relevant. For the economic assessment of each state change the business as usual scenario has been individually developed for the relevant indicators.
Scaled up efforts scenario	Under this scenario it is assumed that society undertakes sufficient (and where needed transformative) efforts which lead to a reversal of negative trends and to the accomplishment of positive objectives. This has been individually defined and developed for the relevant indicators.
Baseline	The baseline is for each impact the point of comparison for the "business as usual" scenario and the "scaled up efforts" scenario. The study uses the year 2020 as baseline and, in cases where no data for 2020 is available, the latest available data. For the economic assessment of each state change the baseline has been individually developed for the relevant indicators.

Source: Own definitions

The Figure below depicts the differences between the scenarios as well as the baseline.

Figure: The relations between the scenarios



Source: Own illustration

Both, the "business as usual" and "scaled up efforts" scenario for each economic assessment where relevant also consider the impact of other trends such as:

- Projected population trends
- Projected GHG emission and global warming trends
- Projected global economic developments
- Possible impacts from COVID19

Definitions of "costs", "benefits" and "damages"

The table below provides an overview of the definitions of "costs", "benefits" and "damages" used in this study. They are based on the three objectives of the Terms of Reference of the study, which are linked to the scenarios mentioned above.

Definitions of "costs", "benefits" and "damages"

Objectives of the study	Definitions
To describe and quantify the economic **costs** and **benefits** of scaling up international efforts on ocean governance	**Costs –** Those are the investments costs which occur when implementing the responses. They are described semi-quantitatively in Appendix 7 of this report for each response, and specific per stakeholder group. **Benefits** – Those are the additional economic gains at societal level from reversing negative trends and reaching the respective positive objectives and are described for each economic assessment.
To estimate the economic **costs** in case of a no-change scenario for the oceans, i.e. pressures remain	**Damages/foregone benefits** – While this objective of the study as defied in the Terms of Reference also refers to "costs", in this study the terms damages/foregone benefits are used instead to

Objectives of the study	Definitions
and/or increase while the ocean-related 2030 Agenda, in particular SDG 14, targets remain unfulfilled	avoid confusion since those are not the same costs. Damages/foregone benefits are defined as the negative economic impacts from the business as usual scenario.
To propose actions to maximise the **benefits**, minimise the **costs** and enable the transformative changes needed to conserve and sustainably use the oceans by 2030	Benefits and costs of this objective are the same as for the first objective.

Overall methodology for economic assessments

Introduction

For each economic assessment this study developed an own approach for quantifying and monetising main relevant indicators under the two scenarios. Also, methodological limitations are described for each assessment separately.

However, a number of overarching considerations have been used to guide and streamline the assessments. They are presented hereunder.

Time horizon

The time horizon is the year until which the appraisal is conducted. It is an important topic since it has impacts on the results and there is no one correct reply for which time horizon should be applied. While for infrastructure investments this time horizon is usually governed by the expected lifespan of the investment, for environmental policies this is less clear.

For this project most of the political targets to be achieved stretch until 2030 (such as the SDGs) which is a first indication. However, most impacts (especially environmental impacts) take time to manifest, even if targets have been achieved; thus, a time horizon stretching longer than 2030 allows to incorporate those impacts. Finally, the time horizon should not be too long since this increases uncertainties in data and assumptions exponentially.

Given the above, a time horizon set at 2050 is considered a good compromise and has been used for the assessments.

Social Discount Rate

For the economic assessments the study applies a 0% social discount rate (SDR), therefore assigning equal weight (i.e., fair ethical treatment) to current and future generations. By doing so, it supports the view that countries should act now to protect future generation from the impacts of deteriorating oceans, and that investment is needed today to limit potentially catastrophic costs in the future.

Investing now to reverse trends will nonetheless provide benefits only in the long-term because environmental impacts need long time spans to reverse, which implies that we need to value the impacts of today's emissions for centuries in the future.

On the contrary, using a higher discount rate reduces the value of the future stream of net benefits or costs. The higher the assumed discount rate, the more we discriminate future generations and the more we underestimate the benefits of scaled up efforts for the oceans.

Finally, a positive discount rate has been historically used to justify the fact that future generations will have higher incomes and more sustained consumption levels, which generally means that they will be wealthier than the current one. However, recent years have shown that sustained growth cannot be assumed, and even before the COVID pandemic many researchers pointed to the fact that the current generation is likely to have lower or, at best, equal income to their parents.

Sensitivity analysis

The aim of the sensitivity analysis is to assess the extent to which the final results are affected when one or more key parameters are changed. For each economic assessment of the considered ecosystem services, the sensitivity analysis is organised in two steps:

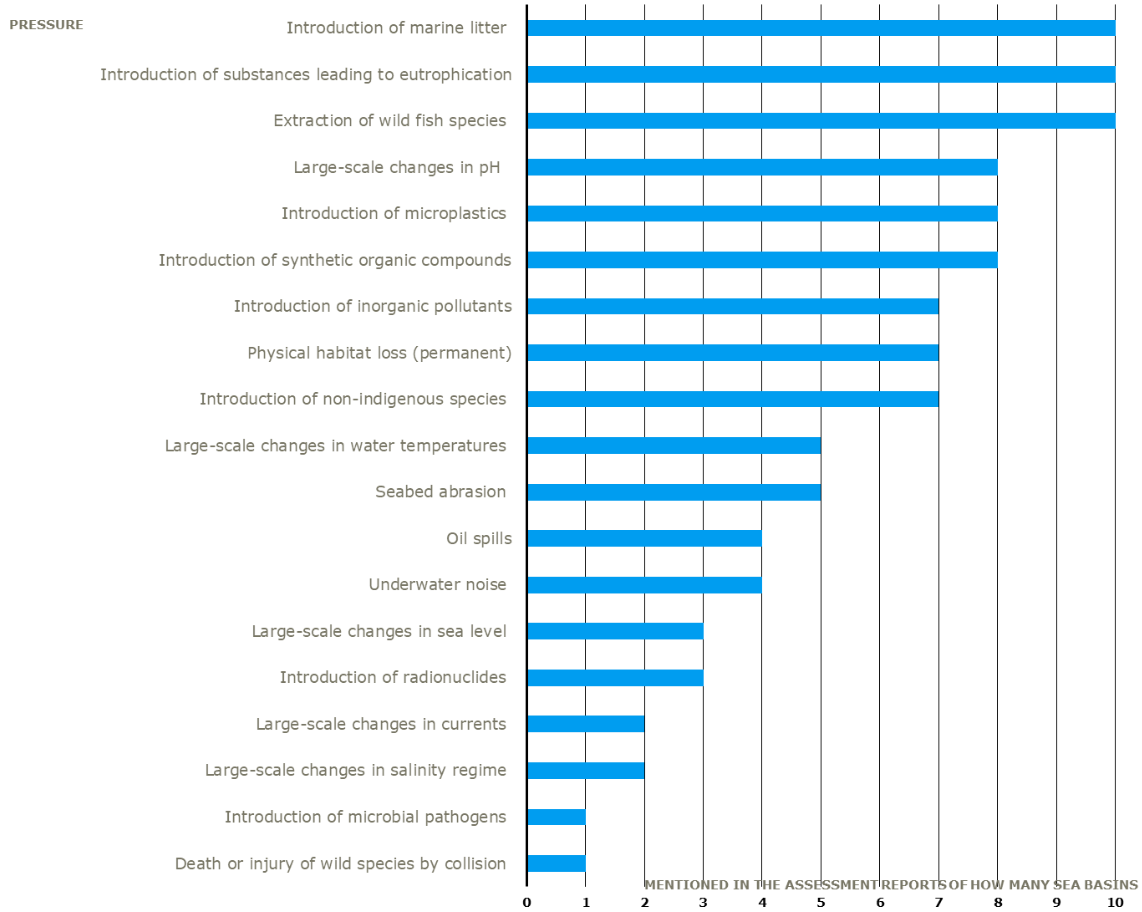
- First a default change (e.g. +- 25%) was applied to each one of the single parameters used in the calculation to identify those that influence the most the final results; this sheds light on the elements that are most critical for the monetisation of the ecosystem services, and the obtained insights can also be used to inform policy recommendations;
- Secondly, the default change was applied to all the parameters at the same time, therefore reflecting the case of a more pessimistic (e.g. -25%) or more optimistic (+25%) scenario compared to the ones considered in the central case. These additional scenarios provide a hint on how much overall results would change in a more conservative or, on the opposite, more optimistic scenario.

APPENDIX 2. – DETAILED DESCRIPTIONS OF PRESSURES

Introduction to the Annex

This chapter presents in more detail each of the identified key pressures on the oceans which have been mapped and qualified through an extensive literature review. The Figure below presents the results of how often each of the pressures was identified in the different sea basin assessment reports[367].

Figure: Overview of pressures mentioned in sea basins assessment reports

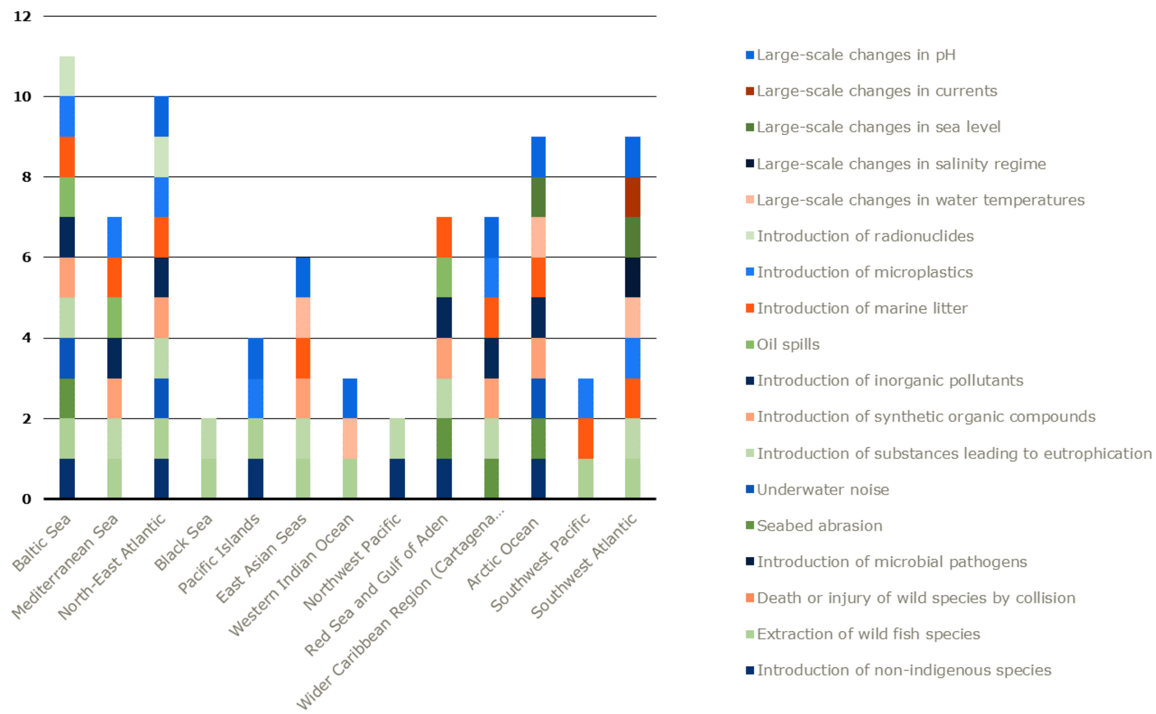


Source: Own illustration

In the following Figure the pressures per Sea Basin are shown.

[367] The study team developed this overview based on a review of the following reports: State of the Baltic Sea – Holistic Assessment; State of the Environment and Development in the Mediterranean; OSPAR Coordinated Environmental Monitoring Programme (CEMP); Black Sea Integrated Monitoring and Assessment Program; Secretariat of the Pacific Regional Environment Programme (SPREP) State of Environment and Conservation in the Pacific Islands: 2020 Regional Report; COBSEA Strategic Directions 2018-2022; Regional State of the Coast Report Western Indian Ocean; Assessment of Major Pressures on Marine Biodiversity in the NOWPAP Region; State Of The Marine Environment Report – THE RED SEA AND GULF OF ADEN; State of the Marine Environment Report; Five state of the Environment reports for Cook Islands, Niue, Papua New Guinea, Solomon Islands and Tonga; State of the Cartagena Convention Area report; AMAP Assessment 2018: Arctic Ocean Acidification; ICES/PICES/PAME Working Group on Integrated Ecosystem Assessment (IEA) for the Central Arctic Ocean (2020); Marine Protected Areas In A Changing Arctic, PAME- Arctic Council (2021); "Fifth ASEAN State of the Environment Report 2017"; The outlook for oceans, seas and marine resources in Latin America and the Caribbean

Figure: Overview of pressures per sea basin



Source: Own illustration

The pressures are resulting from one or more human activities and are the mechanisms that change something in the ocean.

For each of the main pressures, this chapter describes what the pressure entails, its main impacts, as well its geographical distribution, and finally insights on future trends (under the "business as usual" scenario) as well as important knowledge gaps. The information on the geographical distribution is based on the assessment presented in the figure above as well as additional literature review.

Biological pressures

Introduction of non-indigenous species

The oceans are populated by species of animals, plants and microorganisms that have evolved separated by natural barriers. Some of these species move far beyond their natural ranges into a new biogeographical area, where they do not naturally occur[368]. These species are called "non-indigenous species", "introduced species" or "alien species". Many of them do not survive in this new environment but some of them thrive and can start to take over native biodiversity: these are known as invasive species.

[368] Carlton, James T. (1999). The scale and ecological consequences of biological invasions in the world's oceans. See: file:///C:/Users/CAMBA/Downloads/The_Control_of_Biological_Invasions_in_the_Worlds.pdf

The invasion of a biogeographical area by non-indigenous species can lead to major ecosystem changes that can reduce biodiversity, alter community structure and function, diminish fisheries and aquaculture production and impact human health and well-being.

When a species is established is a new environment, it is not subject to natural controls, such as predators, parasites or disease, that keep population numbers in balance within its original natural range. As a result of this, the invasive species tend to increase rapidly, sometimes to the point where they take over their new environment.

They can affect, directly or indirectly, the ecosystems that support healthy and productive human communities. Although there are examples of species that have been occasionally exploited after an intentional introduction, such as the Pacific oyster, the Red Sea prawn or the Asian tiger shrimp, usually the long-term impacts are negative because of a reduction in native diversity. In addition, coastal communities are often negatively impacted by the reduction in overall productivity and resilience of marine systems that traditionally support their fisheries and aquaculture[369].

This phenomenon is exacerbated by climate change, including extreme events, and other human-induced disturbances[370]. Marine ecosystems that are already stressed or degraded because of human-caused impacts, such as overfishing, eutrophication, ocean acidification and habitat alteration, have been shown to be favourable to the establishment of non-indigenous species [371].

It is estimated that globally, about 2,000 marine non-indigenous species have been introduced to new areas through human-mediated movements and activities[372]. However, the available information on non-indigenous species is variable spatially, temporally and taxonomically. It is also difficult to evaluate the extent of invasions as non-indigenous species are not being monitored systematically. However, although global baseline inventories are still lacking, regional inventories and basin-wide assessments are being established for instance for European Union seas and these help to gain a better understanding of both changes in non-indigenous species over space and time and their impacts on ecosystems and human well-being.

Non-indigenous invasive species seems to be a pressure in almost all world regions. It is listed as a pressure in almost all sea-basin reports. In addition, it is highlighted as a key pressure in the assessments of European seas (Baltic Sea, Mediterranean, North-East Atlantic), Northwest Pacific, Arctic Ocean and Pacific Islands.

It is also important to note that some basins are more at risk than others. For example, it is predicted that in the Arctic, changing environmental conditions as a result of climate change will increase the likelihood of new invaders[373]. Environmental and climate pressures may also lead to changes in shipping patterns, with traffic expected to increase along the Northern Sea

[369] Molnar, *et al*. (2008). Assessing the global threat of invasive species to marine biodiversity. See: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.909.7219&rep=rep1&type=pdf

[370] Ojaveer *et al.* (2018). Historical baselines in marine bioinvasions: Implications for policy and management. See: https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0202383&type=printable

[371] Crooks et al.(2011). Aquatic pollution increases the relative success of invasive species. See: https://link.springer.com/content/pdf/10.1007/s10530-010-9799-3.pdf

[372] United Nations (2021) *World Ocean Assessment*, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[373] Goldsmit *et al.* (2018). Projecting present and future habitat suitability of ship-mediated aquatic invasive species in the Canadian Arctic. See: https://www.frontiersin.org/articles/10.3389/fevo.2021.627497/full

Route and become possible along the Northwest passage, which could in turn increase the supply of invasive species such as propagules[374].

Extraction of wild fish species

The livelihood of millions of people living in coastal areas relies since centuries on fisheries. Legal global landings[375] alone from marine water captures have been increasing significantly over the last decades (since the 1950s); since the 1990s they have then levelled at around 90 million tonnes annually[376]. However, most of the world's capture fisheries experience overexploitation, stemming from ineffective management, by-catch and discards, habitat degradation, and illegal, unreported or unregulated fishing (IUU fishing). Fisheries thus exert high pressures on marine species and ecosystems and ultimately threaten societal well-being.

It is widely documented that large parts of the world's fisheries are not managed sustainably and that fish stocks globally are under pressure, and thus that the target calling for sustainable fisheries under SDG14 (i.e., 14.4) is not yet met. This is reflected for example in the fact that around 1/3rd of global marine fish stocks is fished at biologically unsustainable levels when looking at legal fishing alone[377], and that IUU fishing in addition continues and fuels illicit trade in seafood while weakening fisheries governance[378].

The selective extraction of species is identified as a pressure in almost all reviewed sea-basin reports and is described as key pressure in the Black Sea, the Mediterranean, the Baltic Sea, the Pacific and the Indian ocean.

At the same time, significant gaps in knowledge exist with regard to overfishing. More specifically, even with appropriate governance leading to stock rebuilding, the adverse effects of global climate change are expected to impede progress toward sustainability[379]. The impacts of climate change are also expected to include increases in the intensity and frequency of natural hazards, thus affecting the local distribution and abundance of fish populations[380].

Death or injury of wild species by collision

Death or injury of wild species by collision entails the impact between an object present in the marine environment, moving or stable, with a marine species. Most of the scientific research so far focussed on the collision between vessels and whales, in particular in the North Atlantic. However, there is increasing evidence that this phenomenon affects more species, and a recent global study[381] estimates that at least 75 other marine species are affected worldwide, including smaller whales, dolphins, porpoises, dugongs, manatees, whale sharks, sharks, seals, sea

[374] Miller *et al.* (2014). Arctic shipping and marine invaders. See: https://www.researchgate.net/publication/271069861_Arctic_shipping_and_marine_invaders

[375] I.e., excluding discards and IUU fishing.

[376] FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

[377] See footnote 376

[378] Sumaila, U., et al. (2020). Illicit trade in marine fish catch and its effects on ecosystems and people worldwide. *Science Advances*, vol. 6, p. eaaz3801. https://doi.org/10.1126/sciadv.aaz3801 .

[379] Intergovernmental Panel on Climate Change (2019). Summary for policymakers. In *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*, Hans-Otto Pörtner and others, eds. Monaco: IPCC, 51st session, working groups I and II (24 September 2019).

[380] Barange, M., and others (2014). Impacts of climate change on marine ecosystem production in societies dependent on fisheries. *Nature Climate Change*, vol. 4, No. 3, pp. 211–216.

[381] Schoeman P. *et al.* (2020).A Global Review of Vessel Collisions With Marine Animal. See:https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

otters, sea turtles, and penguins. Collisions with smaller species seem to be scarce, most likely because of reporting biases[382].

Besides the immediate direct consequences of the collision i.e. injury or death of the animal, there might be more long-term consequences for individual animals. These are not well-understood to date, but possible long-term consequences include long-term locomotive impairments, for instance related to injuries to fins flippers and flukes, and possible reduced fitness of the animal. This can prevent effective foraging for the animal, and ultimately result in death from starvation. Open wounds and bone fractures might also increase the animal's energy expenditure for body maintenance and have negative effects on growth and reproduction. Other long-term consequences might be related to the high mortality rate and decline in fertile animals due to collisions, which can ultimately cause a decrease in population growth rate. For certain types of whales (e.g. North Pacific blue whales, humpback whales and fin whales, as well as Canary Island sperm whales) comprehensive studies have shown that ship strike rates may exceed population recruitment rates[383].

The risk of collisions taking place varies and depends on factors such as the abundance and type of species, the season, site characteristics and conditions. Evidence of collisions is scarce, and therefore a lot remains unclear regarding the impacts and outcomes of these accidents[384].

Introduction of microbial pathogens

Microbial pathogens are disease-producing agents or microorganisms[385]. They can be both of human origin, or indigenous and autochthonous marine organism that can cause disease in humans. These pathogens exist in many different ocean habitats : they can be freely suspended in water, associate with particles, lie in sediments or on surfaces of other organisms or inanimate objects, and they can exist within the bodies and cells of other organisms[386].

When these pathogens are transmitted to humans, in various ways, including direct contact with contaminated seawater (e.g. in the case of recreational swimming), inhalation or ingestion of contaminated fish or shellfish, they can cause a wide variety of illnesses[387]. Also, fish and shellfish can suffer diseases from microbial pathogens.

Some species, for example filter feeding organisms such as oysters and mussels are more prone to absorbing these pathogens[388]. This issue is particularly concerning for the aquaculture industry since the density of species in cultivation areas offers more opportunities for contact

[382] Schoeman P. *et al.* (2020).A Global Review of Vessel Collisions With Marine Animal. See:https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[383] Schoeman P. *et al.* (2020).A Global Review of Vessel Collisions With Marine Animal. See:https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full full

[384] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[385] Defoirdt T. (2013). Virulence mechanisms of bacterial aquaculture pathogens and antivirulence therapy for aquaculture. See: https://onlinelibrary.wiley.com/doi/abs/10.1111/raq.12030

[386] Munn C. B. (2005) Pathogens in the Sea: An Overview. See: https://link.springer.com/chapter/10.1007/0-387-23709-7_1

[387] Gerba C. P. (2005) Survival of Viruses in the Marine Environment. See: https://link.springer.com/chapter/10.1007/0-387-23709-7_6

[388] Lotz et al (2006) Aquaculture and Animal Pathogens in the Marine Environment with Emphasis on Marine Shrimp Viruses. See: https://www.researchgate.net/publication/226742743_Aquaculture_and_Animal_Pathogens_in_the_Marine_Environment_with_Emphasis_on_Marine_Shrimp_Viruses

among animals, and therefore more opportunities for the transfer of pathogens[389]. Disease outbreaks are in fact one of the main constraints to the development of the aquaculture sector. To control bacterial disease, antibiotics are frequently used, but this is likely to favour the emergence of antibiotic resistance in microbial pathogens[390].

The survival period of microbial pathogens in the water varies depending on a number of factors including ocean temperature, light exposure, pH, ocean salinity and other biological factors[391]. Thus, ocean warming is considered to contribute to the spread of pathogens in the marine environment.[392].

The role of marine plastic as a "means of transport" for microbial pathogens in the marine environment is also considered as emerging threat[393]. In fact, various types of pathogenic bacteria, e.g. vibrio cholerae and some strains of Escherichia coli, can colonise both macro and micro plastic surfaces that form a biofilm by staying in seawater. This biofilm is also considered to enrich pathogenic strains of the bacteria and viruses that colonise them[394]. The potential of macro and micro plastic to be a vector for microbial pathogens is currently understudied but could pose a serious threat to both human and environment health, due to the capacity of these materials to travel across oceans, as well as their ubiquity in the global marine environment. Plastic litter is transported across the oceans via the currents, but micro-plastics can also travel long distances in vessels' ballast water, in conditions that seem to enhance the virulence of microbial pathogens[395]. When "alien" microbial pathogens are transported across oceans (see also the pressure "invasive species"), this can cause the outbreak of diseases in regions that are not used to dealing with the specific pathogen, thus aggravating their capacity to cause harm[396].

Little is known about the many pathogens and absorption processes that occur with the myriad of species and organisms found in natural marine ecosystems, as well as the concentration levels of these pathogens worldwide. Also, no global database of outbreaks of illnesses caused by the spread of microbial pathogens exists. However, a survey of shellfish borne viral

[389] Lotz et al (2006) Aquaculture and Animal Pathogens in the Marine Environment with Emphasis on Marine Shrimp Viruses. See: https://www.researchgate.net/publication/226742743_Aquaculture_and_Animal_Pathogens_in_the_Marine_Environment_with_Emphasis_on_Marine_Shrimp_Viruses

[390] See footnote 385

[391] Gerba C. P. (2005) Survival of Viruses in the Marine Environment. See: https://link.springer.com/chapter/10.1007/0-387-23709-7_6

[392] United Nations (2021). World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[393] Bowley (2021) Oceanic Hitchhikers – Assessing Pathogen Risks from Marine Microplastic. See: https://www.researchgate.net/publication/343635803_Oceanic_Hitchhikers_-_Assessing_Pathogen_Risks_from_Marine_Microplastic

[394] Bowley (2021) Oceanic Hitchhikers – Assessing Pathogen Risks from Marine Microplastic. See: https://www.researchgate.net/publication/343635803_Oceanic_Hitchhikers_-_Assessing_Pathogen_Risks_from_Marine_Microplastic

[395] Naik et al (2019) Microplastics in ballast water as an emerging source and vector for harmful chemicals, antibiotics, metals, bacterial pathogens and HAB species: A potential risk to the marine environment and human health. See: https://www.sciencedirect.com/science/article/abs/pii/S0025326X19306630

[396] Bowley (2021) Oceanic Hitchhikers – Assessing Pathogen Risks from Marine Microplastic. See: https://www.researchgate.net/publication/343635803_Oceanic_Hitchhikers_-_Assessing_Pathogen_Risks_from_Marine_Microplastic

outbreaks performed for the period 1980-2012 showed that the majority of the reported outbreaks were located in East Asia, followed by Europe, Americas, Oceania and Africa[397].

Physical pressures

Seabed abrasion

The seabed is the bottom of the ocean. It is inhabited by plants and invertebrate animals that are called "benthos". Seabed abrasion refers to temporary or permanent changes to the seabed substrate or morphology, and changes to habitat and species inhabiting it[398]. When the changes are temporary and can be reverted if the activity causing the change ceases, this is called "physical disturbance". When the changes are permanent, this leads to a "physical loss" of the seabed "benthic" habitat and species[399].

Seabed abrasion can entail the following consequences[400], [401]:

- The extraction of seafloor substrate: when the seabed is abrased, either due to the direct removal of sediments or because of the contact with infrastructure or specific gear utilised in the area for other purposes, substrate can be removed. This entails the direct removal of benthic fauna, changes in sediment composition, loss or degradation of benthic habitats, disturbance of fauna;
- The production of "extraction and dewatering plumes": The plume is dispersed into the water column and can travel to other areas before being re-deposited on the seafloor. This can significantly disturb the fauna, as organisms get smothered by the plume and can change their behaviour, for instance when the plume makes water turbid and impacts their vision, or when it clogs their feeding, sensorial or breathing structures. The re-deposit of plumes on the sea floor can also change the composition of sediments and the morphology of the seabed.
- Release of substances from sediments: when seabed sediments are disturbed, organic contaminates, heavy metals and other components can be released into the water column. These substances can be toxic, they can release nutrients into water and increase turbidity of the water column. Also, the disturbance of the seafloor is estimated to cause the release of 1 gigaton of CO_2 every year[402].

[397] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[398] HELCOM State of the Baltic Sea. See: https://helcom.fi/baltic-sea-trends/holistic-assessments/state-of-the-baltic-sea-2018/

[399] Idem

[400] Ecorys (2014) Study to investigate state of knowledge of Deep-Sea Mining

[401] Kaikkonen et al. (2018) Assessing the impacts of seabed mineral extraction in the deep sea and coastal marine environments: Current methods and recommendations for environmental risk assessment. Available at: https://www.researchgate.net/publication/327419232_Assessing_the_impacts_of_seabed_mineral_extraction_in_the_deep_sea_and_coastal_marine_environments_Current_methods_and_recommendations_for_environmental_risk_assessment

[402] Sala *et al.* (2021) Protecting the global ocean for biodiversity, food and climate. See: https://www.nature.com/articles/s41586-021-03371-z.epdf?sharing_token=3uCHC_BARvxR4R8PqWDCOdRqN0jAjWel9jnR3ZoTv0MwjSp_dqdYRo11ccDn9dqPW5D1xJuK8fpT__q4KFNUwr3chDwJyG9IO5W1aWFy5om4rjrtPpwoPhh8lecRX4YI2DOaZc_5Z-oJr9OWWYCQTiQu_TyleTEdjrY3qqiOqzIDG24Tb_x2iqFGHkqVdsk0hZl3ZdBIC7ovw49j6wAQhA%3D%3D&tracking_referrer=time.com

Other pressures that impact benthic habitats and fauna are related to seabed abrasion, such as underwater noise and underwater light, but they are addressed as separate pressures in the following chapters.

When seabed abrasion takes place in the deep sea, this has often permanent impacts. This is because deep sea habitats and fauna are in general more stable as they are less exposed to changes compared to other marine areas. For this reason, it is considered that recovery of disturbed deep-sea environments requires considerably more time than recovery in shallow-water environments, ranging from years to even decades[403]. Knowledge of deep-sea ecosystems and their response to abrasion is still scarce to this day, also due to the early stage of mining activities in these areas. This makes it challenging to provide an accurate picture of the consequences of this pressure.

It is challenging to provide an overview of the geographical distribution of seabed abrasion, as no databases on the state of the seabed are kept. Some indications of where this pressure is most prominent can however be deduced from the distribution of the activities that cause it, such as seabed mining and bottom trawling.

Pollution pressures

Introduction of underwater noise

In the past ten years there has been an increasing awareness of the importance of sound to marine life. Sound is an efficient means of communication in the marine environment as sound waves travel very well through water and way faster than in the air.

Noise levels due to anthropogenic activities are variable across space and time. Studies assessing ocean soundscapes demonstrate that human activities contribution to underwater noise is growing[404]. A determinant of this, in addition to the level of human activity present in the environment, are also the acoustic propagation characteristics in the region. The properties of the environment affect sound propagation, ocean bottom and water properties affect the sound speed and bottom topography affects the direction of sound travel.

Concerning human activity, areas with the highest levels of anthropogenic noise include those where industrial use of the maritime space is abundant. This is for example the case in the Gulf of Mexico, the North Sea and the North Atlantic Ocean. Other areas that are likely to experience increasing levels of anthropogenic noise are the Arctic where the sea is opening up to shipping, or Africa where investments and industries expand.

Notably, a reduction in overall levels of anthropogenic noise has been measures which was caused by the slow-down of shipping traffic during the COVID-19 pandemic[405].

[403] Kaikkonen *et al.* (2018) Assessing the impacts of seabed mineral extraction in the deep sea and coastal marine environments: Current methods and recommendations for environmental risk assessment. See: https://www.researchgate.net/publication/327419232_Assessing_the_impacts_of_seabed_mineral_extraction_in_the_deep_sea_and_coastal_marine_environments_Current_methods_and_recommendations_for_environmental_risk_assessment

[404] Duarte *et al.* (2021) The soundscape of the Anthropocene ocean. See: https://www.science.org/doi/10.1126/science.aba4658

[405] Thomson and Carclay (2020) Real-time observations of the impact of COVID-19 on underwater noise. See: https://asa.scitation.org/doi/full/10.1121/10.0001271

Underwater noise has been identified as a pressure only in a few assessments and reports with a global geographical scope, and in only one of the sea-basin reports (State of the Baltic Sea – Holistic Assessment).

Though knowledge about this pressure has substantially increased in the last decades, gaps remain. These mainly regard: the measurement of ambient noise and the modelling of acoustic propagation; the identification of potential hotspots and less well understood risk areas; sound characteristics of data deficient human activities causing noise; cumulative acoustic footprint of increased and scaled up human activities in the oceans, as well as the effects of those at the population level[406].

Underwater noise produces a number of negative impacts on marine life. Given the growing focus on the ocean-based economy, which is projected to double its contribution to global gross domestic product by 2030[407], it is becoming more and more crucial to address this pressure.

Introduction of substances leading to eutrophication

During the 21st century, the oceans have seen a significant increase in anthropogenic inputs of nitrogen and phosphorus to coastal and marine ecosystems through river run-off and due to atmospheric deposition.

This phenomenon consists of an increase in the rate of supply of organic matter to ecosystems[408] and it is proven that anthropogenic nutrient input now exceeds input from natural processes[409].

It is estimated that globally 24% of the anthropogenic nitrogen released in coastal watersheds reach coastal ecosystems.[410] This causes ecosystem degradation in coastal areas worldwide and is even considered today as the most widespread anthropogenic threat to the health of these ecosystems[411]. Indeed, as phytoplankton net primary production relies on the availability of nitrogen in the ocean, the sudden surge in anthropogenic inputs has led to an increase in phytoplankton biomass accordingly.

Combined with other inputs of organic nutrients the resulting accumulation of organic matter drives the eutrophication of coastal ecosystems worldwide (see Figure below).

[406] European Marine Board (2021) Addressing underwater noise in Europe. See: https://www.marineboard.eu/publications/addressing-underwater-noise-europe-current-state-knowledge-and-future-priorities

[407] Ritts and Bakker (2021) Conservation acoustics: Animal sounds, audible natures, cheap nature, Geoforum, See: https://www.science.org/doi/10.1126/science.aba4658

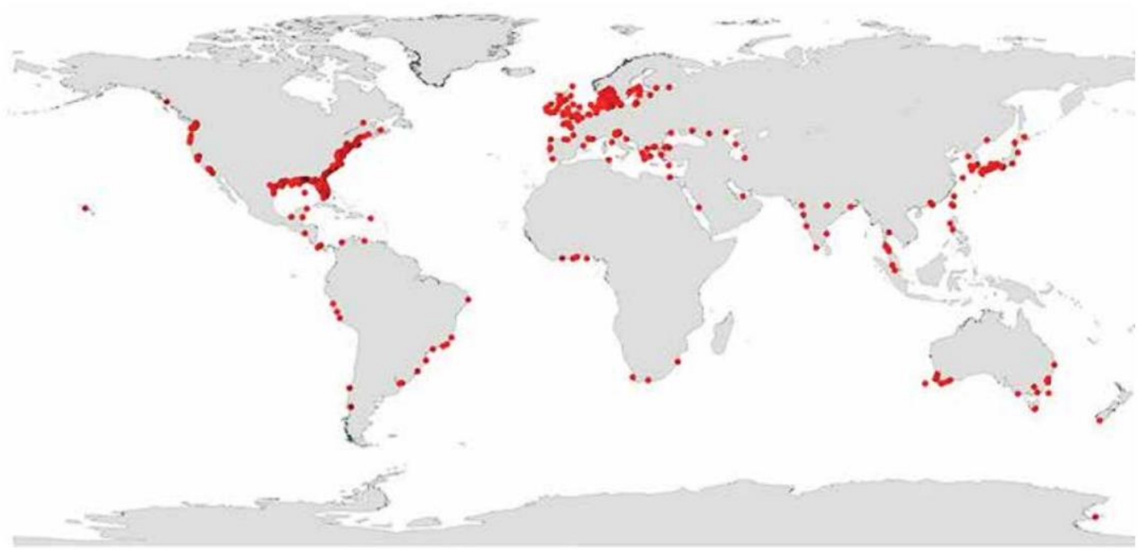
[408] Nixon, S. (1995). Coastal marine eutrophication: a definition, social causes, and future concerns. See: https://www.tandfonline.com/doi/abs/10.1080/00785236.1995.10422044

[409] UN (2021) *World Ocean Assessment*, Volume II.

[410] Malone, C., et al. (2020). The Globalization of Cultural Eutrophication in the Coastal Ocean: Causes and Consequences. See: https://www.frontiersin.org/articles/10.3389/fmars.2020.00670/full

[411] See footnote 410

Figure: Global distribution of eutrophic coastal marine ecosystems



Source: Breitburg et. al (2018) in the World Ocean Assessment (United Nations, 2021)

It has been shown that eutrophication can affect the capacity of coastal ecosystems to support ecosystem services such as the production of oxygen, the mitigation of coastal flooding, the sequestration of atmospheric CO_2 or fisheries[412]. In addition, the surge in organic substances also leads to the development of oxygen-depleted "dead zones", the loss of seagrass beds and increases in the occurrence of toxic phytoplankton blooms. The number of these dead zones has increased at an alarming rate over the last years, from 400 in 2008 to 700 in 2019[413].

Eutrophication is today a pressure found in almost all coastal ecosystems, as it is shown in Figure above. Also in the sea-basin reports, this pressure is listed in almost all sea basins, and as a key pressure in the documents from Regional Sea Conventions of the Baltic Sea, the Mediterranean, the Black Sea, the Northwest Pacific, the Caribbean Region, the Arctic Ocean.

It can be assumed that, as the anthropogenic nitrogen production will likely continue to increase over the course of the 21st century, the risk of coastal eutrophication will increase symmetrically in all large marine ecosystems – more specifically along the coasts of Africa, South America, South Asia and Oceania[414].

In addition, it is expected that the impact of this continued increase will be reinforced by the impact of climate change on marine ecosystems and ocean hydrographical conditions such as the increase in sea temperatures, changes in rainfall patterns and changes in the flux of atmospheric CO_2 into the ocean. It is thus expected that the extent of coastal hypoxia, acidification and toxic algal events will continue to increase as well[415].

It is also important to note that there are still gaps in the understanding of the impacts of eutrophication. This is partly due to a lack of data on coastal ecosystems in the Southern

412 Costanza, Robert, and others (2017). Twenty years of ecosystem services: how far have we come and how far do we still need to go? *Ecosystem Services*, vol. 28, pp. 1–16.

413 UN (2021). The Sustainable Development Goals Report 2021. See: https://unstats.un.org/sdgs/report/2021/The-Sustainable-Development-Goals-Report-2021.pdf

414 United Nations. (2021) *World Ocean Assessment*, Volume II.

415 Townhill, Bryony L., and others (2018). Harmful algal blooms and climate change: exploring future distribution changes. *ICES Journal of Marine Science*, vol. 75, No. 6, pp. 1882–1893.

Hemisphere. Also, there is still a need to understand and measure the synergies between the impacts of nitrogen and phosphorus loading in the coastal ocean and changes in coastal ecosystems linked to climate change[416].

Introduction of inorganic pollutants

There are several types of inorganic pollutants; however, regarding ocean pollution, most of the literature focuses on pollution from heavy metals (e.g., the World Ocean Assessment II[417] report focuses on mercury, cadmium and lead; the GESAMP[418] report on pollution in the open oceans[419] mostly on mercury, but also lead, cadmium, arsenic, nickel and coper; EEA reporting on contaminates in Europe's Seas[420] on mercury, cadmium and lead; or technical guidance[421] on assessing good environmental status with regard to Descriptor 8 "Concentrations of contaminants are at levels not giving rise to pollution effects" under the Marine Strategy Framework Directive[422]). Also, those seem to be the most commonly monitored substances; a study listing more than 2,700 potential chemical contaminants in the marine environment found that only four substances (cadmium, lead, mercury and lindane[423]) are considered under the current lists of chemicals of all European regional sea conventions. Pollution through metals is less visible than pollution such as litter and thus might be less urgent in public perception, while having strong effects on marine ecosystems[424].

Heavy metals in marine ecosystems, if present in too high concentrations, can lead to severe effects in those ecosystems. Also, they are persistent and do not degrade, and thus once emitted, remain in the environment. Finally, they are spread among ecosystems through food chains and can accumulate in some species (bioaccumulation); consuming those can then lead to health effects in humans.

They are emitted to the oceans through riverine and atmospheric transport and can be found in coastal areas as well as in the open ocean. This pressure has been identified in most sea basin reports which can be explained by the wide range of human activities leading to this pressure as well as the emission pathways of this pressure (i.e., riverine and atmospheric).

Given the wide range of human activities leading to this pressure, predictions for future developments are challenging to make. Looking at past trends, there seems to be evidence that the concentration of some heavy metals has remained constant over recent years compared to

[416] Paerl, H.W., and others (2014). Evolving paradigms and challenges in estuarine and coastal eutrophication dynamics in a culturally and climatically stressed world. *Estuaries and Coasts*, vol. 37, No. 2, pp. 243–258.

[417] UN (2021). Chapter 11 Changes in liquid and atmospheric inputs to the marine environment from land (including through groundwater), ships and offshore installations. In: The Second World Ocean Assessment. See: https://www.un-ilibrary.org/content/books/9789216040062

[418] Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) is an advisory body, established in 1969, that advises the United Nations

[419] GESAMP (2009). Pollution in the open oceans: a review of assessments and related studies. See: http://www.gesamp.org/publications/pollution-in-the-open-oceans-review

[420] EEA (2018). Contaminants in Europe's Seas. See: https://www.eea.europa.eu/publications/contaminants-in-europes-seas

[421] See Annex 7 in https://publications.jrc.ec.europa.eu/repository/bitstream/JRC58087/tg8%20report_final_vii.pdf

[422] Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive) (Text with EEA relevance). See: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0056

[423] A chemical used in agricultural insecticides and as a pharmaceutical treatment for lice and scabies

[424] Necibi, M., et al. (2017). The distribution of organic and inorganic pollutants in marine environments. See: https://www.researchgate.net/publication/321668238_The_distribution_of_organic_and_inorganic_pollutants_in_marine_environments

the past (e.g. copper and mercury), while others have been decreasing (e.g. lead and cadmium), while zinc loads seem to have been increasing[425].

Regarding knowledge gaps, there seems to be limited understanding about the ecosystem impacts from heavy metal pollution in the deep sea caused by deep see mining.

Oil spills

An oil spill is the leakage of petroleum onto the surface of a large water body. Oil can end up in the oceans either via accidental oil spills from oil-carrying tankers, or when produced water and drilling waste is discharged into the marine environment, usually close-by to oil extraction facilities.

Oil spills have proven to affect the marine ecosystems in multiple ways. Marine fauna and flora are affected through oiling: oil can directly trap animals, as well as diminish the insulating and water-repellent ability of fur-bearing mammals, thus exposing them to harsh elements and leading them to die from hypothermia[426]. When oil gets mixed with the water column, fish and other species experience reduced growth, enlarged livers, changes in heart and respiration rates, fin erosion, and reproduction impairment[427]. Beyond the "physical" pressure, oil spills also interact with the marine environment "chemically", when toxic components of the oil enter in contact with the marine ecosystem. These toxic compounds can cause severe health problems like heart damage, stunted growth, immune system effects, and even death of marine species[428].

In terms of geographical spread of this pressure, major oil spill incidents registered in 2003-2012 took place in several locations around the world, as depicted in the Figure on the next page.

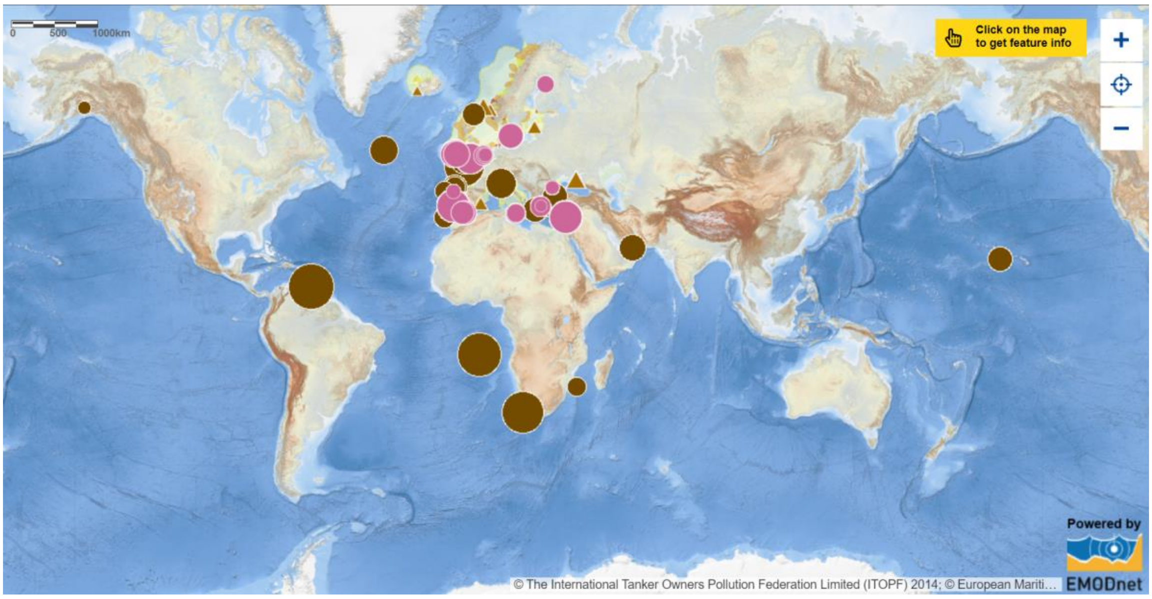
[425] GESAMP (2018). Global Pollution Trends: Coastal Ecosystem Assessment for the Past Century. See: http://www.gesamp.org/publications/global-pollution-trends-coastal-ecosystem-assessment-for-the-past-century

[426] National Ocean Service. How does oil impact marine life? Oil spills are harmful to marine birds and mammals as well as fish and shellfish. See: https://oceanservice.noaa.gov/facts/oilimpacts.html

[427] Idem

[428] Idem

Figure: Overview of main oil spills, World (2003-2012)



Pink dots: Oil spill response vessels (Unit: cubic meters - Year: 2013)
Brown dots and triangles: Major oil spill incidents (Unit: tonnes - Year: 2007-2008)
Source: The International Tanker Owners Pollution Federation Limited (ITOPF) 2014; © European Maritime Safety Agency, 2003-2012[429]

Oil spills have, however, become less and less frequent over the years. In the 1970s, around 79 oil spills per year were registered on average. In the last decade, the annual average is 5 oil spills per year[430].

Concerning produced water and drilling waste, the areas surrounding the main oil drilling facilities appear to be the most at risk. In particular, the report on state and trends in the marine environment in the Red Sea and Gulf of Aden, identifies oil pollution as one of the main threats to coral reefs in the seas of Iran, Oman and Qatar[431].

Introduction of marine litter

The UN Environmental Assembly has recognised marine litter as one of its top priorities through four resolutions[432], and it has recently committed to drafting a legally binding agreement on ending plastic pollution by the end of 2024[433].

Marine litter refers to any "persistent, manufactured or processed solid material discarded, disposed of or abandoned in marine and coastal environments"[434]. Marine litter ranges from

[429] See: https://ec.europa.eu/maritimeaffairs/atlas/maritime_atlas/#lang=EN;p=w;bkgd=1;theme=27:0.52,28:1,50:1;c=3005191.4096569903,627277.7517246474;z=2

[430] ITOPF (2021) Oil Tanker Spill Statistics 2021. See: https://www.itopf.org/knowledge-resources/data-statistics/statistics/

[431] ROPME (2013) State of the Marine Environment Report. See: http://ropme.org/411_SOMER_REPORTS_EN.clx

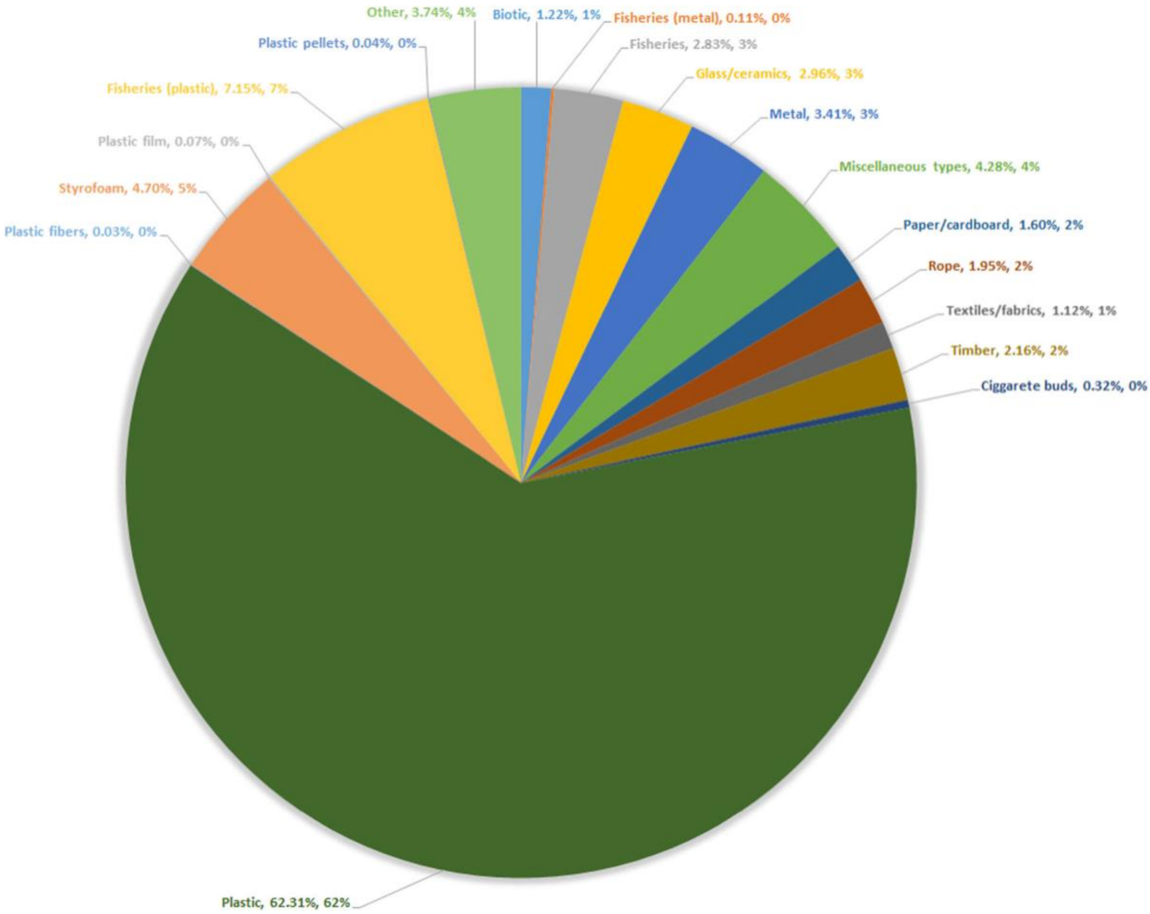
[432] From UNEA-1 in 2014, UNEA-2 in 2016, UNEA-3 in 2017, and UNEA-4 in 2019

[433] United Nations (2022) Nations sign up to end global scourge of plastic pollution. See: https://news.un.org/en/story/2022/03/1113142

[434] World Ocean Assessment II (2021) See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

mega-litter (> 1 m) to nano-litter (< 1 µm)[435]. This includes a wide variety of materials, such as plastic, metal, glass, rubber or wood, coming from fishing gear, industrial pellets, sanitary items and single-use plastics or other sources[436]. It is estimated that 80% of marine litter originates from land-based sources, but sea-based sources also play an important role. Litter ends up in the ocean via runoff, winds, tides, gravity or via rivers[437].

Figure: Global composition estimate of marine litter



Source: Hahladakis (2020), redrawn from [438]www.litterbase.com

Plastic is the main component of marine litter, and makes up for around 80% of marine debris found in surface waters to deep-sea environment[439]. Single-use plastic items are the biggest contributors to marine litter[440].

[435] Idem

[436] Idem

[437] Chassignet et al (2021) Tracking Marine Litter With a Global Ocean Model: Where Does It Go? Where Does It Come From?

[438] See: www.litterbase.com

[439] IUCN. Marine plastic pollution. See: https://www.iucn.org/resources/issues-briefs/marine-plastic-pollution

[440] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

In 2020, approximately 367 million tons of plastic waste were generated worldwide, 55 million tons of which in Europe[441]. Out of this, it is estimated that between 4.8 and 12.7 Mt of plastics end up in the oceans every year, with between 0.5 and 2.7 Mt coming from rivers[442]. Certain Asian rivers for instance are considered to be a major source of plastic pollution[443]. Other sources estimate that least 14 million tons of this plastic end up in the ocean every year[444].

In total, it is estimated that to date more than 150 million tonnes of plastics have accumulated in the world's oceans[445]. The annual flow of plastic waste into the ocean could almost triple by 2040 to 29 million metric tons per year, equivalent to 50 kg of plastic for every metre of coastline worldwide[446].

Marine litter is a global concern, affecting all oceans. Marine litter travels across oceans due to ocean currents. Marine litter is now present in all marine habitats, from densely populated areas to remote regions, from beaches and shallow waters to deep-ocean trenches[447]. It is estimated that around 40% of plastic waste that reaches the oceans is denser than seawater and therefore sinks to the ocean floor near the coast, while the rest is transported away by the surface currents and/or wind[448].

Marine litter can also accumulate in specific areas of the oceans, because of rotating ocean currents called "gyres" and they can form 'garbage patches' [449]. There are currently five gyres in the ocean: one in the Indian Ocean, two in the Atlantic Ocean, and two in the Pacific Ocean. Garbage patches of varying sizes are located in each of these gyre[450]. Notably, the marine litter present in the garbage patches extends from the surface all the way to the ocean floor, and it includes debris of different size[451]. Garbage patches are expected to grow in the future, and their annual growth rate has been estimated at 2.5% per year (conservative estimate)[452].

[441] Plastics Europe. Plastics- The Facts. See: https://plasticseurope.org/knowledge-hub/plastics-the-facts-2021/

[442] Chassignet *et al* (2021) Tracking Marine Litter With a Global Ocean Model: Where Does It Go? Where Does It Come From?. See: https://www.frontiersin.org/articles/10.3389/fmars.2021.667591/full

[443] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[444] IUCN. Marine plastic pollution. See: https://www.iucn.org/resources/issues-briefs/marine-plastic-pollution

[445] European Commission, Our Oceans, Seas and Coasts. See: https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/index_en.htm

[446] Idem

[447] See footnote 443

[448] Chassignet et al (2021) Tracking Marine Litter With a Global Ocean Model: Where Does It Go? Where Does It Come From?. See: https://www.frontiersin.org/articles/10.3389/fmars.2021.667591/full

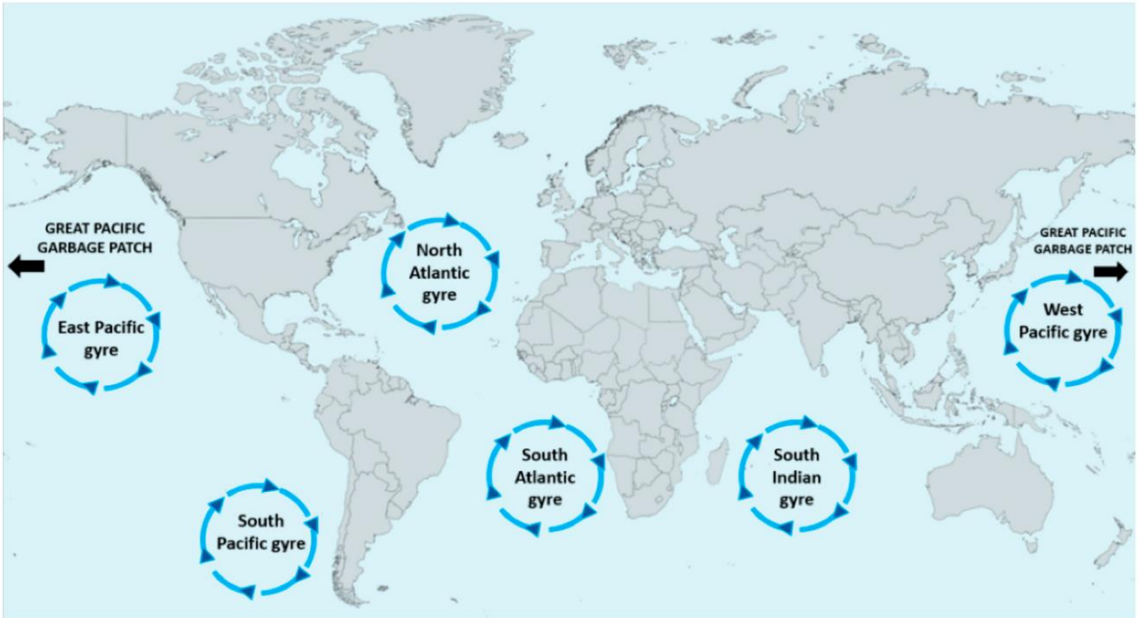
[449] U.S. Department of Commerce, National Oceanic and Atmospheric Administration (2022) Garbage Patches. See: https://marinedebris.noaa.gov/info/patch.html

[450] Idem

[451] Idem

[452] Filho *et al.* (2021) Garbage Patches and Their Environmental Implications in a Plastisphere. See: https://www.mdpi.com/2077-1312/9/11/1289/htm#table_body_display_jmse-09-01289-t002

Figure: Overview of the main gyres (and related garbage patches)



Source: Filho et al (2021)[453]

The main hotspots for marine litter, where there is potential for long-term, large-scale risks to ecosystem functioning and human health are found in the Mediterranean Sea, Arctic Ocean, East and Southeast Asia[454]. This is because of the enclosed nature of the Mediterranean Sea, the specific characteristics and fragilities of the Arctic ecosystem, as well as the sheer volume of uncontrolled waste discharged into the Indian and Pacific Ocean[455].

Marine litter is a significant pressure on the marine environment and its inhabitants. Marine fauna is impacted by litter mainly via entanglement and ingestion. Entanglement and ghost fishing[456] usually threatens larger marine animals, such as top predators, while ingestion affects a wider range of marine organisms. Smothering and damages to benthic organisms are also associated with marine litter. Marine litter can also be a vector for the transport of non-indigenous species, harmful algal blooms and pathogens, that can get dispersed into different environments and impact local ecosystems[457]. Finally, the decomposition of marine litter might cause the release of chemicals that could also impact the marine environment[458].

Despite the growing attention gained by marine litter, much remains unknown about this pressure. Data is scarce from many of the regions that are estimated to mismanage the largest amounts of plastic waste, such as Asia. Data gaps have also been identified in relations to the

[453] See: https://www.mdpi.com/2077-1312/9/11/1289

[454] United Nations Environment Programme (2021) From pollution to solution: a global assessment of marine litter and plastic pollution. See: https://wedocs.unep.org/bitstream/handle/20.500.11822/36963/POLSOL.pdf

[455] Idem

[456] Ghost fishing is a term that describes what happens when derelict fishing gear 'continues to fish and trap animals' once discarded into the oceans.

[457] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[458] Filho et al. (2021) Garbage Patches and Their Environmental Implications in a Plastisphere. See: https://www.mdpi.com/2077-1312/9/11/1289/htm#table_body_display_jmse-09-01289-t002

concentration and distribution of marine litter in open seas and deep sea, including the whole water column down to the seafloor. A lack of standardisation of methods has also been identified as a factor that makes it makes it difficult both to assess and to compare litter densities within and across the different environmental compartments in time and space[459].

Introduction of microplastics

Microplastics are plastic pieces or fragments less than 5 millimetres in diameter. Microplastics can be primary or secondary, depending on whether they are purposefully manufactured as such (e.g. plastics pellets), or whether they are derived from the fragmentation of macro-plastics items[460]. Primary microplastics enter directly into the environment, while secondary microplastics are broken down by solar UV radiation, wind, currents and other natural factors and then enter the oceans. Common sources of secondary microplastics are single-use plastics (e.g., cutlery, trays, straws, cigarette butts, caps and lids, plastic bottles and shopping bags), synthetic textiles and clothing, coatings and paints, and tyres[461]. Atmospheric transport also seems to be an additional pathway through which microplastics enter the ocean[462].

The two main components of primary microplastics released into the oceans are eroded synthetic textiles (34.8%) and vehicle tyres (28.3%). The rest is attributed to "city dust"[463], rests of paint used for road markings and marine coating, among others[464].

[459] Haarr *et al* (2021) Global marine litter research 2015–2020: Geographical and methodological trends. See: https://reader.elsevier.com/reader/sd/pii/S0048969722002522?token=0D5727114F964B742BFD9EF6146D9A8E268EFB1F0616B9A936C60CB2B2A5EF87804D0951CFFE384F16E9FBBFD798888B&originRegion=eu-west-1&originCreation=20220329144547

[460] Secretariat of the Convention on Biological Diversity (2016) Marine Debris: Understanding, Preventing and Mitigating the Significant Adverse Impacts on Marine and Coastal Biodiversity. See: https://www.cbd.int/doc/publications/cbd-ts-83-en.pdf

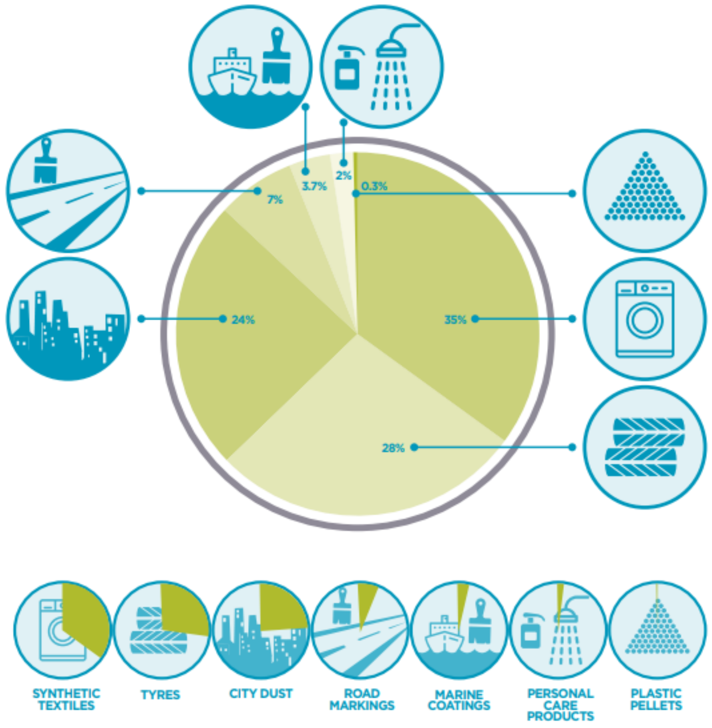
[461] IUCN. Marine Plastic Pollution. See: https://www.iucn.org/resources/issues-briefs/marine-plastic-pollution

[462] See footnote 457

[463] City Dust includes losses from the abrasion of objects (synthetic soles of footwear, synthetic cooking utensils), the abrasion of infrastructure (household dust, city dust, artificial turfs, harbours and marina, building coating) as well as from the blasting of abrasives and intentional pouring (detergents).

[464] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

Figure: Global releases of primary microplastics to the world oceans by source (in %)



Source: IUCN (2017)[465]

It is estimated that between 0.8 and 2.5 Mt of primary microplastics are released into the oceans every year[466], and that the concentration of oceanic microplastics could increase fourfold by 2050, and by 50 times by 2100[467].

Microplastics are a persistent pollutant that is today already present in all marine habitats. Due to their size, microplastics can easily be ingested by organisms, and accumulate throughout the food chain. In addition, they also often contain chemical additives, such as phthalates and brominated flame retardants and capture other contaminants as well. These additional contaminants can therefore also be released into the environment and cause additional exposure for organisms[468]. Microplastics have also been found in seafood, salt, honey, fruits and drinking water – and the impacts on human health are currently being investigated[469].

465 See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

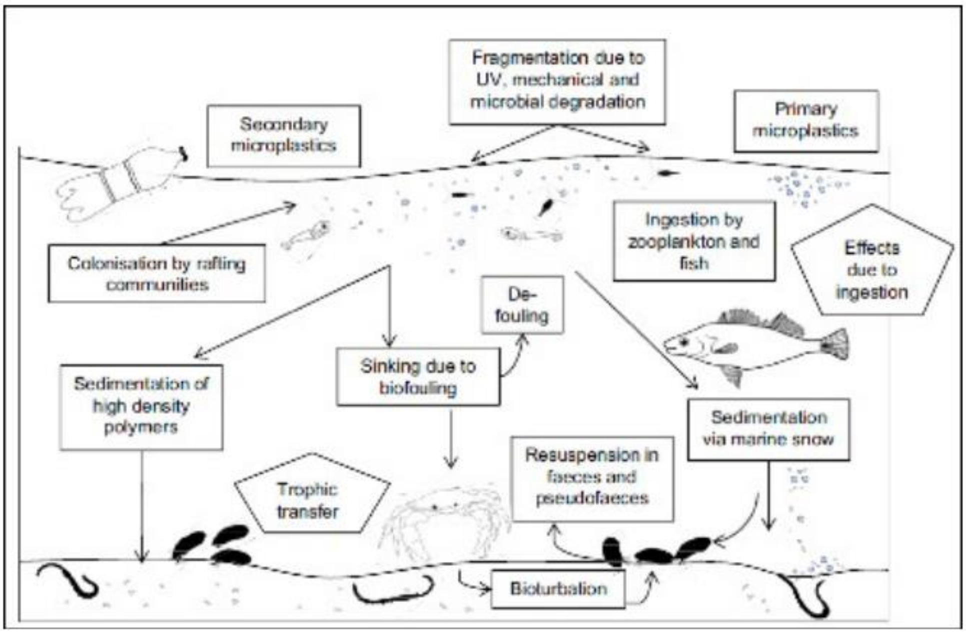
466 IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

467 WWF (2022) Impacts of plastic pollution in the oceans on marine species, biodiversity and ecosystem. See: https://wwfint.awsassets.panda.org/downloads/wwf_impacts_of_plastic_pollution_on_biodiversity.pdf

468 United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

469 United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

Figure: Pathways for the transportation of microplastics and its biological interactions



Source: CBD[470]

Introduction of radionuclides

Radionuclides are atoms that exhibit radioactivity[471]. Radionuclides are naturally present in the environment, but they can also be generated by human activities. They can be released into the marine environment directly via global atmospheric fallout (e.g., in the case of nuclear weapons tests) or from river runoff (e.g., when nuclear waste is released directly into the environment). They may also be discharged directly into the ocean as liquid waste or from dumped solid wastes[472].

Some radionuclides stay in the water in soluble form, whereas others are insoluble or adhere to particles and thus, sooner or later, be transferred to marine sediments[473]. Ocean currents further help these radionuclides travel to other areas of the oceans – so much so that reportedly "all waters, biota and sediments of the ocean all contain radioactivity"[474].

There have been no significant studies of the global distribution of natural or anthropogenic radionuclides since 2017. The most up-to-date information on global levels of natural and anthropogenic radioactivity in the ocean relies on studies conducted between 1995 and 2005. According to those studies, both naturally occurring radioactivity in the ocean and the nuclear sources of anthropogenic inputs of radioactive material are significantly concentrated in the northern hemisphere – with the North-East Atlantic registering the highest levels of

[470] See: https://www.cbd.int/doc/publications/cbd-ts-83-en.pdf

[471] See: https://www.eea.europa.eu/help/glossary/eea-glossary/radionuklide

[472] IAEA (2005) Worldwide marine radioactivity studies (WOMARS): Radionuclide levels in oceans and seas. See: https://www-pub.iaea.org/MTCD/Publications/PDF/TE_1429_web.pdf

[473] Idem

[474] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

concentration of radionuclides[475] which is largely stemming from the deposition following the Chernobyl accident in 1986. In the years following the accident, the contamination from the Baltic Sea spread into the North Atlantic and Arctic Oceans. The Antarctic continent has the lowest prevalence of anthropogenic radionuclides. In the southern parts of the Pacific, Indian and Atlantic Oceans, the concentrations of radionuclides are about 40 times lower than those found in the North-East Atlantic[476].

OSPAR collects information on discharges from the nuclear and non-nuclear sector and on environmental concentrations of indicator radionuclides associated with the nuclear and non-nuclear sectors[477]. In the North-East Atlantic, discharges to the ocean of radioactive substances from nuclear power plants and nuclear reprocessing plants continue to decline[478].

In general, although the ocean contains most of the anthropogenic radionuclides released into the environment, the radiological impact of this contamination is low. Radiation doses from naturally occurring radionuclides in the marine environment (e.g. 210Po), are on the average two orders of magnitude higher[479].

Introduction of air pollutants

Air pollutants such as sulphur dioxide[480], nitrogen oxides[481] and particulate matter can end up in the ocean via wet or dry deposition[482]. Wet deposition is the process whereby atmospheric gases mix with suspended water in the atmosphere and are then washed out through rain, snow or fog (e.g. acid rain is an example of wet deposition). Dry deposition is the free fall to Earth directly from the atmosphere[483].

The largest emissions of sulphur dioxide come from industrial facilities that burn fossil fuels, either to generate electric power or to extract metal from ore (smelter)[484]. For the marine environment, another relevant source of air pollution is the combustion of marine fuel, in particular that with high sulphur content. When combined with water in the atmosphere, sulphur dioxide forms sulfuric acid that is the main component of acid rain[485]. Sulphur dioxides and

[475] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[476] IAEA (2005) Worldwide marine radioactivity studies (WOMARS): Radionuclide levels in oceans and seas. See: https://www-pub.iaea.org/MTCD/Publications/PDF/TE_1429_web.pdf

[477] OSPAR Coordinated Environmental Monitoring Programme. See: https://oap.ospar.org/en/ospar-monitoring-programmes/cemp/

[478] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[479] IAEA (2005) Worldwide marine radioactivity studies (WOMARS): Radionuclide levels in oceans and seas. See: https://www-pub.iaea.org/MTCD/Publications/PDF/TE_1429_web.pdf

[480] Sulfur dioxide (SO2) is a toxic gas released when materials that contain sulfur, an element found in all types of coal and oil resources, are burned. Fine particulate matter (PM2.5) is also produced when SO2 reacts with other air pollutants. See: https://www.greenpeace.org/static/planet4-mena-stateless/a372e5fe-so2-report-english.pdf

[481] Nitric oxide (NOx) is a chemical compound of oxygen and nitrogen which is formed by these reacting with each other during combustion at high temperatures, mainly the combustion of fuels such as oil, diesel, gas and organic material.

[482] Raut et. al (2022) Impact of shipping emissions on air pollution and pollutant deposition over the Barents Sea. See: https://www.sciencedirect.com/science/article/pii/S026974912200046X

[483] World Meteorological Organization. Atmospheric Deposition. See: https://public.wmo.int/en/our-mandate/focus-areas/environment/atmospheric-deposition

[484] Dahiya *et al.* (2020) Global SO2 emission hotspot database. See: https://www.greenpeace.org/static/planet4-mena-stateless/a372e5fe-so2-report-english.pdf

[485] Wankhede (2021) What is Sulphur Oxides or SOx air pollution from Ships? See: https://www.marineinsight.com/maritime-law/what-is-sulphur-oxides-or-sox-air-pollution-from-ships/

nitrogen oxides are also present in the wash water released into the ocean by vessels that use scrubbers to clean the exhaust gas used[486]. Volcanoes are also a major natural source of sulphur dioxide, accounting for around one-third (32%) of present-day sulphur dioxide emissions[487]. Air pollutants can travel for thousands of kilometres before deposition and damage occur.

The deposition of these air pollutants, which are highly soluble, can be damaging to vegetation and water bodies and marine ecosystems. Moreover, nitrogen deposition can also lead to eutrophication and may affect the marine nitrogen cycle. The deposition of sulphuric acid can also increase ocean acidity locally[488]. In particular, in areas with high vessel traffic density, such as the North Sea, the decrease in ocean pH attributable to sulphur dioxide deposition can be higher than that of climate change[489].

These air pollutants can also be harmful to human health causing chronic (e.g. respiratory and cardiovascular) disease and premature death, even at low concentrations[490].

Changes in water properties due to climate change

Large-scale changes in water temperatures

Ocean warming is caused by anthropogenic climate change. Ocean warming is now a well-documented phenomenon and has been described thoroughly in the IPCC Fifth Assessment Report (AR5)[491]. Measurements over the last decade confirm the warming trend of all the layers of the oceans, and in particular the top layers (0-2000 meters). In addition, it is indicated that it is likely that the deeper layers, the abyssal and deep seas, also experience the warming, and that the rate of ocean warming increases since 1993.

Changes in oceans' water temperatures induce a range of effects[492]:

- Changes in water temperatures are not uniform: the upper ocean is being stratified as the warming of the surface ocean are making it less dense over time relative to the deeper ocean. In consequence, the exchange between surface and deep waters is inhibited. This perturbs open ocean nutrient cycles.
- Ocean warming affects marine organisms at multiple trophic levels. It does so by impacting the biogeography of organisms – from phytoplankton to marine mammals. The shift in species range has for consequence a change in communities' composition and even an alteration of interactions between organisms, leading to the alteration of certain ecosystem structures. For instance, warming-induced range expansion of tropical species to higher

[486] Duliere *et at* (2020) Potential impact of wash water effluents from scrubbers on water acidification in the southern North Sea. See: https://www.researchgate.net/publication/341642158_Potential_impact_of_wash_water_effluents_from_scrubbers_on_water_acidification_in_the_southern_North_Sea

[487] Dahiya *et al.* (2020) Global SO2 emission hotspot database. See: https://www.greenpeace.org/static/planet4-mena-stateless/a372e5fe-so2-report-english.pdf

[488] Raut *et al* (2022) Impact of shipping emissions on air pollution and pollutant deposition over the Barents Sea. See: https://www.sciencedirect.com/science/article/pii/S026974912200046X

[489] See footnote 486

[490] See footnote 488

[491] IPCC., (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

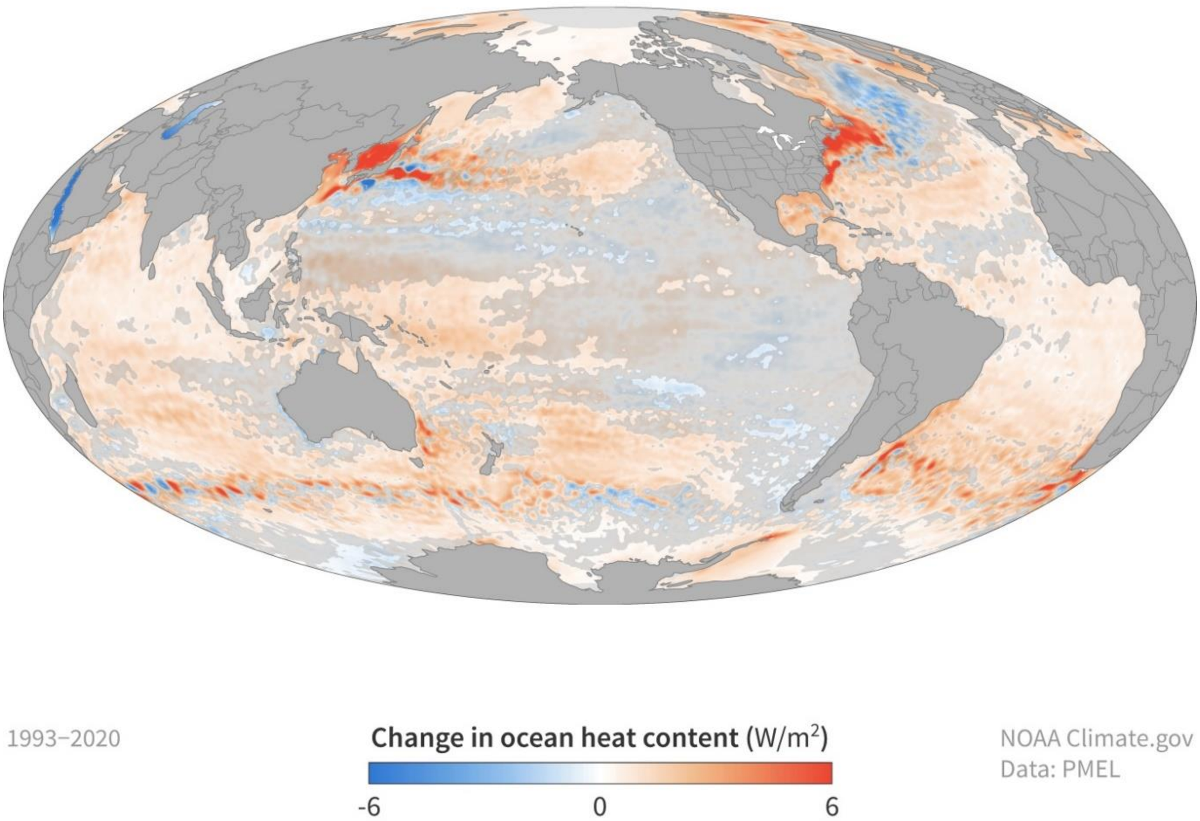
[492] IPCC., (2019). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

latitudes has led to increased grazing on some coral reefs, rocky reefs, seagrass meadows and epipelagic ecosystems, leading to altered ecosystem structure..

- Ocean warming impacts fisheries and ultimately has implications for food production and human communities. As a result of warming-induced changes in spatial distribution and abundance of fish stocks, fisheries catches are impacted and threatens their economic benefits for local communities.

Ocean warming is concentrated in the upper ocean and anthropogenic heat penetrates into the ocean following the established circulation pathways. It is also shown that there is a greater warming between 700 and 2000 meters in the Atlantic than the Pacific or Indian Oceans.

Figure: Ocean heat trends (1993-2020)



Change in heat content in the upper 2,300 feet (700 meters) of the ocean from 1993-2020. Between 1993–2019, heat content rose by up to 6 Watts per square meter in parts of the ocean (dark orange). Some areas lost heat (blue), but overall, the ocean gained more heat than it lost. The changes in areas covered with the grey shading were not statistically significant.
Source: NOAA Climate.gov image, based on data from NCEI.

In the sea-basin reports large-scale change in water temperatures is very commonly listed as a pressure. It is also highlighted as a central issue in the assessments from the 6th Status of Coral Reefs where the impact of ocean warming on coral reef ecosystems is extensively described, more specifically in East Africa, South-East Asia, Australia and Central America seas. Ocean warming is also indicated as a key pressure in the assessment from the Artic Council. Indeed, in Arctic seas, sea surface temperatures are particularly increasing due to the increased absorption of solar radiation as a result of sea ice loss[493]. This causes a risk of marine heatwaves being more frequent and intense in the Arctic.

The scenarios by the IPCC climate models project that in all cases (RCP 8.5 or RCP 2.6) ocean warming will certainly continue and the impacts by 2090 will be substantially larger and more widespread, both throughout the surface and deep oceans. Ultimately, ocean warming is expected to have negative consequences for income, livelihood and food security of the dependent human communities.

Large-scale changes in salinity regime

Salinity is an important factor in determining many aspects of the chemistry of natural waters and of biological processes within it. Changes in salinity regimes are observed and projected to evolve in ways that reflect the increased intensity of the Earth's hydrologic cycle and the increasing near-surface ocean stratification[494].

Salinity is an important ecological factor because it influences the types of organisms that live in the environment. A change in the salinity balance would lead to ecological stress of flora and fauna. In addition, the degree of salinity is a driver of the oceans' circulation. Density changes of waters due to both salinity and temperature changes at the surface of the oceans leads to changes in buoyancy which cause the sinking and rising of water masses. Therefore, changes in salinity of the oceans can have important consequences. For instance, as CO_2 is less soluble in more saline waters, the ability of oceans to store carbon dioxide could be hindered.

Changes in salinity regime of the oceans are expected to be different for surface waters and for subsurface waters[495]. The ocean surface in areas that currently have net evaporation are expected to become saltier, while areas with net precipitation are expected to get fresher. This might lead e.g. to an increasingly salty tropical and subtropical Atlantic and Mediterranean contrasting with a freshening Pacific and polar Arctic. In contrast, it is expected that there will be a freshening of the high latitudes in the north Atlantic, West Pacific and Arctic basin, as a result of hydrological cycle changes and sea ice melting[496]. Salinity regime changes in the subsurface oceans project a freshening of the Antarctic waters and an increased salinity of Mediterranean waters and north Atlantic.

Changes in salinity regime is a pressure described in global assessments such as the SROCC or the Second World Ocean Assessment. It should be noted, however, that not many sea basin reports highlighted it was pressure. It was listed in the reports from the Black Sea, the Red Sea, and the Mediterranean Sea, often described as a result of climate change.

[493] IPCC., (2019). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

[494] Zika, J.D. et al., 2018: Improved estimates of water cycle change from ocean salinity: the key role of ocean warming. Environ. Res. Lett., **13**(7), 074036, doi:10.1088/1748-9326/aace42

[495] IPCC., (2019). IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press.

[496] Rhein, M. et al., 2013: Observations: Ocean. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 255–316.

Salinity regime of the oceans is a complex variable for which there are still gaps in knowledge on both changes in salinity in space and time and on the potential impacts of these changes on marine ecosystems and ocean hydrographical conditions[497].

Large-scale changes in sea level

Sea levels have been monitored consistently for multiple decades now at the global and regional levels. Since 1993, the global mean sea level has been rising at a mean rate of 3.1 ± 0.3 mm per year, with a clear acceleration of approximately 0.1 mm per year[498].

Sea level rise occurs because of global warming. First, glaciers and ice sheets are melting and add water to the oceans. Second, as ocean water temperatures rise, the volume of the oceans expands in a process called ocean thermal expansion. Finally, a decline in the amount of water on land (i.e., in aquifers, lakes and reservoirs, rivers) is caused a by shift of liquid water from land to ocean due to groundwater pumping.

Sea level rise has severe impacts on coastal ecosystems. In addition, these ecosystems are under stress from ocean warming, as well as more frequent and intense extreme weather events and others. An important effect are also impacts on coastal communities which are subject to more severe flooding risk.

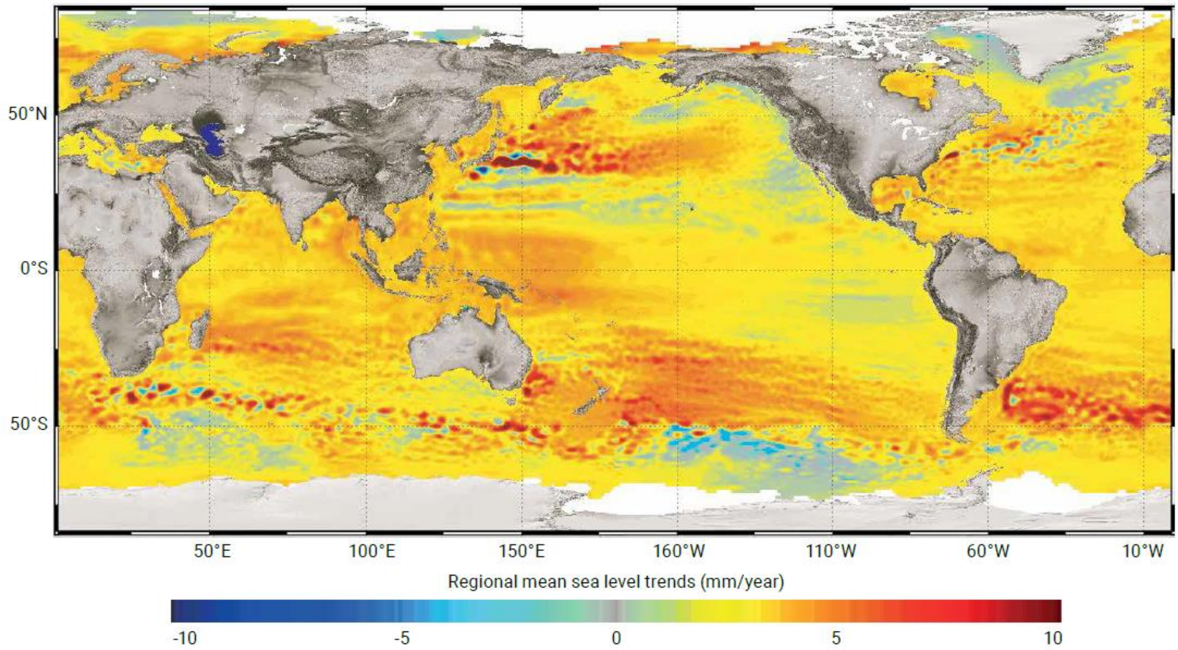
Satellite altimetry has revealed strong regional variability in the rates of sea level change, with regional rates up to two to three times more than the global mean in some regions. In addition, at the local level, additional small-scale processes are added to the global mean and regional sea level components and can make coastal sea levels deviate from open ocean sea level rise[499]. For instance, changes in wind, waves and small-scale currents close to the coast, as well as freshwater input in river estuaries, can modify the density structure of sea waters, and therefore the coastal sea level.

[497] Lehmann, A., Myrberg, K., Post, P., Chubarenko, I., Dailidiene, I., Hinrichsen, H.H., Hüssy, K., Liblik, T., Lips, U., Meier, H.E. and Bukanova, T., (2021). Salinity dynamics of the Baltic Sea. *Earth System Dynamics Discussions*, pp.1-36.

[498] World Climate Research Programme Global Sea Level Budget Group, 2018

[499] Woodworth 2019 WOA volume i

Figure: Regional trend patterns in sea level from satellite altimetry (January 1993 to October 2019)



Source: Copernicus Marine Environment Monitoring Service.

Sea level rise is a pressure that is mentioned frequently in sea basin reports.

Large-scale changes in currents

Major ocean currents play are important contributors to regulating climate and supporting marine life by transporting heat, carbon, oxygen, and nutrients throughout the world's oceans. However, global warming affects those currents by changing their course, slowing them down and weakening them, or otherwise influencing them.

While monitoring of ocean currents is challenging, there is evidence of several of the major global currents changing; also, detailed climate models predict additional changes in the future[500].

For example, the major current around the Antarctic, the Antarctic Circumpolar Current, is expected to move closer to the pole in the future and through this will lead to increased warming in the region, which in turn has effects on the ice shelves.[501] Also, the Atlantic meridional overturning circulation, a major current throughout the Atlantic Ocean (as well as the Pacific and Indian Ocean), shows signs of weakening which is expected to lead to increased extreme weather hazards[502].

[500] Delorme, B., et al. (2017). Ocean Circulation and Climate: an Overview. See: https://www.ocean-climate.org/wp-content/uploads/2017/03/ocean-circulation-climate_ScientificNotes_Oct2016_BD_ppp-3.pdf

[501] See footnote 500

[502] Yin, J. (2021). Influence of the Atlantic meridional overturning circulation on the U.S. extreme cold weather. See: https://www.nature.com/articles/s43247-021-00290-9

Large-scale changes in pH

Ocean acidification (i.e., a decreasing average marine acidity) is caused by the uptake of atmospheric CO2 by the ocean, which changes the chemical composition of the seawater. Ocean surface pH declined from 8.2 to below 8.1 over the industrial era. This decline corresponds to an increase in oceanic acidity of about 30%. In recent decades, ocean acidification has been occurring 100 times faster than during natural events over the past 55 million years.

In addition to being a separate target in the 2030 Agenda (i.e. 14.3), ocean acidification is also recognised in the 'Aichi Biodiversity Targets' in Target 10.

Acidification can lead to several problems, including coral bleaching, creating corrosive conditions for aragonite (a mineral present in the shells and skeletons of marine organisms), and others.

Changes in pH have happened globally. However, there are regional differences, and there is evidence that changes where more strongly pronounced in the North Atlantic, North Pacific, as well as the Southern Ocean.[503] Models consistently project further ocean acidification worldwide. Ocean surface pH is projected to decrease to values between 8.05 and 7.75 by the end of the 21st century, depending on future CO2 emission levels. The largest projected decline represents more than a doubling in acidity[504]. These pH changes are very likely to cause 16–20% of the surface ocean, specifically the Arctic and Southern Oceans, as well as the northern Pacific and north western Atlantic Oceans, to experience year-round corrosive conditions for aragonite by 2081–2100[505].

[503] See glodap data v2 here: https://www.glodap.info/

[504] IPCC (2019). Chapter 5 Changing Ocean, Marine Ecosystems, and Dependent Communities. In: The Ocean and Cryosphere in a Changing Climate A Special Report of the Intergovernmental Panel on Climate Change. See: https://www.ipcc.ch/srocc/

[505] See footnote 504

APPENDIX 3. – DETAILED DESCRIPTION OF ACTIVITIES LEADING TO PRESSURES

Introduction to the Annex

This chapter identifies for each pressure the main activities and drivers leading to them. Those activities have been identified for each pressure as being the most relevant ones, i.e. those, who are the biggest sources of the pressure. It should be noted again that in several cases, those also include land-based sources.

For each activity, where information is available and relevant, the following points are covered:

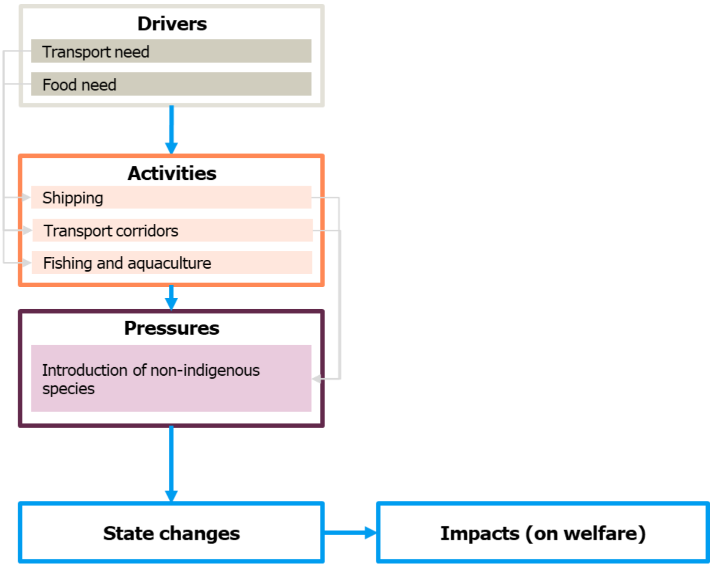
- Information on driver(s) leading to the activity;
- Information on past trends of the activity;
- Information on geographical distribution of activities; and
- Information on specific stakeholder groups involved in the activities.

Biological pressures

Introduction of non-indigenous species

The Figure below summarises the drivers and activities leading to this pressure.

Figure: Flowchart for the pressure



Source: Own illustration

Shipping

Non-indigenous species can be transported as stowaway on ships, boats or other watercrafts. This includes the unintentional transportation of species via fishing vessels or their equipment, as well as species travelling into the ballast water of ships and boats. Sport fishing can also be a source of unintentional introduction.

A 2019 study[506] found that shipping accounts for 60 to 90 percent of the introduction of exotic species into new territories, and that given the steep increase in shipping demand, "the

[506] Nature (2019) Invasive species to surge as ship traffic soars on the high seas. See: https://www.nature.com/articles/d41586-019-00870-y

emerging global shipping network could yield a three-fold to 20-fold increase in global marine invasion risk between now and 2050"[507]. The study also suggests that the rising demand for shipping will promote the spread of non-indigenous species even more than the effects of climate change. Shipping is considered the main vector for non-indigenous species in all sea-basins[508].

Fishing and aquaculture

Non-indigenous species can intentionally be introduced into the marine environment. For instance, alien fish can be introduced to increase local catches or for conservation purposes. Alien species can also be introduced for the purpose of fish farming. The trade in live seafood or live fish bate, as well as the use of aquariums, can also be a cause of introduction of non-indigenous species [509].

Creation of transport corridors

Non-indigenous species can be introduced by travelling along artificially created infrastructure corridors such as artificial waterways connecting previously unconnected water bodies, basins or seas.

Extraction of wild fish species

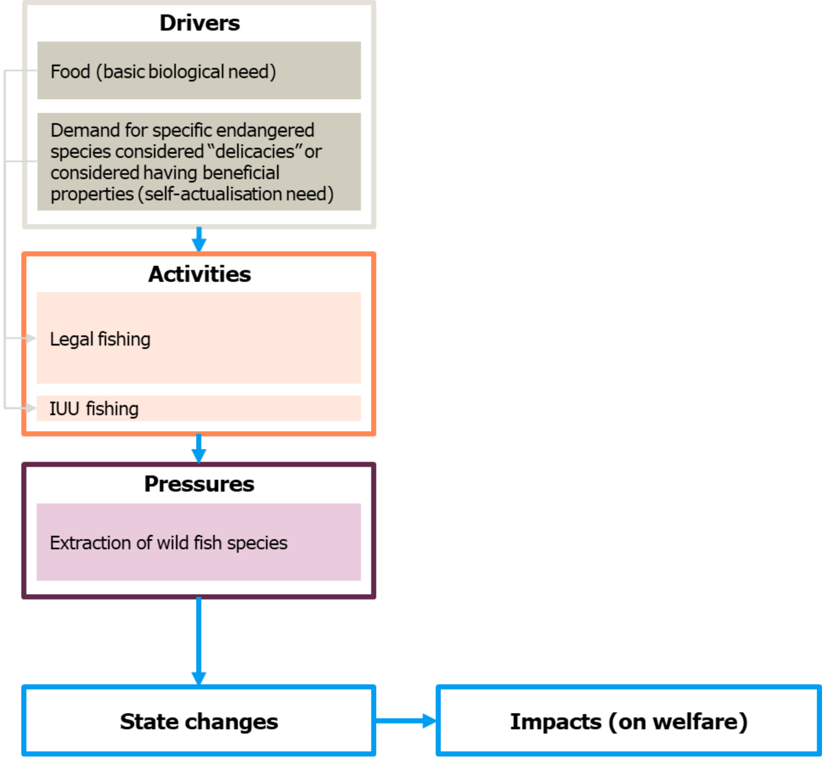
The Figure below summarises the drivers and activities leading to this pressure.

[507] Nature (2019) Invasive species to surge as ship traffic soars on the high seas. See: https://www.nature.com/articles/d41586-019-00870-y

[508] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[509] IUCN. Marine Menace: Alien invasive species in the marine environment. See: https://www.iucn.org/downloads/marine_menace_en_1.pdf

Figure: Flowchart for the pressure



Legal fishing

Fishing is globally an important source of food (animal protein) as well as an important economic sector. Annual per capita consumption of fish is around 20kg on global average, which accounts for around 17% of the consumed animal proteins with differences between world regions[510].

Global landings of marine capture fisheries increased significantly between 1950 and 1990 but has somewhat stabilised since then around 80 million tons annually; in contrast, inland captures have constantly grown from 1950 one but is only around 10 million tons annually.[511]

Fishing is conducted in all seas and oceans worldwide. However, there are differences between regions as shown in the next Figure which gives an overview of capture production per fishing area. It shows that the fishing area for which the capture production is the highest, the Pacific Northwest, fishing outputs have been relatively stable between the 2000s and today[512]. The Arctic and Antarctic Sea basins have seen an increase of more than 100% of the production capture between 2000 and now, i.e., it more than doubled[513]. However, other sea basins have experienced a significant reduction in fisheries, such as the Pacific Southeast (-40%) or the Pacific Southwest (-33%).

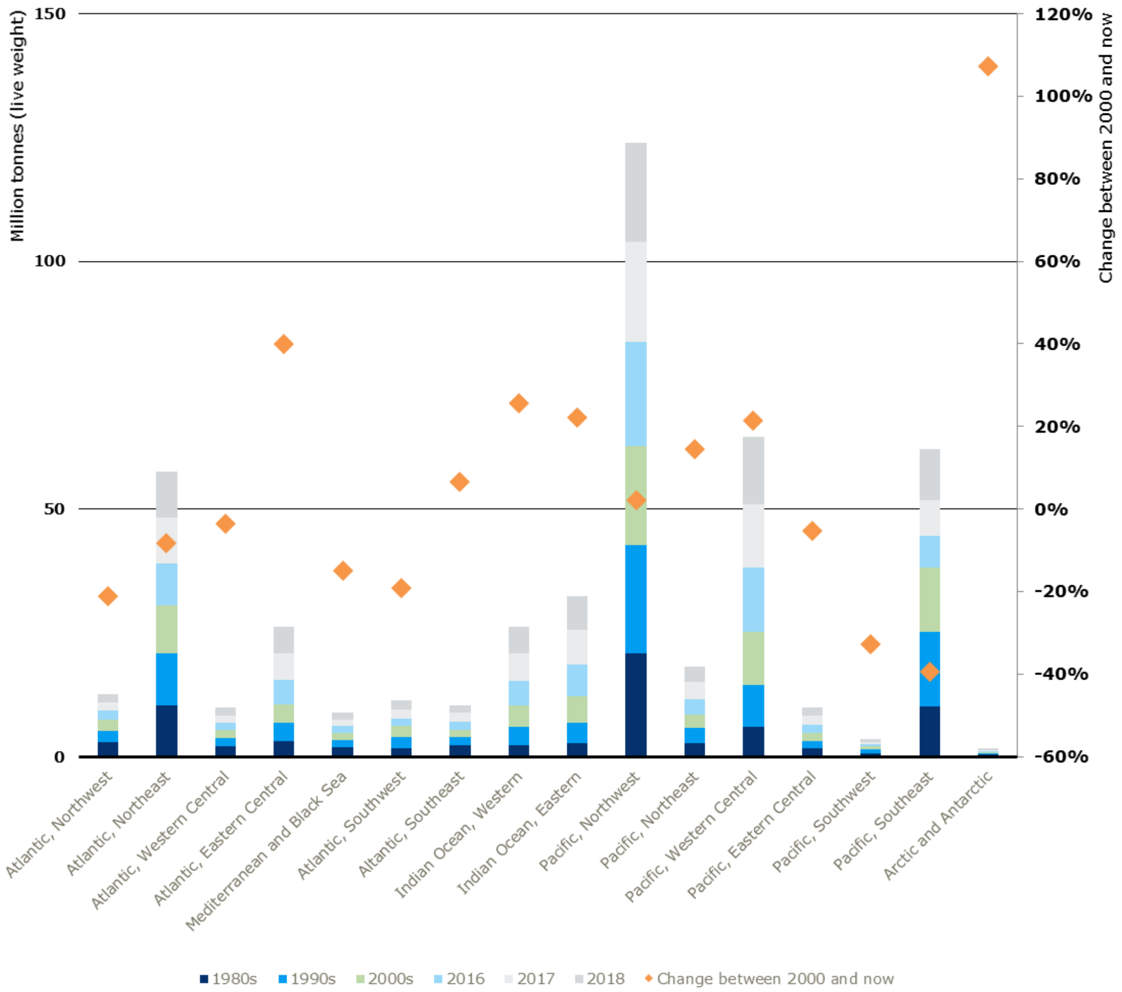
[510] FAO (2021). FAO Yearbook. Fishery and Aquaculture Statistics 2019/FAO annuaire. Statistiques des pêches et de l'aquaculture 2019/FAO anuario. Estadísticas de pesca y acuicultura 2019. See: https://www.fao.org/fishery/en/publications/287024

[511] FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

[512] This change is shown as percentage and in the orange marks. "Now" is defined as the arithmetic average of the last three years for which data is available, i.e. 2016 to 2018, to even out annual changes

[513] See footnote 512

Figure: Fishing areas and capture production[514]



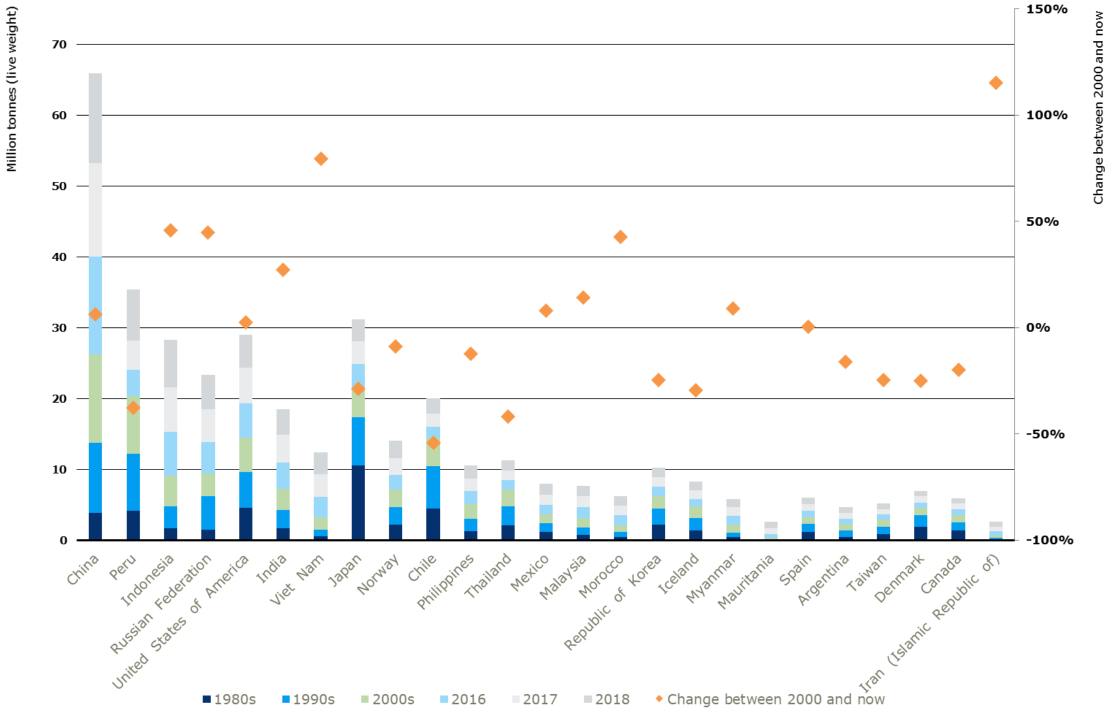
Source: Own illustration based on data in Table 4 in FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

It should be noted that many fishing fleets operate globally and that the distribution above thus does not represent the fishing done by fleets of neighbouring countries to the respective fishing areas.

The next Figure presents the fishing done per country for the top 25 countries in terms of marine capture production, which together account for 80% of global catches.

[514] The changes between the 200s and now are plotted against the secondary vertical axis (on the right). The 2000s value is compared to the arithmetic average of the years 2016-2018 to even out annual changes.

Figure: Marine capture production[515]

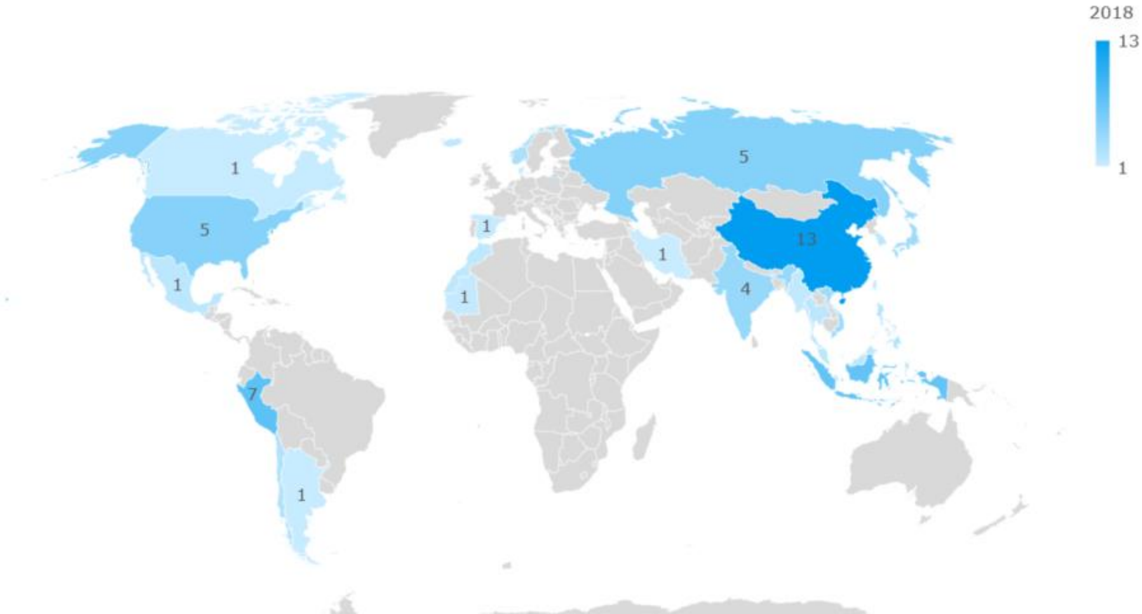


Source: Own illustration based on data in Table 2 in FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

Those 25 countries and their marine captures in the latest year for which data is available (2018) are shown in the map below.

[515] The changes between the 200s and now are plotted against the secondary vertical axis (on the right). The 2000s value is compared to the arithmetic average of the years 2016-2018 to even out annual changes. Not pictured is the change for Mauretania for which the change was more than 300%.

Figure: Map of major producing countries and their captures in 2018 (in million tons)



Source: Own illustration based on data in Table 2 in FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. See: https://doi.org/10.4060/ca9229en

Globally, there are around 39 million fishermen[516] and several million more are employed in the sector. It is estimated that small-scale fisheries employ more than 90% of the people involved in capture fisheries; also, around 90% of the catches from small-scale fisheries are destined for local human consumption, thus making a sizable contribution to food security and nutrition.

However, over the last 10 years or so there has been a growing globalisation trend in fishing, which increases the vulnerability of small-scale fisheries to the depletion of some locally important stocks.[517]

Illegal, unreported and unregulated (IUU) fishing

Illegal, unreported and unregulated (IUU) fishing is a broad term that captures a wide variety of fishing and fishing related activities, such as fishing without a valid license, fishing in a restricted area, or fishing in a way non-consistent with national laws or international obligations[518]. This exacerbates efforts of fishing at sustainable levels and thus can endanger fish stocks and ecosystems.

[516] FAO (2021). FAO Yearbook. Fishery and Aquaculture Statistics 2019/FAO annuaire. Statistiques des pêches et de l'aquaculture 2019/FAO anuario. Estadísticas de pesca y acuicultura 2019. See: https://www.fao.org/fishery/en/publications/287024

[517] UN (2021). Chapter 15 Changes in capture fisheries and harvesting of wild marine invertebrates. In: The Second World Ocean Assessment. See: https://www.un-ilibrary.org/content/books/9789216040062

[518] A comprehensive definition of IUU fishing is provided in the FAO International Plan of Action. Available at: http://www.fao.org/3/Y3536E/y3536e04.htm

While exact data on this is challenging to produce, it is estimated that in 2016, IUU fishing was responsible for annual catches of up to 26 million tons[519]; this would be more than 40% of legal catches of the top 25 countries mentioned in the last section.

No data is available on past trends of IUU fishing, i.e., how it developed over the years and if numbers are decreasing thanks to international and national measures being taken, such as the Agreement on Port State Measures to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing (PSMA) which was adopted by the FAO Conference in 2009 and entered into force in 2016[520].

Also, regarding current prevalence of IUU fishing across the globe only very limited data is available. One data source is the "IUU Fishing Index"[521] which rates countries globally, among others, on prevalence of IUU fishing based on a wide range of indicators[522]. Based on this data, the map below presents the 25 worst rated countries globally in terms of prevalence of IUU fishing.

Figure: Prevalence of IUU fishing in 2021 based on data from the IUU Fishing Index[523]

Source: Own illustration based on data from the "IUU Fishing Index".

Regarding higher prevalence of IUU fishing in small-scale fishing on the one hand and industrial fishing on the other hand, very little information seems to exist. However, there seems to be evidence that IUU fishing is more significant in industrial fishing than in small-scale fishing.[524]

[519] FAO (2016c). The FAO Agreement on Port State Measures (PSMA) to Prevent, Deter and Eliminate Illegal, Unreported and Unregulated Fishing. See: www.fao.org/port-state-measures/en

[520] See here for more information: https://www.fao.org/port-state-measures/en/

[521] See: https://www.iuufishingindex.net/

[522] For the full methodology see here: https://www.iuufishingindex.net/methodology.pdf

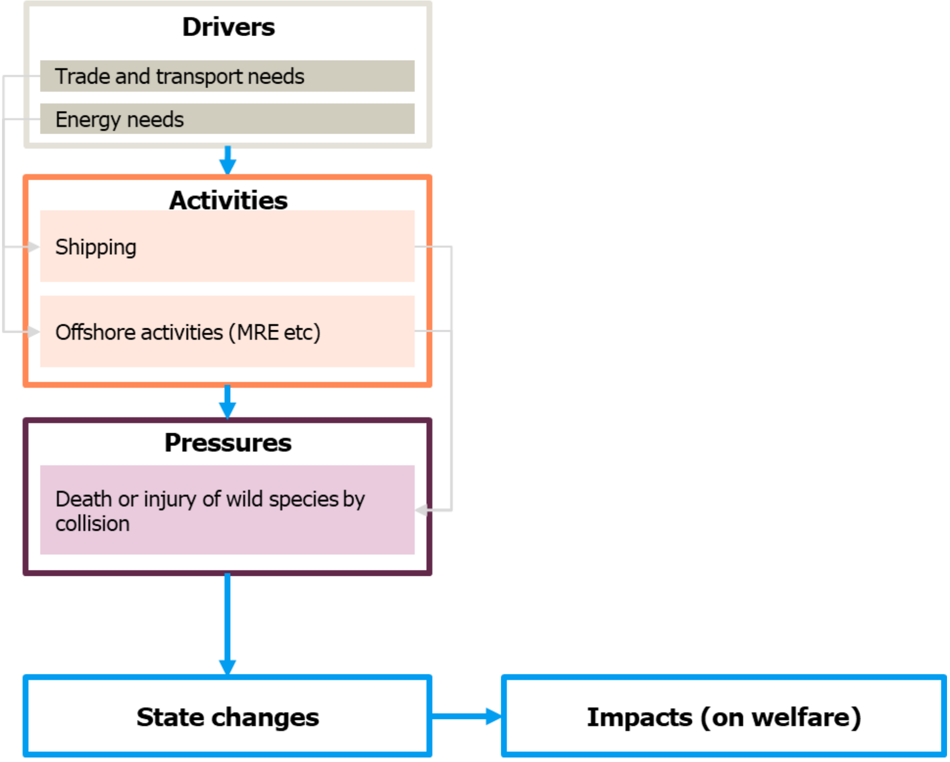
[523] As all indicator frameworks, the results of this index should be treated with caution. A full disclaimer for the data can be found on the following page: https://www.iuufishingindex.net/data-files

[524] FAO (2008). Small-scale capture fisheries: A global overview with emphasis on developing countries. See: http://pubs.iclarm.net/resource_centre/Big_Numbers_Project_Preliminary_Report.pdf

Death or injury of wild species by collision

The Figure below summarises the drivers and activities leading to this pressure.

Figure: Flowchart for the pressure



Source: Own illustration

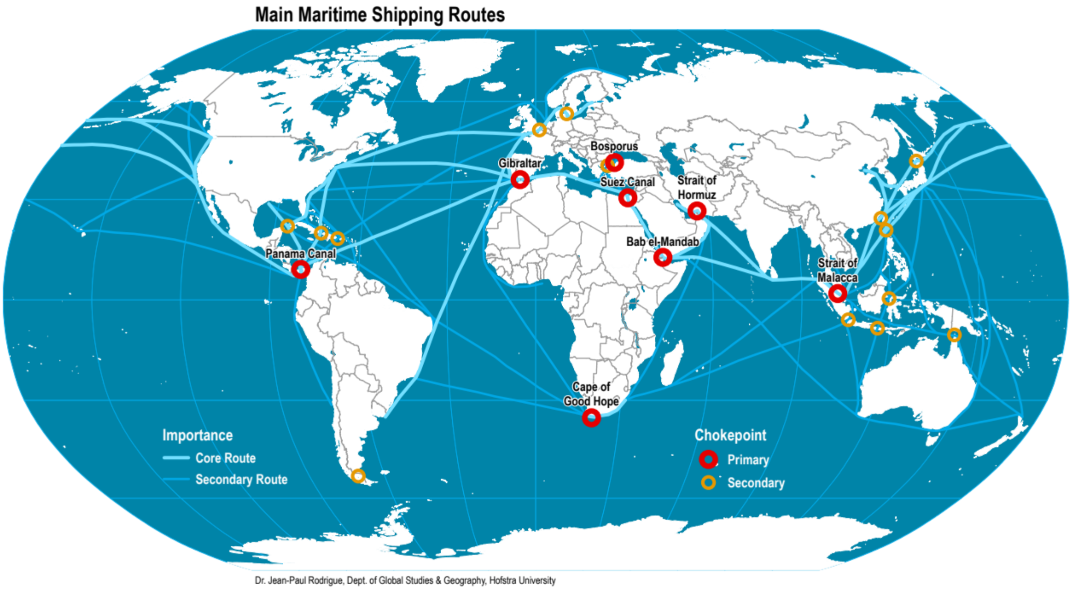
Shipping

Shipping is one of the main causes of collision. Wild species can collide with vessels, most commonly with their bow or propeller, and this causes physical trauma or death of the animal. These events can cause serious damage to vessels, as well as people on board when the animal is of large size. With the increase in the use of large commercial vessels, collisions with wild species are becoming a growing concern globally[525].

Collision risk is higher in areas where high levels of marine traffic coincide with biodiversity hotspots, as well as areas where vessel speed is high. The map below provides an overview of the main shipping routes globally, showing how the Atlantic, Indian and Pacific oceans are all sea-basins with high traffic.

[525] See: https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

Figure: Main maritime shipping routes



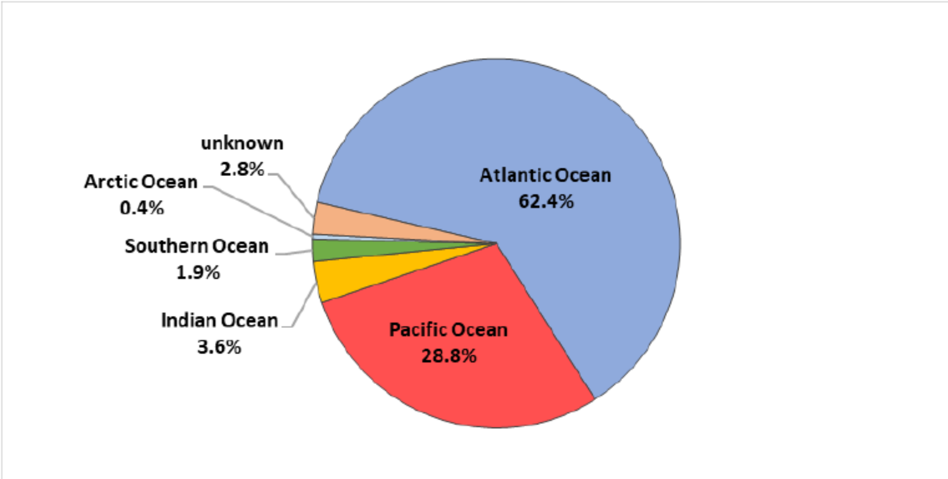
Source: https://transportgeography.org/wp-content/uploads/Map_Main-Maritime-Routes.pdf

With the receding of sea ice, it is also likely that the Arctic will become a more common shipping and tourism route in the future, and therefore this risk could extend to this area[526].

A global assessment of ship strikes is only available for collisions with whales, and the data is summarised in the following Figure.

[526] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

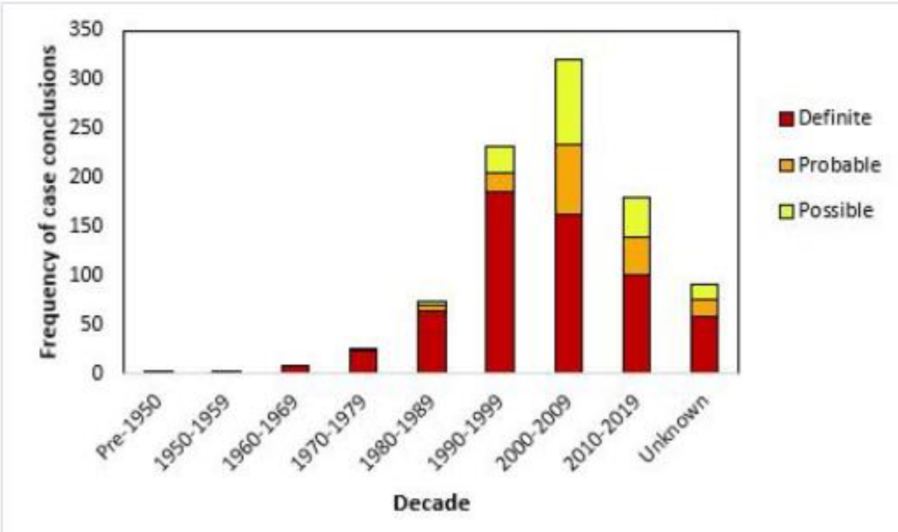
Figure: Ship strikes on cetaceans per ocean, by ocean basin (1820 - 2019)



Source: Winkler et al (2020), from IWC Ship Strike Database[527]. Total number of registered strikes is 933

Based on the data collected on that database, ship strikes increased in the decade 2000-2009, but then decreased again in the past decade.

Figure: Ship strikes on cetaceans per decade, by case conclusion (1820 - 2019)



Source: Winkler et al (2020), from IWC Ship Strike Database[528]

[527] Winker et al (2020) Global Numbers of Ship Strikes: An Assessment of Collisions Between Vessels and Cetaceans Using Available Data in the IWC Ship Strike Database.

[528] Winker et al (2020) Global Numbers of Ship Strikes: An Assessment of Collisions Between Vessels and Cetaceans Using Available Data in the IWC Ship Strike Database. See: https://www.researchgate.net/publication/342734400_Global_Numbers_of_Ship_Strikes_An_Assessment_of_Collisions_Between_Vessels_and_Cetaceans_Using_Available_Data_in_the_IWC_Ship_Strike_Database_Report_to_the_International_Whaling_Commission_IWC68BSC_HI

Offshore activities

Wild species can also collide with offshore installations such as marine renewable energy installations. For instance, fish might get caught in underwater turbines, or marine birds and bats might collide with offshore wind farms. Wild species such as marine mammals might also get entangled in mooring lines, cables and anchors[529].

Offshore wind is projected to "play an important role in future energy systems"[530]. Global installed offshore capacity has been growing rapidly over the last decades and is projected to expand globally in the future[531]. At the end of 2020, around 35 GW of offshore wind capacity was installed across the world, 14 times higher than 10 years ago[532]. China and the UK are the largest deployers of offshore wind, followed by Germany.

Collision risk with offshore installations is poorly monitored, therefore an overview at the global level is not available. In fact, despite the potential for collisions, the frequency of occurrence of these events and their consequences are largely unknown[533].

Introduction of microbial pathogens

The Figure below summarises the drivers and activities leading to this pressure.

529 United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

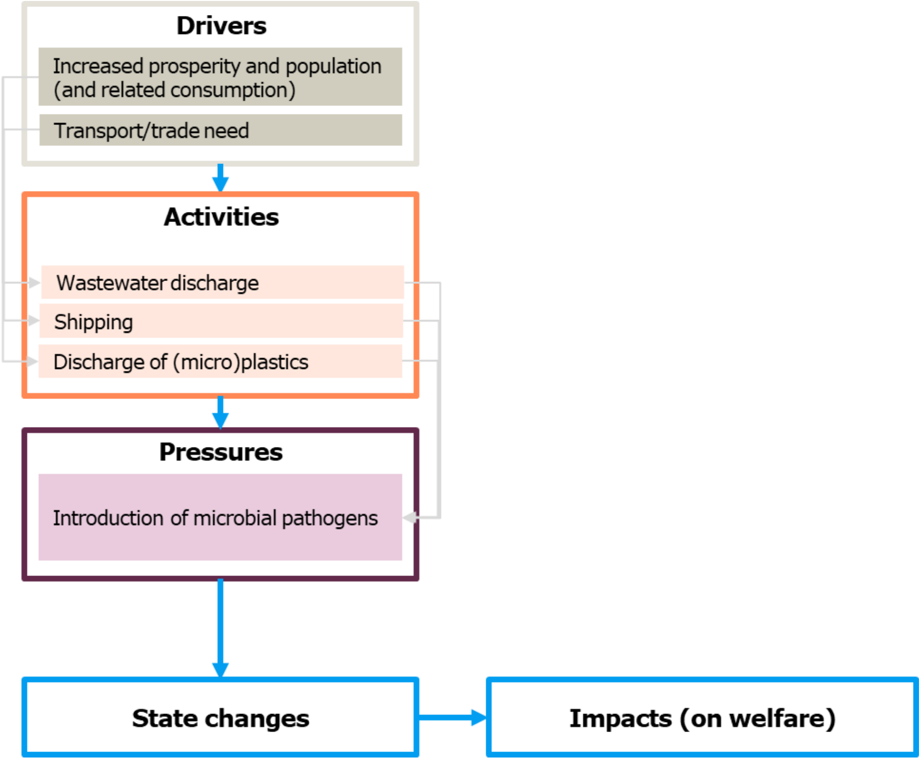
530 IEA (2019) Offshore Wind Outlook 2019. See: https://www.iea.org/reports/offshore-wind-outlook-2019

531 United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

532 Global Wind Energy Council (2021) Global Offshore Wind Report 2021. See: https://gwec.net/wp-content/uploads/2021/09/GWEC-Global-Offshore-Wind-Report-2021.pdf

533 Sparling et al.(2020). Collision Risk for Animals around Turbines. See: https://tethys.pnnl.gov/sites/default/files/publications/OES-Environmental-2020-State-of-the-Science-Ch-3_final_hr.pdf

Figure: Flowchart for the pressure



Source: Own illustration

Wastewater discharge

Sewage water can contain microbial pathogens. When untreated or poorly treated sewage is discharged into the marine environment, this can lead to the dispersion of microbial pathogens[534]. This can happen in areas that do not have well-functioning sewage systems; or where the sewage system is unable to contain excess run-off in case of heavy rainfalls or flooding[535].

Globally, around 60% of people are connected to a sewer system. High-income countries usually rely on centralised sewer systems, while developing countries mostly treat their wastewater through decentralised or self-provided services.

Around 44% of household wastewater worldwide is not safely treated[536] (see map below for the geographical distribution), and over 80% of wastewater is released into the environment without adequate treatment[537]. Moreover, it appears that incomplete disinfection of faecal waters, even in effluents from wastewater treatment plants with tertiary treatment (the most advance form of treatment) is "commonplace"[538].

[534] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

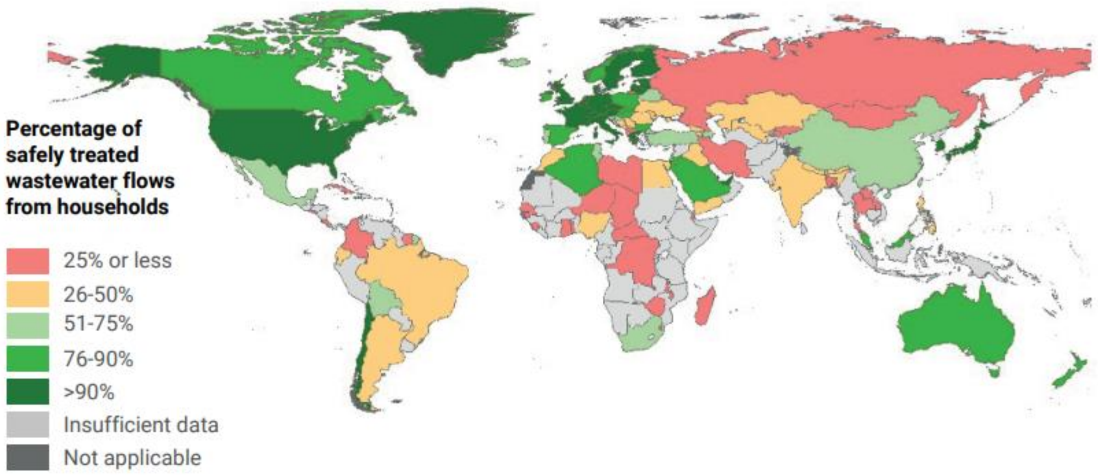
[535] Idem

[536] United nations (2021) Summary Progress Update 2021: SDG 6 — water and sanitation for all. See: https://www.unwater.org/app/uploads/2021/12/SDG-6-Summary-Progress-Update-2021_Version-July-2021a.pdf

[537] WWAP (United Nations World Water Assessment Programme) (2017) The United Nations World Water Development Report 2017. See: http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/

[538] Beiras (2018) Chapter 4 - Microbial Pollution. See: https://www.sciencedirect.com/science/article/pii/B9780128137369000040?via%3Dihub

Figure: Estimated proportions of household wastewater safely treated (2020)



Source: UN (2021)[539]

Shipping

Microbial pathogens can be transferred by vessels via ballast water and hull fouling[540]. They can get onboard at ports, and then get discharged at other ports or in the high seas. Ports with high connectivity to other ports can be major hotspots for the transfer of these pathogens[541].

Certain pathogens may die during long travels, while others can survive and colonise recipient habitats at different ports, or on the high seas, when ballast water is discharged. The survival rate depends on the type of pathogen and recipient habitat[542]. Pathogens such as cholera (Vibrio cholera) have been found in ballast water[543].

While no comprehensive monitoring of this phenomena is available, it is considered likely that the prevalence of micro-organisms associated with vessel biofouling might be growing together with the increase in shipping.

[539] See: https://www.unwater.org/app/uploads/2021/09/SDG6_Indicator_Report_631_Progress-on-Wastewater-Treatment_2021_EN.pdf

[540] Hull fouling refers to the way organisms can attach themselves to the hull of a ship during a voyage and transport themselves long distances this way.

[541] Costello et al (2022) Assessing the potential for invasive species introductions and secondary spread using vessel movements in maritime ports. See: https://reader.elsevier.com/reader/sd/pii/S0025326X22001783?token=2461A0D8C95B515ED6B0FE7D619DF81A51660D6082E41F922D9C84FCAA9EC9549C7BE1F69967F172BAFF555F217C63B3&originRegion=eu-west-1&originCreation=20220329152546

[542] Georgiades et al (2021) The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges. See: https://www.frontiersin.org/articles/10.3389/fmars.2021.660125/full

[543] International Maritime Organization (IMO) Ballast water management - the control of harmful invasive species. See: https://www.imo.org/en/MediaCentre/HotTopics/Pages/BWM-default.aspx

Discharge of (micro)plastics

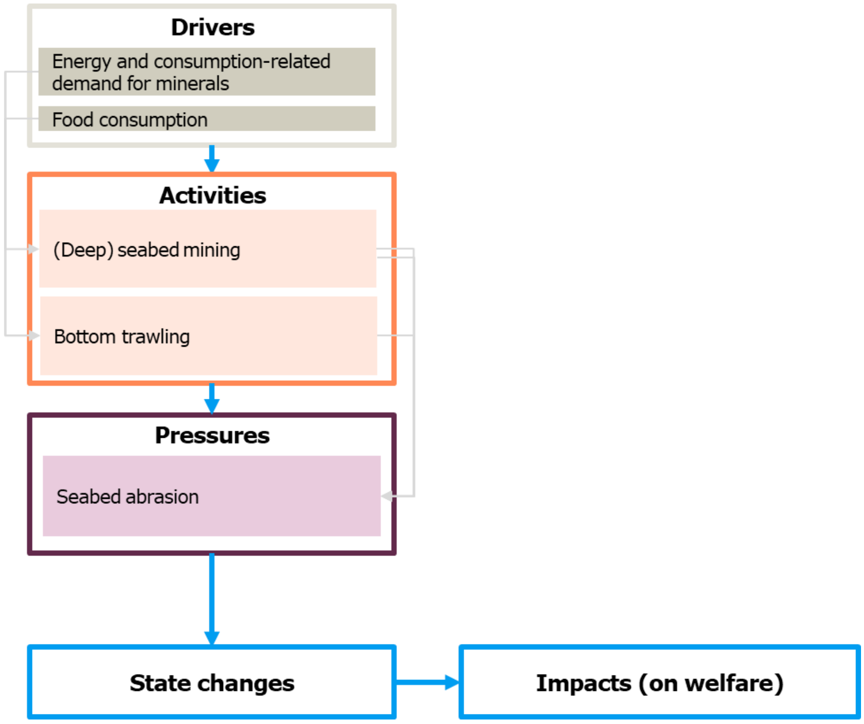
Macro and microplastics are emerging as a potential vector for microbial pathogens in the seas. In particular, microplastics found in ballast water is considered as a potential vector for the transfer of these pathogens across the globe[544].

Physical pressures

Seabed abrasion

The Figure below summarises the drivers and activities leading to this pressure.

Figure: Flowchart for the pressure



Source: Own illustration

Seabed mining

The demand for minerals has been growing steadily in the past century. It is expected that this demand will continue to grow in the coming decades, in particular as minerals will play a key role in the green transition. Minerals and metals such as aluminium, cobalt, copper, iron ore, lead, lithium, nickel, manganese, rare earth metals (e.g. cadmium, molybdenum, neodymium, and indium) as well as silver, stell, titanium and zinc are necessary for the deployment of renewable energy technologies such as solar and wind, as well as for the production of the

[544] Naik et al (2019) Microplastics in ballast water as an emerging source and vector for harmful chemicals, antibiotics, metals, bacterial pathogens and HAB species: A potential risk to the marine environment and human health. See: https://pubmed.ncbi.nlm.nih.gov/31470206/

necessary energy storage batteries[545]. The demand for metals used to produce wind and solar technologies is expected to double if the Paris Agreement goals are to be achieved. That of metals for energy battery storage technologies is expected to increase by more than 1,000 %. A more recent report by the IEA indicates that "in a scenario that meets the Paris Agreement goals, their share of total demand rises significantly over the next two decades to over 40% for copper and rare earth elements, 60-70% for nickel and cobalt, and almost 90% for lithium."[546]

These metals are currently mostly sourced from land-based reserves. The quality of resources is decreasing across a range of commodities, and the growing scrutiny around environmental and social performance of production and processing of minerals might disrupt supply if left unaddressed. Finally, many land-based mineral reserves are increasingly exposed to climate hazards, which can also disrupt supply[547].

Because of this, and the growing demand for metals, other avenues for their sourcing are being explored, including seabed mining. This includes both nearshore mining (between 0 and 200 miles from the coast), as well as offshore mining (beyond 200 miles from the coast)[548]. Deepwater seabed mining refers to mining that takes place 200 meters below the ocean surface[549]. Offshore mining can be undertaken both within national jurisdiction and beyond.

Nearshore mining is well established within the Exclusive Economic Zones of many countries worldwide. Aggregates are currently the most mined materials in the marine environment and demand for this material is growing. For instance, sand and gravel mining takes place in Western European countries, diamond mining in Namibia, tin mining in South-East Asian countries, ironsand mining in New Zealand[550].

Commercial mining of the deep seabed is not currently performed, but a number of exploration licenses were granted in the last years, within national jurisdictions, and the first deep-water seabed test mining was carried out for the first time in 2017, in Japan. Pacific Island States are also working on the development of seabed mining legislation for areas within national jurisdiction[551]. It is projected that most of the deep water seabed mining activities will occur in areas beyond national jurisdiction[552].

[545] The World Bank (2017) The Growing Role of Minerals and Metals for a Low Carbon Future. See: https://documents1.worldbank.org/curated/en/207371500386458722/pdf/117581-WP-P159838-PUBLIC-ClimateSmartMiningJuly.pdf

[546] IEA (2021) The Role of Critical Minerals in Clean Energy Transitions Report extract Executive summary. See: https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

[547] Idem

[548] Allsopp *et al.* (2013) Review of the Current State of Development and the Potential for Environmental Impacts of Seabed Mining Operations. See: https://www.greenpeace.to/greenpeace/wp-content/uploads/2013/07/seabed-mining-tech-review-2013.pdf

[549] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[550] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[551] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[552] Idem

Bottom trawling

Bottom trawling is the considered to be the most widespread human activity affecting seabed habitats"[553] However, only limited information is available on the exact extent to which bottom trawling takes places, and its geographic distribution, in particular at the global level.

One-quarter of wild marine landings, around 19 million tons of fish per year, are caught through bottom trawling worldwide[554]. The impact of bottom trawling is determined by the type of gear deployed, the type of seabed affected, direct effects of the passage of a trawl, the footprint of the trawl and the trawling frequency and the sensitivity of the seabed and benthic ecosystem[555].

A study on the footprint of bottom trawling[556], performed on 24 selected regions of Africa, the Americas, Australasia, and Europe, showed that less than 10% of the analysed sea bed areas were trawled overall. However, the situation changes when looking at specific areas. In particular, trawling takes place in around 10-30% of the analysed seabed areas in the Irish Sea, North Benguela Current, South Benguela Current, Argentina, East Agulhas Current, and west of Scotland, and between 30-81% of the analysed seabed areas were trawled in the northeast Atlantic and Mediterranean. In general, European seas were the most frequently trawled among the analysed regions. More than one-half of the analysed seabed area in the Adriatic Sea is trawled at least once per year, on average, and over one-quarter of the analysed seabed area is trawled with the same frequency in five of the other eight European seas[557] (see figure below).

[553] Hiddink *et al.* (2017) Global analysis of depletion and recovery of seabedbiota after bottom trawling disturbance. See: https://www.pnas.org/doi/epdf/10.1073/pnas.1618858114

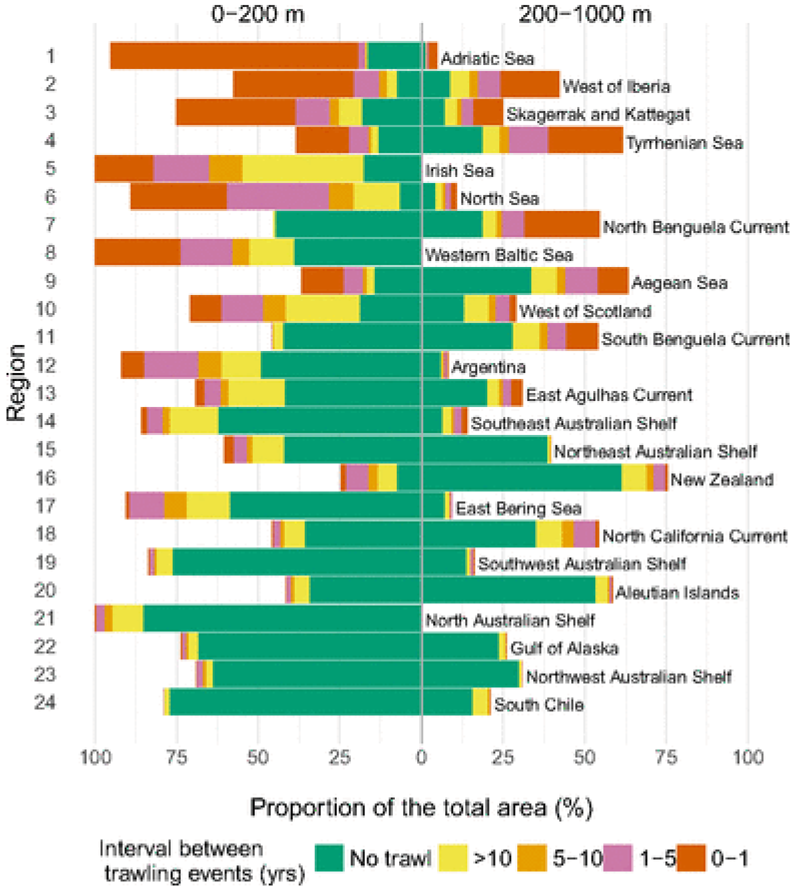
[554] Amoroso *et al.* (2018) Bottom trawl fishing footprints on the world's continental shelves. See: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6205437/

[555] Eigaard et al. (2017) The footprint of bottom trawling in European waters: distribution, intensity, and seabed integrity. See: https://academic.oup.com/icesjms/article/74/3/847/2631171

[556] The study considered bottom trawling as all towed gears making sustained contact with the seabed, including beam and otter trawls and dredges. Footprints were defined as the area of seabed trawled at least once in a specified region and time period, with area trawled determined from gear dimensions and tow locations. See: https://www.pnas.org/content/115/43/E10275#sec-1

[557] See footnote 553

Figure: Proportion of total area trawled and frequency of trawling, selected regions (2015-2018)



Proportions of the total area of each region, at depths of 0–200 and >200–1,000 m, trawled at different frequencies. Region code numbers increase as regional SAR[558] decreases. Source: Amoroso et al (2018) Bottom trawl fishing footprints on the world's continental shelves[559]

Another study[560], conducted at the EU-level, showed that bottom trawling hotspots, where trawling takes place more than 10 times per year, occur in localised areas. These are mainly the coast of northern Norway, areas off the coasts of Ireland and United Kingdom, south and west of Portugal, and the coasts of Italy and other coasts of the Adriatic Sea.

Pollution pressures

Introduction of underwater noise

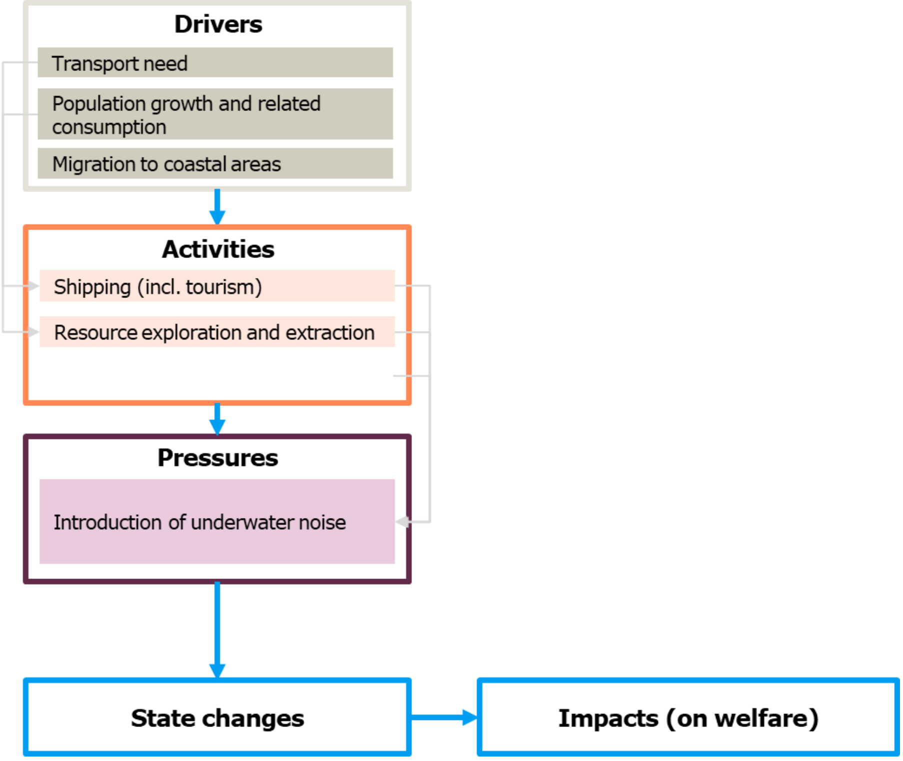
The Figure below summarises the drivers and activities leading to this pressure.

[558] SAR is defined as the total area swept by trawl gear over a defined time period (usually 1 y) divided by the total seabed area at a defined spatial scale (usually from grid cell to region). The total area swept within a defined area (e.g., a grid cell) is calculated as the product of trawling time, towing speed, and dimensions of gear components contacting the seabed.

[559] Amoroso *et al.* (2018) Bottom trawl fishing footprints on the world's continental shelves. See: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6205437/

[560] Eigaard et al. (2017) The footprint of bottom trawling in European waters: distribution, intensity, and seabed integrity. See: https://academic.oup.com/icesjms/article/74/3/847/2631171

Figure: Flowchart for the pressure

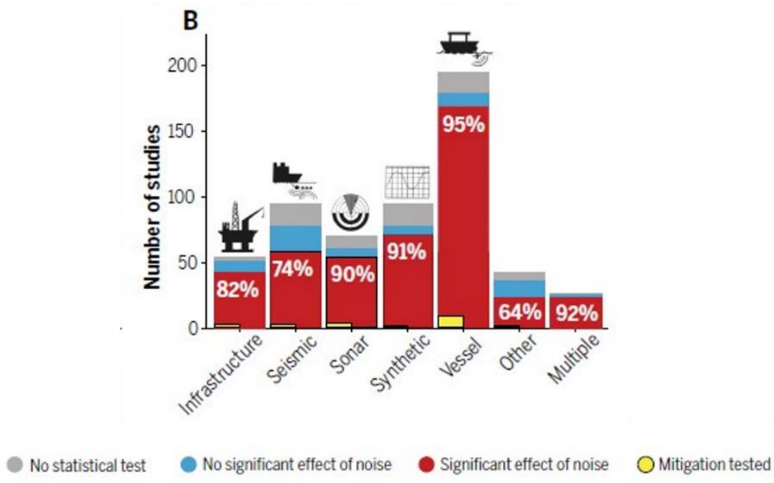


Source: Own illustration

Shipping (incl. tourism)

The most relevant source of noise is marine vessels (e.g., merchant ships, fishing vessels and recreational and cruise ships).

Figure: Overview of the effects of different human activities on underwater noise as presented in literature



Source: Duarte et al (2021) The soundscape of the Anthropocene Ocean. See: https://www.science.org/doi/10.1126/science.aba4658

Noise comes from cavitation, turbulence generated by propellers and machinery. There is also noise generated as the ship advances on the water. However, the level of noise generated depends on physical variables such as ship's dimensions, tonnage, draft, load and speed, as well as wind and sea conditions[561].

A study estimated that increased shipping has contributed to a 32-fold increase in the low-frequency noise present along major shipping routes, in the past 50 years[562]. Coastal regions are the most affected, as vessel concentration increases noise considerably – despite the fact that vessel noise does not propagate far in shallow waters. Notably, vessel noise is also prominent in ocean regions that are far away from shipping lanes, because of the long-range propagation at low-frequency[563].

Resource exploration and exploitation

Resource exploration and exploitation can generate underwater noise through a number of activities such as seismic surveys, drilling and production phases, generation of energy on the platforms, and installation of pipelines for oil and gas exploration and extraction; renewable energy development and deployment (i.e. power-generating wind turbines in deeper waters, as well as other forms of ocean energy); and others[564]. These activities, undertaken at different levels (i.e. onshore, shoreline, nearshore or offshore) produce a compound impact that is to this day poorly understood[565].

.

Introduction of substances leading to eutrophication

The Figure below summarises the drivers and activities leading to this pressure.

[561] Richardson *et al.* (1995). *Marine Mammals and Noise*. San Diego: Academic Press. See: https://doi.org/10.1016/B978-0-08-057303-8.50003-3.

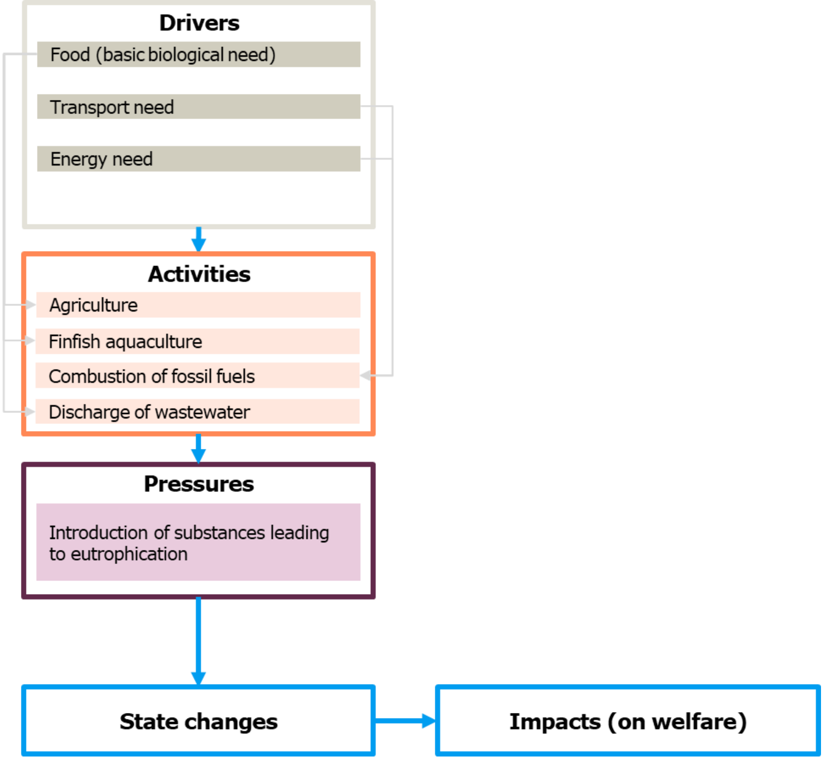
[562] Ritts and Bakker (2021) Conservation acoustics: Animal sounds, audible natures, cheap nature, Geoforum, See: https://www.sciencedirect.com/science/article/abs/pii/S0016718521001214

[563] Idem

[564] Richardson *et al.* (1995). *Marine Mammals and Noise*. San Diego: Academic Press. See: https://doi.org/10.1016/B978-0-08-057303-8.50003-3.

[565] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

Figure: Flowchart for the pressure



Source: Own illustration

Agriculture

Agriculture is the main source of food of the global population. Agricultural practice and output have been constantly growing globally over at least the last decades.[566] Fertilisers (artificial or natural) are used globally in the majority of agriculture land in order to maintain and increase the fertility of soils used for agriculture. Fertiliser use is especially high in intensive farming in order to increase agricultural outputs. While fertiliser use can be beneficial in increasing agricultural output, it is also one of the main sources of inputs of substances leading to eutrophication through runoff from agricultural areas; consequently, agriculture is considered to be a major cause of eutrophication in many global regions.[567] The risk of fertilisers polluting water increases when there is a surplus in nutrient balances, i.e. when the quantity of nutrient inputs entering an agricultural system is higher than the quantity of nutrient outputs leaving the system; such a surplus seems to consistently occur in all countries where data is available (OECD countries).[568]

[566] See e.g. FAO data on development of the value of agricultural production: https://www.fao.org/faostat/en/#data/QV

[567] Withers, P., et al. (2014). Agriculture and Eutrophication: Where Do We Go from Here? See: https://www.mdpi.com/2071-1050/6/9/5853

[568] OECD (2022). Environmental performance of agriculture - nutrients balances. See: https://doi.org/10.1787/d327d2a9-en (accessed on 09 Feb 2022)

Currently, the highest use of fertiliser[569] globally can be observed in a few global hotspots which include most parts of Europe, eastern parts of the USA, North India and Bangladesh, and eastern China.[570] [571]

Mainly driven by a growing population, but also growing global GDP, agricultural production is projected to increase in the future by around 1.4% annually (albeit that is a slowdown compared to the last decade). This production growth is expected to primarily take place in emerging economies and low-income countries and to be driven by productivity-increasing investments in agricultural infrastructure, including an increase in the use of fertiliser[572].

Finfish aquaculture

Aquaculture also provides important contributions for providing food security. However, finfish aquaculture is also one of the main sources of anthropogenic nutrients in the oceans with a growing trend of emissions which have increased worldwide by a factor of 6 between 1985 and 2005.[573]

Over the past decades, world aquaculture production has surpassed that of capture fisheries for most categories (e.g. inland fishing); however, farming of marine fishes is unlikely to overtake marine capture production in the future. Within aquaculture, marine aquaculture accounts for approximately 40% of all production. Within marine aquaculture, finfish aquaculture accounts for around one fourth of all production, i.e., around 7.5 million tons (in 2018).[574]

Marine finfish aquaculture is practiced in almost all regions in the world, with densest concentrations in South, Southeast and East Asia and Latin America, while also in Europe there is a substantial finfish aquaculture sector.[575] By far the largest charge of aquaculture production takes place in Asia (89% of global production in 2016)[576]; EU aquaculture accounts for less than 2% of global aquaculture production.[577]

[569] Including manure

[570] Potter, P., et al. (2010). Characterizing the Spatial Patterns of Global Fertilizer Application and Manure Production. Earth Interactions. See: https://www.researchgate.net/publication/237966463_Characterizing_the_Spatial_Patterns_of_Global_Fertilizer_Application_and_Manure_Production

[571] The paper also provides evidence of close geographical overlap at global scale between areas with high use of fertilisers and marine eutrophication.

[572] OECD/FAO (2021). OECD-FAO Agricultural Outlook 2021-2030. See:

[573] Malone, C., et al. (2020). The Globalization of Cultural Eutrophication in the Coastal Ocean: Causes and Consequences. See: https://www.frontiersin.org/articles/10.3389/fmars.2020.00670/full

[574] FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. https://doi.org/10.4060/ca9229en

[575] See footnote 574

[576] Garlock, T., et al. (2019). A Global Blue Revolution: Aquaculture Growth Across Regions, Species, and Countries. See: https://www.researchgate.net/publication/336652599_A_Global_Blue_Revolution_Aquaculture_Growth_Across_Regions_Species_and_Countries

[577] COM/2021/236 final COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030. See: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:236:FIN

Combustion of fossil fuels

Combustion of fossil fuels is another principal contributor to global marine eutrophication; this includes combustion for power generation as well as for transport.

Combustion of fossil fuels is done globally in order to generate electricity and the global electricity consumption has continuously grown over the last decades; between 1980 and 2019, electricity consumption tripled. This is partly due to a growing world population (which grew by 75% over the same period), but also to a large extent due to industrialisation[578].

Regarding road transport, diesel cars emit considerably more NOx than petrol cars. Newer vehicle diesel standards for heavy-duty vehicles and light-duty vehicles are more effective in reducing emissions than older ones, and vehicles with newer standards are more prevalent in some world regions (e.g., USA, Canada, Japan, and to some extent the EU even though to a lower degree than the others), while vehicles with older standards are more prevalent in other regions such as Mexico, India, Russia, Brazil or Australia)[579].

Discharge of wastewater

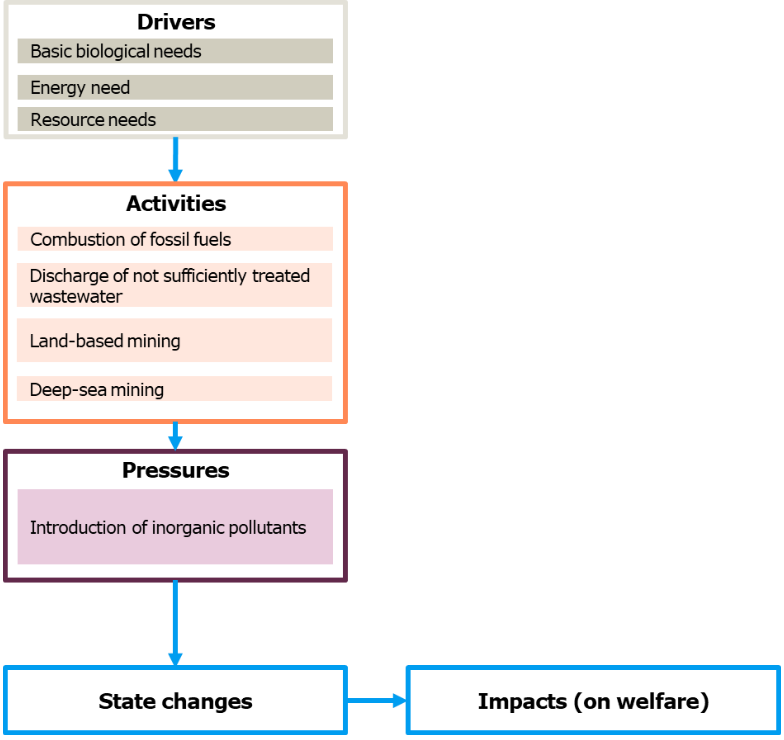
See "Discharge of wastewater" in the discussion on human activities leading to the pressure of introduction of microbiological pathogens; the information in there is also relevant for this section and is thus not repeated.

[578] Indicator "Net electricity consumption worldwide in select years from 1980 to 2019" on https://www.statista.com/statistics/280704/world-power-consumption/. Accessed on 15 December 2021

[579] Anenberg, S., et al. (2017). Impacts and mitigation of excess diesel-related NOx emissions in 11 major vehicle markets. See: https://www.nature.com/articles/nature22086

Introduction of inorganic pollutants

Figure: Flowchart for the pressure



Source: Own illustration

Combustion of fossil fuels

Combustion of fossil fuels (mostly coal) is one of the global main emitters of mercury into the air (accounting for approx. 25% of global mercury air emissions[580]) and large parts of those emissions are deposited in the oceans, accounting globally for 16% of mercury emissions to water[581]. Atmospheric emissions of mercury can travel long distances; for example, mercury emissions from Asia account for more than one quarter of the mercury deposited into the Mediterranean and Black Seas every year and also have a negative impact on mercury levels in the north Pacific Ocean[582]. Combustion of coal also emits several other heavy metals, including e.g., cadmium, arsenic, zinc and others. Globally, 80 countries use coal for power generation and the practice generates nearly 40% of the global energy. The largest hotspots are China (with significant increase of coal-generated electricity capacities since 2000 and accounting today for more coal-generated electricity than all other world regions combined), USA and the EU (both with decreasing trends), India and other Asian regions[583].

[580] EEA (2018). Mercury in Europe's environment. A priority for European and global action. See: https://www.eea.europa.eu/publications/mercury-in-europe-s-environment

[581] UN (2018). Chapter 6 Anthropogenic releases of mercury to water. In: Global mercury assessment 2018. See: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment

[582] See footnote 580

[583] See: https://www.carbonbrief.org/mapped-worlds-coal-power-plants. Accessed on 11 January 2022

Discharge of not sufficiently treated wastewater

Wastewater, both municipal and industrial, usually shows high concentrations of several heavy metals. In industrial wastewater, those include among others lead, zinc, arsenic, and mercury, stemming from a wide range of industrial activities.[584] Also in municipal wastewater considerable concentrations of heavy metals can usually be found, which stem from a wide range of sources such as metal roofs, tire and break abrasion from cars, car washes and countless others[585]. Historically, industrial wastewater was one of the main sources of heavy metals in municipal wastewater; however, today there is evidence that diffuse sources such as the ones mentioned before are the main source of heavy metals in wastewater due to more stringent legislation.

Even though wastewater treatment cannot degrade those heavy metals, they can be removed either from final effluent or else in the sludge produced [586]. However, globally currently only 56 % of municipal wastewater flows are safely treated[587] as discussed in more detail in "Discharge of wastewater" in the discussion on human activities leading to the pressure of introduction of microbiological pathogens.

Land-based mining

Land-based mining is the extraction of valuable materials from the Earth on the continents. Heavy metal pollution from mining activities is caused when wastewater from mining operations is discharged untreated into the environment or when heavy metals contained in excavated rock (i.e., mining waste, which in the EU makes up approx. 30% of the total volume of waste produce in the EU) or exposed in an underground mine come in contact with water. Metals are leached out and carried downstream, including into the oceans. With proper management most severe contamination threats can be avoided. In practice, however, proper management and handling does not always take place[588]. For example, ore mining and processing accounts for 40% of all mercury releases into water[589]. While mining is done in most regions of the world, some regional differences can be observed: for example, only five countries (China, Australia, USA, Russia, and Chile) account for half of all mining areas globally [590].

A special role plays small-scale gold mining which is one of the global main sources of mercury atmospheric emissions, accounting for almost 40% [591] of atmospheric emissions which then can

[584] Agarwal, R., et al. (2017). Heavy metal removal from wastewater using various adsorbents: a review. See: https://www.semanticscholar.org/paper/Heavy-metal-removal-from-wastewater-using-various-a-Renu-Agarwal/d3c924bc5d32e56a1e7d95cee9e50ca3e10e194d

[585] Sörme, L, et al. (2002). Sources of heavy metals in urban wastewater in Stockholm. See: https://www.sciencedirect.com/science/article/abs/pii/S0048969702001973#!

[586] Briffa, B., et al. (2020). Heavy metal pollution in the environment and their toxicological effects on humans. See: https://www.sciencedirect.com/science/article/pii/S2405844020315346

[587] UN (2020). Progress on Wastewater Treatment – 2021 Update. See: https://www.unwater.org/publications/progress-on-wastewater-treatment-631-2021-update/

[588] Schoderer, M., et al. (2020). Water policy and mining: Mainstreaming in international guidelines and certification schemes. See: https://www.sciencedirect.com/science/article/pii/S1462901119310299

[589] UN (2018). Chapter 6 Anthropogenic releases of mercury to water. In: Global mercury assessment 2018. See: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment

[590] Maus, V., et al. (2020). A global-scale data set of mining areas. See: https://www.nature.com/articles/s41597-020-00624-w

[591] UN (2018). Chapter 3 Mercury emissions to air. In: Global mercury assessment 2018. See: https://www.unep.org/explore-topics/chemicals-waste/what-we-do/mercury/global-mercury-assessment

get deposited in oceans. The vast majority of releases from this activity occur in South America (more than 50%) and East and Southeast Asia (36%).[592]

Box: And what about deep-sea mining?

Little information seems to be available about the potential emissions of pollutants such as heavy metals from deep-sea mining activities.

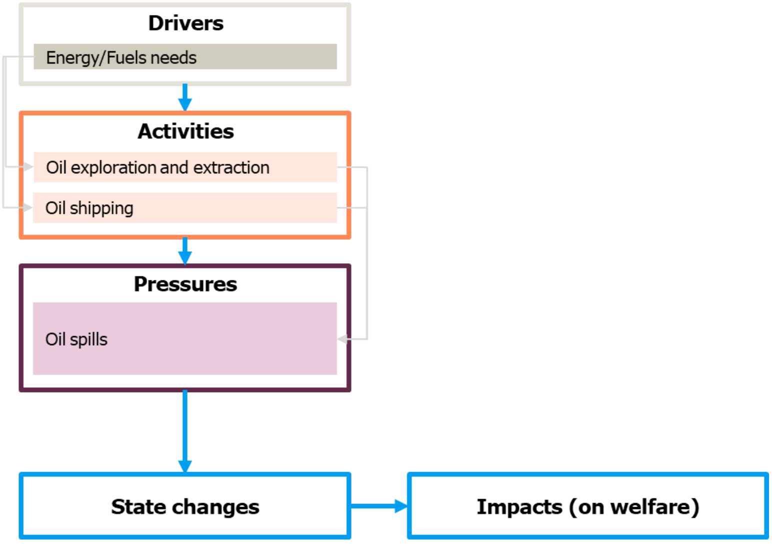
Concerning the actual emissions, there could be issues with mobilising heavy metals which have been deposited in sediment before; those plumes of mobilised sediments could travel tens to hundreds of kilometres from the actual mining sites, both vertically and horizontally, and thus impact ecosystems.[593] This could introduce heavy metals in the deep sea in concentrations exceeding4000 times the limits considered to be safe.[594]

Finally, there still seems to be little understanding on the impact on different ecosystems caused by this. While extensive data is available on toxicity of heavy metals in shallow-water ecosystems, those may be different for deep-sea ecosystems[595] as well as midwater ecosystems[596].

Oil spills

The Figure below summarises the drivers and activities leading to this pressure.

Figure: Flowchart for the pressure



Source: Own illustration

[592] See footnote 589

[593] Drazen, J., et al. (2020). Midwater ecosystems must be considered when evaluating environmental risks of deep-sea mining. See: https://www.pnas.org/doi/10.1073/pnas.2011914117

[594] Coffey (2008). Environmental Impact Statement: Solwara 1 Project. Nautilus Minerals Niugini Limited. See : http://www.cares.nautilusminerals.com/Downloads.aspx

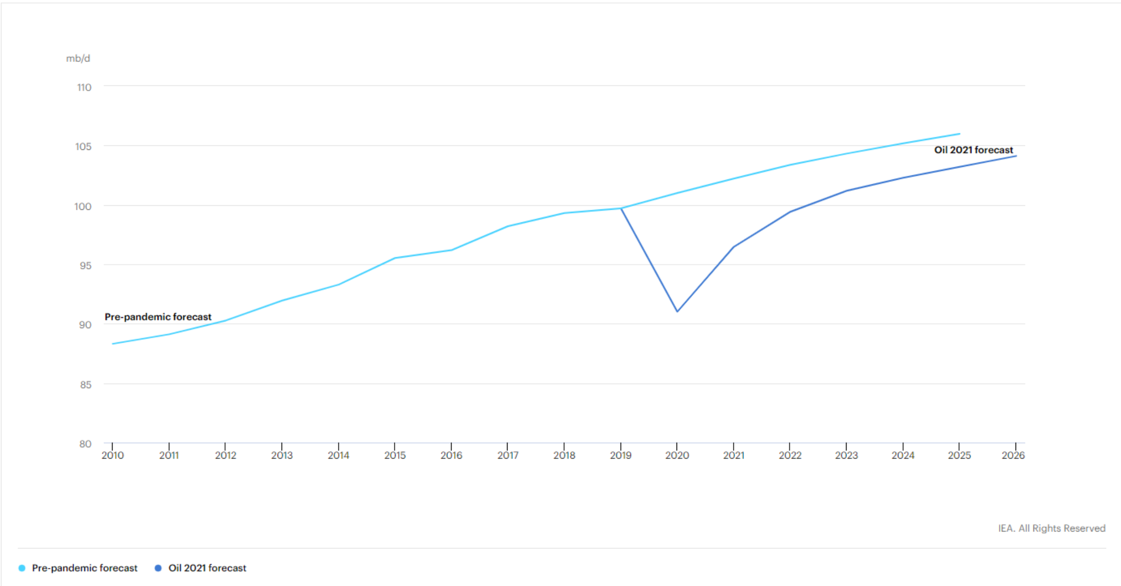
[595] Hauton, C., et al. (2017). Identifying Toxic Impacts of Metals Potentially Released during Deep-Sea Mining—A Synthesis of the Challenges to Quantifying Risk. See: https://web.archive.org/web/20131103175932/http://www.cares.nautilusminerals.com/Downloads.aspx

[596] See footnote 593

Oil exploration and extraction

To date, oil still accounts for the largest share in total energy supply (around 32% of total energy supply), though global dependence on it dropped substantially since the 1970s[597]. The outbreak of COVID also had a significant impact on the oil demand, with 2020 demand being 9 mb/d below the level seen in 2019. This notwithstanding, the IEA foresees that global oil consumption will reach 104.1 mb/d in 2026, which is above 2019 levels, in the absence of rapid policy intervention and behavioural changes[598].

Figure: Oil demand forecast, 2010-2026, pre-pandemic and in Oil 2021[599]



Source: IEA

The main impact from this is due to operational discharges i.e. the discharge of water produced through the exploration or extraction activity, and the disposal of drilling waste. This water contains hydrocarbons and metals that can impact the environment, though knowledge on their long-term impacts is scarce[600]. On average, three barrels of water are produced for each barrel of oil extracted. This ratio is larger for older wells. In addition, the installation of pipelines and related infrastructure also contributes to certain discharges into the marine environment.[601]

Leakage of production water and drilling waste is therefore more likely to take place in the waters of oil-producing countries.

[597] See: http://energyatlas.iea.org/#!/tellmap/-1920537974

[598] IEA (2021) Oil 2021 Analysis and forecast to 2026. See: https://iea.blob.core.windows.net/assets/1fa45234-bac5-4d89-a532-768960f99d07/Oil_2021-PDF.pdf

[599] IEA (2021) Oil demand forecast, 2010-2026, pre-pandemic and in Oil 2021. See: https://www.iea.org/data-and-statistics/charts/oil-demand-forecast-2010-2026-pre-pandemic-and-in-oil-2021

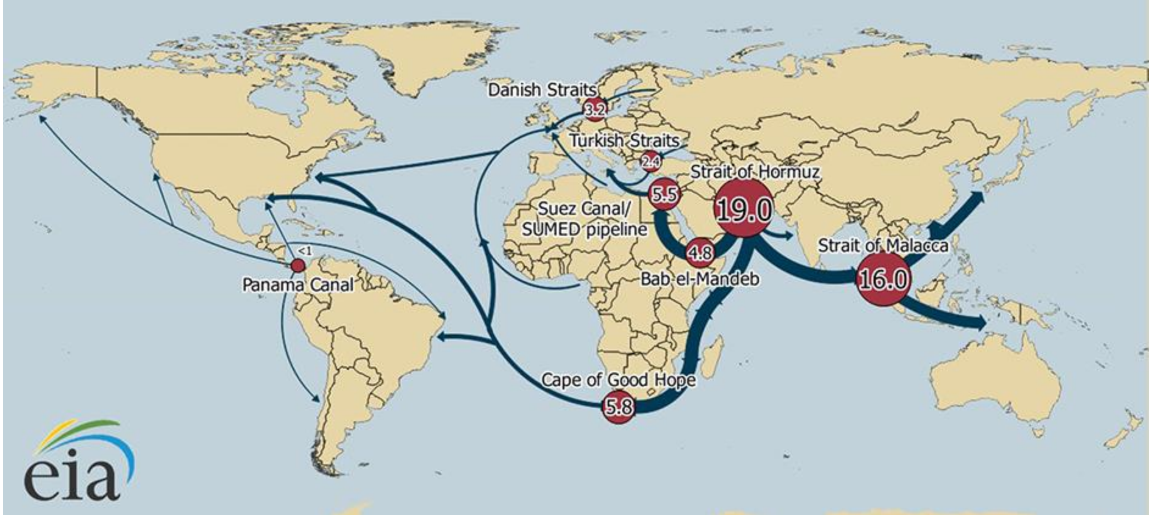
[600] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[601] Idem

Oil shipping

Around 61% of the oil consumed globally, is transported via seaborne trade[602]. The main shipping routes pass through the Atlantic, as well as Indian Ocean and Mediterranean Sea, to connect exporters and importers. The largest exporters of crude oil (in terms of net trade) in 2019 were Saudi Arabia, the Russian Federation, Iraq, the United Arab Emirates and Canada. Meanwhile, the largest net importers were China, India, Japan, Korea and Germany[603].

Figure: Daily transit volumes through world maritime oil chokepoints (2016)



Source: U.S. Energy Information Administration[604]

While overall oil trade volume has increased overtime, the number of shipping accidents leading oil spills (over 7 tons) have decreased substantially since the 1970s. This is likely related to improved surveillance and action capabilities that led to an increased awareness about the issue[605].

Notably, the majority of oil spilled in the oceans is the result of a few large accidents occurred in the past decades, that had huge impacts. In the 1980s, 1990s, 2000s, 2010s, ten major oil spills in each period were responsible for around 70 to 80% of total oil spilled in the oceans for each given decade. Most major oil spill accidents happened in the Atlantic Ocean to the west of Europe[606].

Introduction of marine litter

The Figure below summarises the drivers and activities leading to this pressure.

[602] U.S. Energy Information Administration (2017) World Oil Transit Chokepoints. See: https://www.eia.gov/international/analysis/special-topics/World_Oil_Transit_Chokepoints

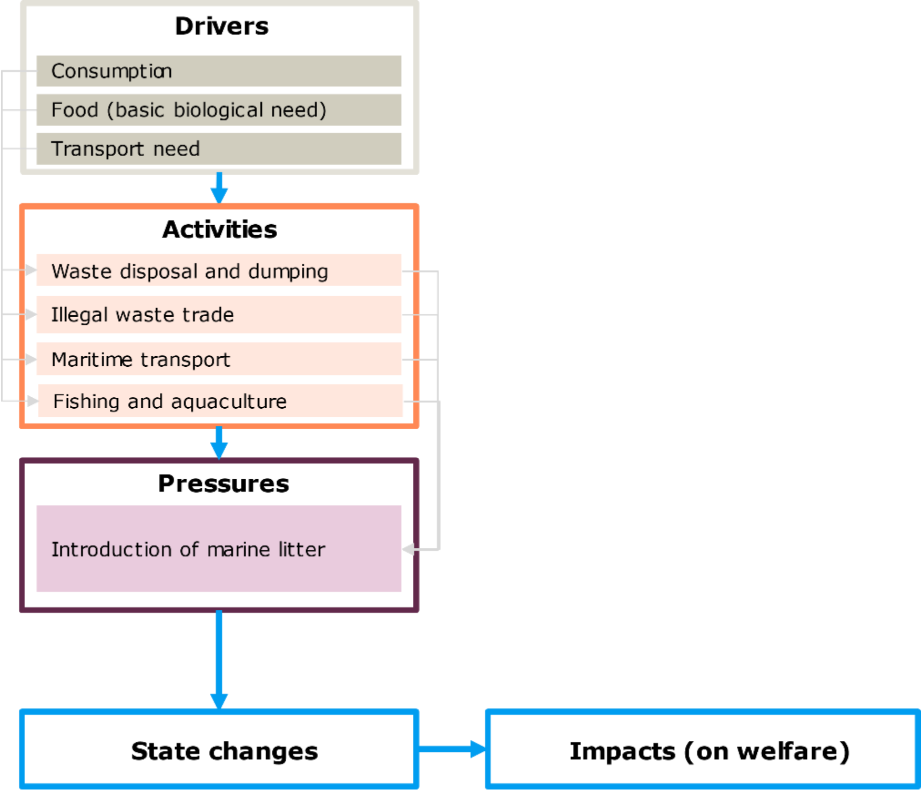
[603] IEA Atlas of Energy. See: http://energyatlas.iea.org/#!/tellmap/-1920537974

[604] See: https://www.eia.gov/international/analysis/special-topics/World_Oil_Transit_Chokepoints

[605] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[606] Chen *et al* (2019) Oil spills from global tankers: Status review and future governance. See: https://agris.fao.org/agris-search/search.do?recordID=US201900230509

Figure 5.1 Flowchart for the pressure



Source: Own illustration

Waste disposal and dumping

Most marine litter (around 80%) originates from land-based sources[607]. A multitude of human activities on land generate waste, and plastics (the main component of marine litter) are today used in almost all major product categories. Plastic packaging is the largest application of plastics by weight, but they are also used widely in the textile, consumer goods, transport, and construction sectors. Most of the plastic waste generated every year is from short-lived or single use applications, such as plastic packaging or textiles[608].

Reliable cross-country data on plastics production are sparse, but available sources indicate that the main regional producers of primary plastics are China, Europe and North America. When it comes to the production of waste, countries with higher levels of consumption tend to generate relatively large volumes of waste.[609].

Once generated, (plastics) waste is either collected through (formal or informal) waste management systems, or leaks into the natural environment (mainly through rivers). In 2010, it was estimated that around 10% of global plastics waste generation (or 30 Mt) was

[607] European Commission. Our Oceans, Seas and Coasts. See: https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/index_en.htm

[608] OECD (2019) Issue Brief: Improving Resource Efficency to Combat Marine Plastic Litter. See: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

[609] OECD (2019) Issue Brief: Improving Resource Efficency to Combat Marine Plastic Litter. See: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

mismanaged[610] - 50% of this mismanaged material coming from G20 countries[611]. In fact, many countries lack the infrastructure to prevent plastic pollution which leads to waste leakage into rivers and the ocean[612].

Sewage sludge, the solids arising from the settlements and treatment of sewage and other waste waters directed to the sewer system, can also carry significant loadings of contaminants, again including chemicals and plastics (especially microplastics) from a wide variety of sources[613]

Illegal (plastic) waste trade

The legal and illegal global trade of plastic waste may also damage ecosystems, where waste management systems are not sufficient to contain plastic waste.[614] The global trade in plastic waste is small relative to overall plastics waste generation. Of the 300 million tonnes of plastics waste generated in 2015, only around 14 million tonnes (or 4%) was exported outside the country of origin. The largest importers of waste are China (around 60% in 2016), followed by Hong Kong and Germany, while the largest exporters were the United States, Japan and Germany[615].

Plastic waste can also be traded illegally, and this causes severe pressures on the environment. This waste can be exported to third countries for the purpose of disposal or recovery, in breach of existing laws[616]. Plastics are also often mixed with hazardous waste to disguise illegal shipment of the latter, and therefore can also be contaminated. According to INTERPOL[617], the total amount of plastic illegally traded has increased in both export countries and in emerging import countries. This involves waste disposal in illegal landfills, irregular waste fire, illegal recycling facilities. Most of this plastic waste is destined to South and South-East Asia, as well as Eastern Europe (to a lesser extent). Notably, Some African countries already receive large quantities of plastic material "soon-to-be waste", embedded in illegally imported e-waste. These regions are chosen as destinations because of their limited waste management and waste enforcement capacities.

[610] Jambeck et al (2015) in OECD (2019) Issue Brief: Improving Resource Efficency to Combat Marine Plastic Litter. See: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

[611] OECD (2019) Issue Brief: Improving Resource Efficency to Combat Marine Plastic Litter. See: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

[612] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[613] GESAMP (2021) Sea-based sources of marine litter. See: http://www.gesamp.org/publications/sea-based-sources-of-marine-litter

[614] IUCN Marine Plastic Pollution. See: https://www.iucn.org/resources/issues-briefs/marine-plastic-pollution

[615] OECD (2019) Issue Brief: Improving Resource Efficency to Combat Marine Plastic Litter. See: https://www.oecd.org/g20/summits/osaka/OECD-G20-Paper-Resource-Efficiency-and-Marine-Plastics.pdf

[616] Internationally, this refers to The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (1992). For the EU, this would be in breach of the Waste Shipping Regulation.

[617] INTERPOL (2020) Strategic Analysis Report – Emerging criminal trends in the global plastic waste market since January 2018. See: https://www.interpol.int/content/download/15587/file/INTERPOL%20Report%20_criminal%20trends-plastic%20waste.pdf

Fishing and aquaculture

Fishing can contribute to litter in the oceans. In commonly used fishing grounds, large marine litter is often to large extent composed of abandoned, lost or otherwise discarded fishing gear. It is estimated that 5.7% of all fishing nets, 8.6% of all traps and 29% of all lines are lost around the world each year[618]. The frequency and magnitude of the abandonment, loss and discard of fishing gear also differs across fisheries and regions – and significant knowledge gaps remain concerning the amounts and rates of this practice[619].

Aquaculture can generate marine litter as a significant portion of the gear utilised for this activity, both in marine and freshwater systems, is made up of plastic. Normal wear and tear of plastic gear, accidents that damage equipment such as the interaction of aquaculture equipment with vessels, catastrophic losses during extreme weather events, and improper waste management by aquaculture operators are among the causes of plastic leakage by aquaculture[620]. Aquaculture production has grown steadily from the 2000s, at rates between 5.8 and 4% annually.

Maritime transport

Marine litter can be generated by maritime transport through different avenues. Ships generate cargo waste, operational wastes (from cargo stowage and handling), sewage, galley waste, domestic waste from crews, and maintenance wastes. The end-of-life of vessels can also contribute to marine litter, when vessel components, including waste from ship-breaking end up in the oceans. [621]. Lost containers or cargoes from shipwrecked vessels that contain industrial pellets or packaging items also pose a risk, including for their chemical content[622].

Offshore oil and gas exploration

Activities related to the construction, operation, and maintenance of oil and gas exploration and exploitation platforms might cause the production of waste. When these platforms are located offshore, this can lead to the deliberate or accidental dumping, discard or abandonment of waste in the oceans. Debris can also fall, blow or wash off structures into the water. Different types of plastic substances, including microplastics can be found on these platforms, including in drilling in industrial abrasives. These can be dispersed into the environment during use[623].

In early 2018, the global rig fleet comprised over 1,300 offshore oil rigs, including stacked and under construction rigs. The highest concentration of offshore oil is in the North Sea, with 184 rigs, followed by the Gulf of Mexico, with 175 rigs[624].

Introduction of microplastics

The Figure below summarises the drivers and activities leading to this pressure.

[618] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[619] GESAMP (2021) Sea-based sources of marine litter. See: http://www.gesamp.org/publications/sea-based-sources-of-marine-litter

[620] Idem

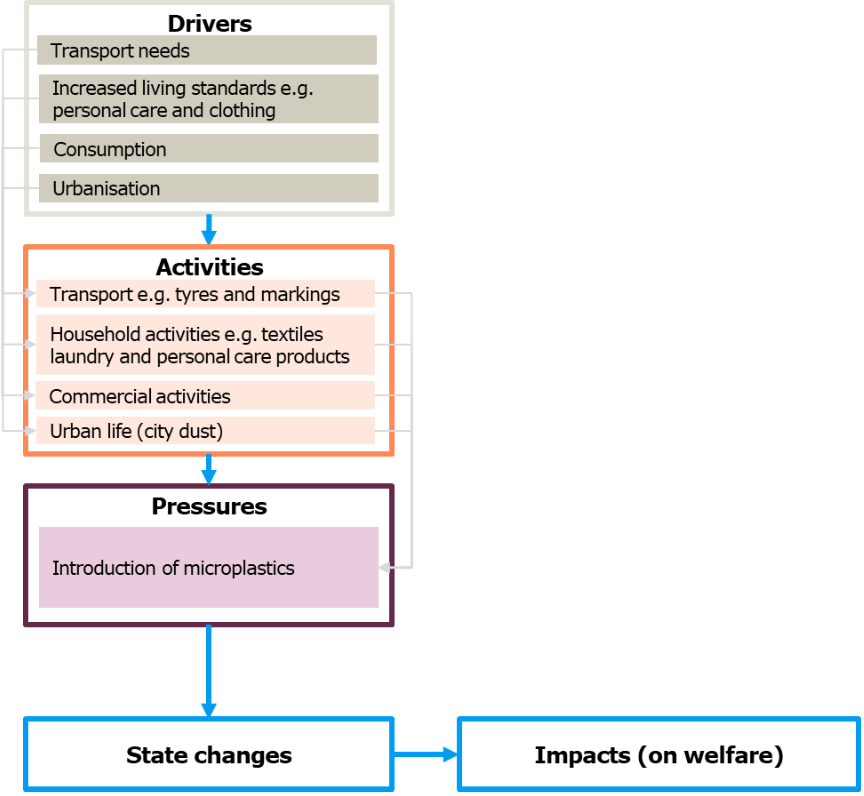
[621] Idem

[622] Idem

[623] Idem

[624] Idem

Figure: Flowchart for the pressure



Source: Own illustration

It is estimated that 98% of microplastics in the oceans stem from land-based activities[625]. As only a very small share of microplastics is generated by sea-based activities (also addressed in the marine litter section), this section focuses on land-based activities in this report.

Passenger (and freight) transport

Road transport is a source of microplastics, via two main avenues: tyres and road markings. Microplastics are created through the abrasion of tyres, that get eroded when used. These particles consist of a mix of synthetic polymers, that turn into dust and can be spread by the wind or washed off the road by rain, and then end up in the oceans. In a similar way, the materials used for road marking (mainly paint, but also thermoplastic, preformed polymer tape and epoxy) get weathered, or abrased by vehicles, and then get spread by wind or washed off roads by rain. Through this, they reach surface waters and potentially the oceans[626].

The total number of vehicles has steadily increased over the last fifteen years, and most vehicles are in Asia, Europe and North America. Rubber is used to produce tyres, and in fact synthetic rubbers in tyres represents around 57% of all synthetic rubber uses. The global consumption of synthetic rubber has increased by 27.3% between 2002 and 2010, mainly driven by China[627].

[625] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

[626] Idem

[627] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

Europe, Central Asia and North America are the main contributors to the release of tyre-based microplastics into the oceans[628].

Household activities

Household activities, such as the laundry of synthetic textiles, and the use of personal care products, are a source of microplastics. The washing of synthetic textiles creates primary microplastics through the abrasion and shedding of fibres which then can can then end up in the ocean[629].

The global fibre production has almost doubled in the last 20 years, from 58 million tonnes in 2000 to 109 million tonnes in 2020. The majority of synthetic fibres (62.7%) are nowadays consumed in developing economies. India and South-East Asia are the main contributors to the release of textile-based microplastics into the oceans, followed by China and Oceania[630].

Personal care and cosmetic products contain plastic microbeads that can get released into the environment, when used, through wastewater streams. The share of plastic beads can be up to 10% of total product weight, for some products[631].

Commercial activities

Commercial activities cause the release of microplastics into the (marine) environment. For instance, microplastics can be released as a consequence of the manufacturing, processing, transport and recycling of plastic pellets. The release takes place due to small or large incidents along the plastic value chain[632]. Industrial laundry of synthetic textiles is also a source of microplastics[633].

Urban life

Cities can be a source of microplastics as they produce a series of dusts that contain plastics. These include losses from the abrasion of objects (synthetic soles of footwear, synthetic cooking utensils), the abrasion of infrastructure (household dust, city dust, artificial turfs, harbours and marina, building coating) as well as from the blasting of abrasives and intentional pouring (detergents). The individual contribution of each of these sources to microplastics is small but taken together they are estimated to constitute around 24% of all microplastics released into the oceans[634].

Introduction of radionuclides

The Figure below summarises the drivers and activities leading to this pressure.

[628] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

[629] Idem

[630] Idem

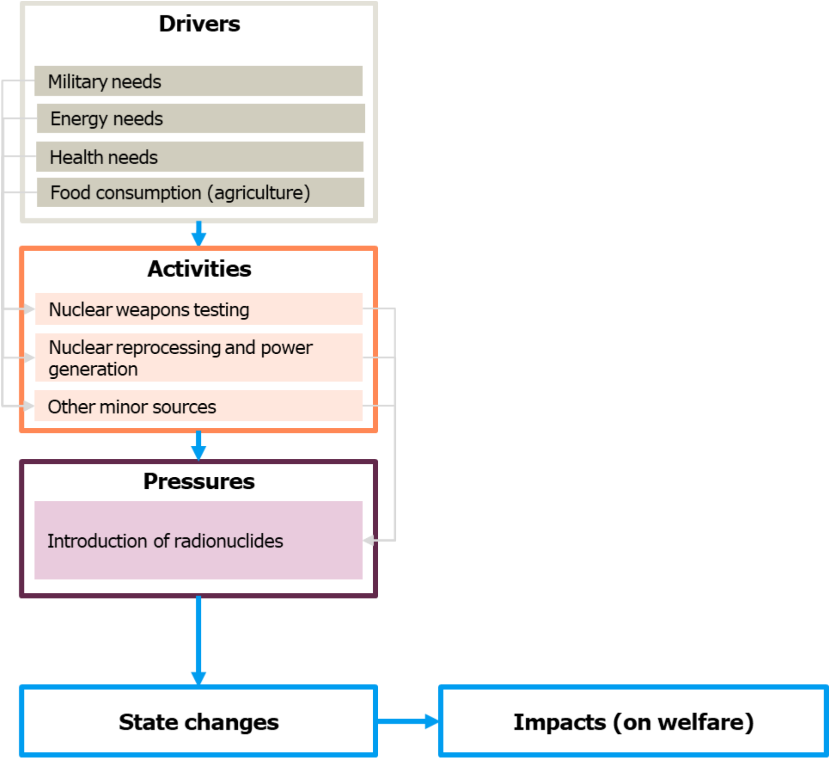
[631] Idem

[632] Idem

[633] Idem

[634] Idem

Figure: Flowchart for the pressure



Source: Own illustration

Nuclear weapons testing and use

Historically, the main source of input of radionuclides in the marine environment has been nuclear weapons testing[635]. Different types of nuclear weapon testing exist, depending on where they take place. They can be atmospheric, high-altitude, underground and underwater testing. Most nuclear weapons testing have taken place underground (75%) or in the atmosphere. Atmospheric nuclear weapons testing was partially banned by the Partial Test Ban Treaty (1963), and then fully banned by the Comprehensive Nuclear-Test-Ban Treaty (1996) – which has however not yet entered into force, as it has not reached the necessary number of ratifications[636]. This notwithstanding, the last atmospheric test took place in China in 1980[637], and the World Ocean Assessment does not consider this as a current source of input of radioactivity into the oceans anymore[638].

Nuclear energy production and reprocessing plants

Nuclear reprocessing plants are now the dominant source of anthropogenic radioactive inputs, together with nuclear power plants.

Nuclear reprocessing plants recover fissile material (plutonium and enriched uranium) and separate waste products from 'spent' (used) fuel rods from nuclear reactors. Reprocessing is used to extract plutonium for producing nuclear weapons, but it is now also used to recycle this

[635] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[636] United Nations. Comprehensive Nuclear-Test-Ban Treaty (CTBT). See: https://www.un.org/disarmament/wmd/nuclear/ctbt/

[637] CTBTO World Overview. See: https://www.ctbto.org/nuclear-testing/history-of-nuclear-testing/world-overview/

[638] See footnote 635

material for nuclear energy production. According to the World Ocean Assessment II, nuclear reprocessing plants are either currently operative or expected to become operational in the near future, in China, France, India, Russia and the UK. The report informs that the nuclear reprocessing plants at Cap de la Hague and Sellafield continue to represent the dominant source of anthropogenic radioactive inputs to the North-East Atlantic, though there have been substantial reductions in the average discharges in the last years (40% 40% reduction in total alpha discharges and about 85% in total beta discharges)[639].

Nuclear power plants are concentrated in about 30 countries worldwide, with the highest capacity being located in the United States, Europe and Asia[640].

Up to date information concerning the discharge of radionuclides into the environment is available only for nuclear power plants in the catchments of the Baltic and North-East Atlantic, and these show continuing reductions in the discharges. Notably, "the IAEA database on discharges of radionuclides to the atmosphere and the aquatic environment (information provided by national authorities on a voluntary basis) has not been updated since 2012, and much of the data in it are substantially older than that". The level of discharges is in general related to the level of electricity generation (more energy generated equals to more discharges), and there is currently no accepted abatement technology to prevent these[641].

Nuclear incidents taking place in nuclear power plants, are also a source of input of radionuclides into the environment. The last major nuclear incident took place in Fukushima in 2011, and although traced of radionuclides have been found in US continental waters, the levels measured in Japan in the marine environment are considered "low and relatively stable"[642].

Other minor sources

Offshore hydrocarbon installations and pipelines. The water coming from reservoirs containing oil and gas, as well as the scale that they deposit into pipelines, contain low levels of radionuclides and can be discharged into the environment when these platforms and pipelines are located offshore. There is no published data concerning these discharges besides the North-East Atlantic[643].

Production of agricultural fertilizers from phosphate rock. This process produces phosphogypsum, a compound that contains naturally occurring radioactive material. This has often been discharged as slurry to the sea, but that now seems to have been widely phased out, besides some countries like Morocco, Tunisia. There is no published data concerning these discharges, but for the case of Morocco, the government has set up a system for improving management of phosphogypsum discharges, which reportedly complies with international standards[644].

Nuclear medicine. Radionuclides can be used in medicine for both diagnostic and therapeutic use, as well as in biomedical research. In nuclear medical applications the main part of the radioactive waste consists of radionuclides with short half-life and low radiotoxicity. There is no published data concerning these discharges.

[639] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[640] https://www.iaea.org/newscenter/news/iaea-releases-2019-data-on-nuclear-power-plants-operating-experience

[641] See footnote 639

[642] Idem

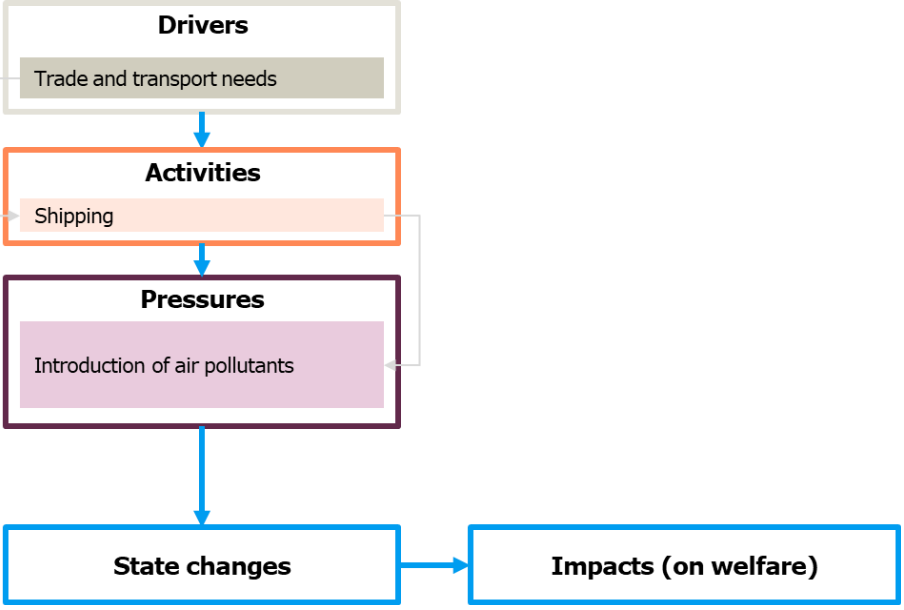
[643] Idem

[644] Idem

Introduction of air pollutants

The Figure below summarises the drivers and activities leading to this pressure.

Figure: Flowchart for the pressure



Source: Own illustration

Shipping

The emissions of air pollutants from shipping depend on fuel use and efficiency of the vessel: different fuels have varying CO2, SOx, NOx and methane emissions, and inefficient ships use more fuel[645]. In 2015, around 72% of global maritime fuel consumption was residual fuels (e.g. heavy fuel oil HFO), followed by 26% of distillates (e.g. marine diesel oil) and 2% liquified natural gas (LNG). HFO typically has a high sulphur content and the contribution of international shipping to global SOx emissions in 2012 was calculated to be 13% annually[646]. Low-carbon and alternative fuels, such as ammonia, hydrogen, biofuels, methanol, LNG[647], have a very low penetration rate in the shipping industry to date.

Total global annual NOx emissions from shipping have been estimated at about 19,000 kilotons (2013–2015), of which about 91% derives from international shipping, with the rest deriving from domestic shipping and fishing vessels (6% and 3%, respectively)[648]. For SOx, it was estimated that in 2014, 16% of the total anthropogenic emissions of SOx were from international shipping[649]. Notably, the contribution of shipping emissions increased from 6% 249 in 1960 to 16% in 2014[650].

[645] Balcombe et al (2019) How to decarbonise international shipping: Options for fuels, technologies and policies.

[646] Balcombe et al (2019) How to decarbonise international shipping: Options for fuels, technologies and policies.

[647] https://www.eafo.eu/shipping-transport/shipping-overview/af-for-shipping

[648] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[649] See: https://pubs.acs.org/doi/abs/10.1021/acs.est.9b07696

[650] See: https://pubs.acs.org/doi/abs/10.1021/acs.est.9b07696

With the volume of seaborne trade projected to rise in the future, the impact of this activity on air pollution is also projected to grow – if ambitious polices are not put in place.

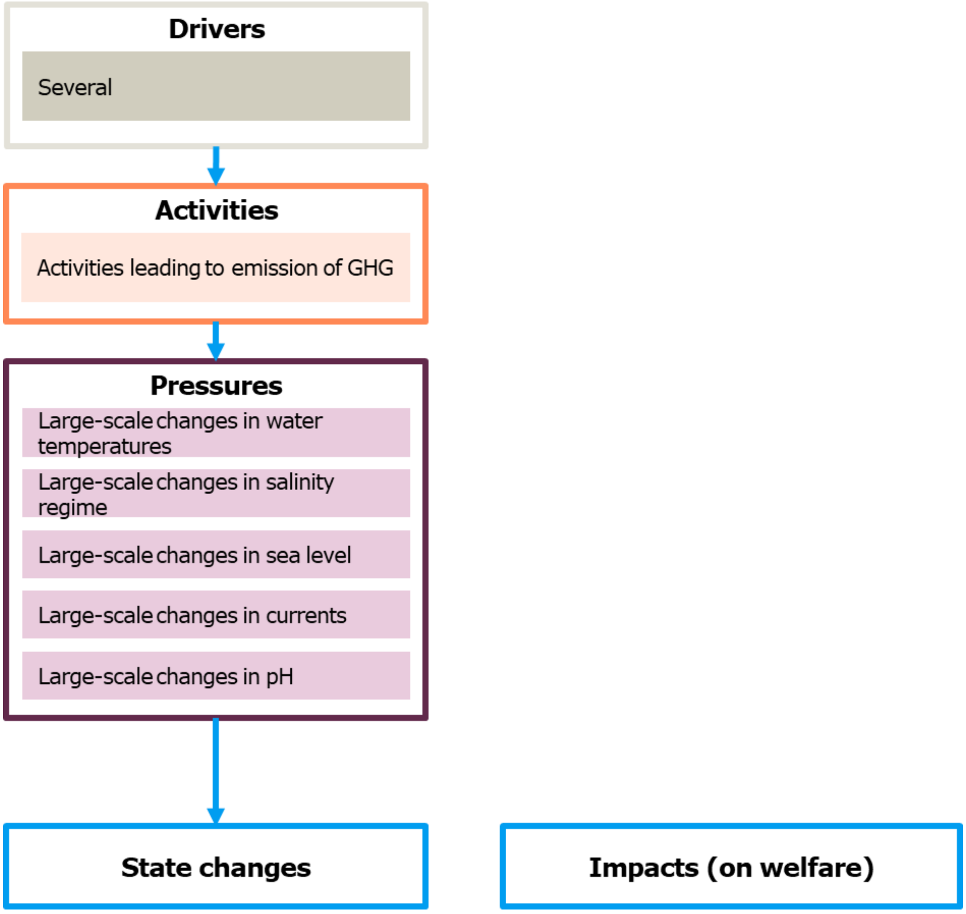
Changes in water properties due to climate change

The main human activities leading to GHG emissions include energy supply (power generation), transport, buildings, industry, AFOLU[651], and waste; however, countless other activities also emit greenhouse gases (GHGs) and thus contribute to climate change[652].

This in turn contributes significantly to all the pressures listed in this chapter. Thus, those activities are not discussed separately for all pressures.

The Figure below summarises the flowchart of those pressures.

Figure: Flowchart for the pressure



Source: Own illustration

[651] Agriculture, Forestry, Other Land Use

[652] Blanco, G., et al. (2014). Drivers, Trends and Mitigation. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. See: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter5.pdf

APPENDIX 4. – OVERVIEW OF ECOSYSTEM SERVICES, ABIOTIC FLOWS AND SPATIAL FUNCTIONS

List of provisioning services

Type of Ecosystem service	Ecosystem service	Description (UN, 2021)
Biomass provisioning services	Wild fish provisioning services Wild marine invertebrates provision services	Ecosystem contributions to the growth of fish and other aquatic biomass that are captured in uncultivated production contexts by economic units for various uses, primarily food production. This is a final ecosystem service
	Aquaculture provisioning services (fish / marine invertebrates) Aquaculture provisioning services (seaweed)	Ecosystem contributions to the growth of animals and plants (e.g., fish, shellfish, seaweed) in aquaculture facilities that are harvested by economic units for various uses. This is a final ecosystem service.
Genetic material services		Ecosystem contributions from all biotas (including seed, spore or gamete production) that are used by economic units, for example (i) to develop new animal and plant breeds; (ii) in gene synthesis; or (iii) in product development directly using genetic material. This is most commonly recorded as an intermediate service to biomass provisioning.[653]

List of regulation and maintenance services

Type of Ecosystem service	Ecosystem service	Description (UN, 2021)
Global climate regulation services	Carbon sequestration	Ecosystem contributions to the regulation of the chemical composition of the atmosphere and oceans that affect global climate through the accumulation and retention of carbon and other GHG (e.g., methane) in ecosystems and the ability of ecosystems to remove carbon from the atmosphere
Rainfall pattern regulation services (at subcontinental scale		Ecosystem contributions of vegetation, including phytoplankton and seagrass, in maintaining rainfall patterns through evapotranspiration at the sub-continental scale
Local (micro and meso) climate regulation services		Ecosystem contributions to the regulation of ambient atmospheric conditions (including micro and mesoscale climates) through the presence of vegetation that improves the living conditions for people and supports economic production

[653] Medicinal material services and Ornamental services are not listed in the SEEA EA (UN, 2021)

Type of Ecosystem service	Ecosystem service	Description (UN, 2021)
Air filtration services		ecosystem contributions to the filtering of airborne pollutants through the deposition, uptake, fixing and storage of pollutants by ecosystem components, particularly plants, that mitigates the harmful effects of the pollutants
Solid waste remediation services		Ecosystem contributions to the transformation of organic or inorganic substances, through the action of micro-organisms, algae, plants and animals that mitigates their harmful effects
Soil and sediment retention services		Soil erosion control services are the ecosystem contributions, particularly the stabilising effects of vegetation, that reduce the loss of soil (and sediment) and support use of the environment (e.g., agricultural activity, water supply)
Water purification services (water quality regulation)	Retention and breakdown of organic pollutants including excess nutrients and inorganic pollutants	Ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health
Water regulation services	Baseline flow maintenance services	Ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and gradually release water during dry seasons or periods through evapotranspiration and hence secure a regular flow of water
Water regulation services	Peak flow mitigation services	Ecosystem contributions to the regulation of river flows and groundwater and lake water tables. They are derived from the ability of ecosystems to absorb and store water, and hence mitigate the effects of flood and other extreme water-related events. Peak flow mitigation services will be supplied together with river flood mitigation services in providing the benefit of flood protection
Flood control services	Coastal protection services	Ecosystem contributions of linear elements in the seascape, for instance coral reefs, sand banks, dunes or mangrove ecosystems along the shore, in protecting the shore and thus mitigating the impacts of tidal surges or storms on local communities

Type of Ecosystem service	Ecosystem service	Description (UN, 2021)
Storm mitigation services		The ecosystem contributions of vegetation including linear elements, in mitigating the impacts of wind, sand and other storms (other than water related events) on local communities
Biological control services	Pest and disease control service	Ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of pests on biomass production processes or other economic and human activity Ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of species on human health
Nursery population and habitat maintenance service		The ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy either through the maintenance of habitats (e.g., for nurseries or migration) or the protection of natural gene pools

List of cultural services

Type of Ecosystem service	Description (UN, 2021)
Recreation-related services	Ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (i.e. visitors, including tourists). Recreation-related services may also be supplied to those undertaking recreational fishing and hunting
Visual amenity services	Ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual. This service combines with other ecosystem services, including recreation-related services and noise attenuation services to underpin amenity values
Education, scientific and research services	Ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment
Spiritual, artistic and symbolic services	Ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance.

Type of Ecosystem service	Description (UN, 2021)
	These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media
Ecosystem and species appreciation services[654]	Concerns the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use

List of Abiotic Flows

Type of Abiotic Flow	Abiotic Flow	Description (UN, 2021)
Geophysical sources	Extraction of water (including groundwater)	water resources of benefit that are not underpinned by or reliant on ecological characteristics and processes
Geophysical sources	Renewable Energy Generation	energy inputs from renewable sources of benefit that are not underpinned by or reliant on ecological characteristics and processes
Geological sources	Extraction of hydrocarbons	energy inputs from non-renewable sources of benefit that are not underpinned by or reliant on ecological characteristics and processes
Geological sources	Extraction of minerals (salt production)	(salt) mineral inputs of benefit that are not underpinned by or reliant on ecological characteristics and processes
Geological sources	Extraction of minerals (seabed mining)	mineral inputs of benefit that are not underpinned by or reliant on ecological characteristics and processes

List of Spatial Functions

Type of Spatial Function	Spatial Function
Flows related to the use of the environment as the location for transportation and movement, and buildings and structures	Land reclamation from the sea
	Coastal developments
	Submarine infrastructure
	Marine transportation

[654] In UN (2021) this is noted as "flows related to non-use values"

Type of Spatial Function	Spatial Function
Flows related to the use of the environment as a sink for pollutants and waste (excluding the mediation of pollutants and wastes recorded as ecosystem services	Dumping at sea

APPENDIX 5. – OVERVIEW OF LINKS BETWEEN STATE CHANGES AND ECOSYSTEM SERVICES

Description of state changes influencing provisioning services

Type of Ecosystem service	Ecosystem service	State change(s)	Interdependency description
Biomass provisioning services	Wild fish provisioning services	*Changes to fish populations *Changes to ecosystems	Changes in fish biodiversity have direct impacts on commercial and subsistence fisheries (FAO, 2018 in UN, 2021b) as well as on other marine biodiversity Changes to ecosystems such as mangroves, that act as nursery and feeding areas, in the wider sense (e.g. degradation, climate change impacts on benthic habitats, etc) can create pressures on fish populations, however, these are more difficult to correlate / quantify. There is limited understanding of the extent to which changing conditions could contribute to shifts in marine ecosystem structures and functioning and the subsequent impacts on marine productivity (UN, 2021b).
	Wild marine invertebrates provision services	*Changes to marine invertebrates *Changes to ecosystems	Changes in marine invertebrates (benthic shrimps, worms, gastropods, bivalves and others) have direct impacts on commercial and subsistence shellfish fisheries. E.g. coral reefs are an important source of income and protein to millions of people through fishing Increased risk to food security linked to decreases in seafood availability varies greatly on the local and cultural scales. However, for many coastal indigenous peoples and local communities, the harvesting of benthic invertebrates, in particular intertidal species, contributes significantly to their culture and to community-scale food security (IPBES, 2018a, b; IPCC, 2019, in UN, 2021b).
	Aquaculture provisioning services (fish / marine invertebrates)	*Changes to water quality	Water quality can determine productivity in the aquaculture sector, pollution or presence of pathogens can affect aquaculture resources and their overall productivity. At the same time, the sector continues to develop pathogen-free and pathogen-resistant specimen to use in aquaculture, reducing the vulnerability of the sector to potential changes in water quality.

Type of Ecosystem service	Ecosystem service	State change(s)	Interdependency description
			Accordingly, the extent to which changes in water quality may impact the potential for oceans to support this activity is not clear.
	Aquaculture provisioning services (seaweed)	*Changes to marine ecosystems *Changes to water quality	Changes to marine ecosystems can influence productivity of seaweed harvesting. Typhoons are known to affect the sector in South-east Asia, and water quality can also affect productivity.
Genetic material services		*Changes to marine invertebrates	Marine invertebrates (e.g. corals, sponges) are of increasing interest as genetic resources for the development of pharmaceutical products, which would be affected by the loss of species and habitats (Molinski et al, 2009; Rocha et al, 2011, in UN, 2021b)

Description of state changes influencing regulation and maintenance services

Type of Ecosystem service	Ecosystem service	State change(s)	Interdependency description
Global climate regulation services	Carbon sequestration	*Changes to marine invertebrates *Changes to algae and seaweed * Changes in pelagic and benthic fixation of carbon through photosynthesis *Changes to marine mammal populations	Marine organisms/ecosystems (e.g. corals, sponges, marine mammals) actively sequester carbon through both feeding and carbonate precipitation in the deep ocean Phytoplankton sequesters carbon through photosynthesis and produces organic matter that sinks to the bottom of the ocean
Rainfall pattern regulation services (at subcontinental scale		*Changes to water properties	Changes to water properties, such as temperature can affect established cycles and current that influence climate patterns
Local (micro and meso)		*Changes to coastal ecosystems	Changes to coastal ecosystems, particularly mangroves, can have a strong influence on their capacity to regulate local climates

Type of Ecosystem service	Ecosystem service	State change(s)	Interdependency description
climate regulation services			Mangrove canopy cover and microclimate: the presence of mangroves has effects on air temperature and relative humidity, rainfall, and wind. * mangrove cover has a dampening effect on maximum air temperatures and daily temperature ranges *mangrove density, leaf shape, and root/branch architecture increase rainfall interception and result in rainwater pooling in catchment areas * within the mangrove canopy, wind speed measurements are decreased by about 70 to 85 percent due to intensity-diminishing effects of vegetation
Air filtration services		*Changes in plants and organisms that absorb atmospheric pollutants in seawater	Alteration of the plants and organisms filtrating air and absorbing pollutants in sea water leads to less good quality of air
Solid waste remediation services		*Changes in marine ecosystems and species (micro-organisms, algae, plants and animals)	Solid waste remediation takes place through different ways: - Microbial degradation, mineralization, transformation and conversion of toxicants to less toxic substances; burial of toxicants - Sequestration of pollutants by living organisms - Storage of excess organic carbon in living biomass and burial in sediment - Microbial reduction and cycling of excess nutrient facilitated through bioturbation The loss of healthy microbial communities/ living marine organisms can alter the treatment and alteration of waste and thus the degradation of waste
Soil quality regulation services		*Changes in coastal and marine ecosystems	Changes in coastal and marine ecosystems can affect their capacity to decompose biological materials.
Soil and sediment retention services		*changes in coastal ecosystems	Changes to coastal ecosystems, such as mangroves, coral reefs, and seagrasses, can affect the extent to which these are capable of minimising erosion and maintaining the integrity of coastal areas, which can be particularly important for a number of socioeconomic activities and infrastructure. At the same time, socioeconomic activities and infrastructure occurring on coastal ecosystems are the main factor causing destruction of such ecosystems and driving coastal erosion, and

Type of Ecosystem service	Ecosystem service	State change(s)	Interdependency description
			therefore, halting / reversing coastal erosion rates may require reducing the pressure of socioeconomic activities and infrastructure away from coastal areas, reducing their economic value
Water purification services (water quality regulation)	Retention and breakdown of organic pollutants including excess nutrients and inorganic pollutants	*Changes to marine and coastal ecosystems	Changes to coastal ecosystems, such as mangroves, tidal flats, estuaries or generally coastal vegetation can affect the ability of these ecosystems to purify inland water flows to the ocean from organic and inorganic pollutants.
Water regulation services	Baseline flow maintenance services	*Changes to coastal ecosystems	Changes to coastal ecosystems, such as mangroves, coral reefs and seagrasses can affect the extent to which these regulate sea water flows or influence currents and wave action.
Water regulation services	Peak flow mitigation services	*Changes to coastal ecosystems	Changes to coastal ecosystems, such as mangroves, coral reefs and seagrasses can affect the extent to which these regulate sea water flows or influence currents and wave action.
Flood control services	Coastal protection services	*Changes in marine invertebrates	Corals, oysters and other living reefs can dissipate up to 97% of the wave energy reaching them, thus protecting structures and human lives (Ferrario and others, 2014)
Storm mitigation services		*Changes to coastal ecosystems	The degradation of marine and coastal ecosystems (such as vegetation and linear elements) can prevent the mitigation of storms impacts on local communities
Biological control services	Pest and disease control service	Loss of predators and competitors to control nuisance organisms Loss of resilient and robust community structure	The loss of predators/competitors/resilient community structure could reduce the control of nuisance organisms lead to an increase in the incidence of pests and/or diseases

Type of Ecosystem service	Ecosystem service	State change(s)	Interdependency description
Nursery population and habitat maintenance service		Loss of suitable habitat / shelters from predators Not enough provision of food resources	The alteration of suitable habitat/provision of food leads to the loss of the contribution of a particular marine habitat to migratory and resident species' populations, thus leading to population depletion (no critical habitat for feeding, or reproduction and juvenile maturation) and productivity

Description of state changes influencing cultural services

Type of Ecosystem service	State Change(s)	Interdependency description
Recreation-related services	Changes to fish populations Changes to marine invertebrates Changes to ecosystems	Changes in fish biodiversity have direct impacts on recreational fisheries and alternative sources of income, including tourism (FAO, 2018, in UN, 2021b)) Coral reefs are an important source of income through tourism (Cinner et al. 2016b in UN, 2021b; Kittinger et al. 2012 in UN, 2021b) Marine and coastal ecosystems provide recreation through activities such as boating, swimming, wildlife watching and fishing, and therefore any changes (such as pollution or degradation) can diminish their value to support recreational activities.
Visual amenity services	Changes to marine / coastal ecosystems	Changes to quality and condition of marine and coastal ecosystems determine the extent to which these are enjoyed.
Education, scientific and research services	Changes to marine / coastal ecosystems	However, this relationship may not be of interdependence, the more we know about the ocean condition and the pressures exerted, the more we want to know about how to address these; and even if the overall condition of coastal and marine ecosystems were considered good, research would still be funded to increase our understanding of less known traits in marine ecology, exploration of deep-sea areas, human pressures, etc
Spiritual, artistic and symbolic services	Changes to marine invertebrates Changes to ecosystems	Coral reefs are an important basis for sociocultural identity in some societies (Cinner et al. 2016b in UN, 2021b; Kittinger et al. 2012 in UN, 2021b) Changes in estuaries and coastal areas owing to urbanization can lead to the loss of identity and cultural practices in communities that depend on such resources for their livelihoods.

Type of Ecosystem service	State Change(s)	Interdependency description
Ecosystem and species appreciation services[655]	Changes to marine / coastal ecosystems	Changes to quality and condition of marine and coastal ecosystems can determine the extent to which they secure wellbeing. There may be some overlap with other cultural services

[655] In UN (2021) this is noted as "flows related to non-use values"

APPENDIX 6. – DETAILED ECONOMIC ASSESSMENTS

6. Provisioning ecosystem services

6.1 Wild Fish Provisioning Services

Box 5.1 Relevant definitions[656]

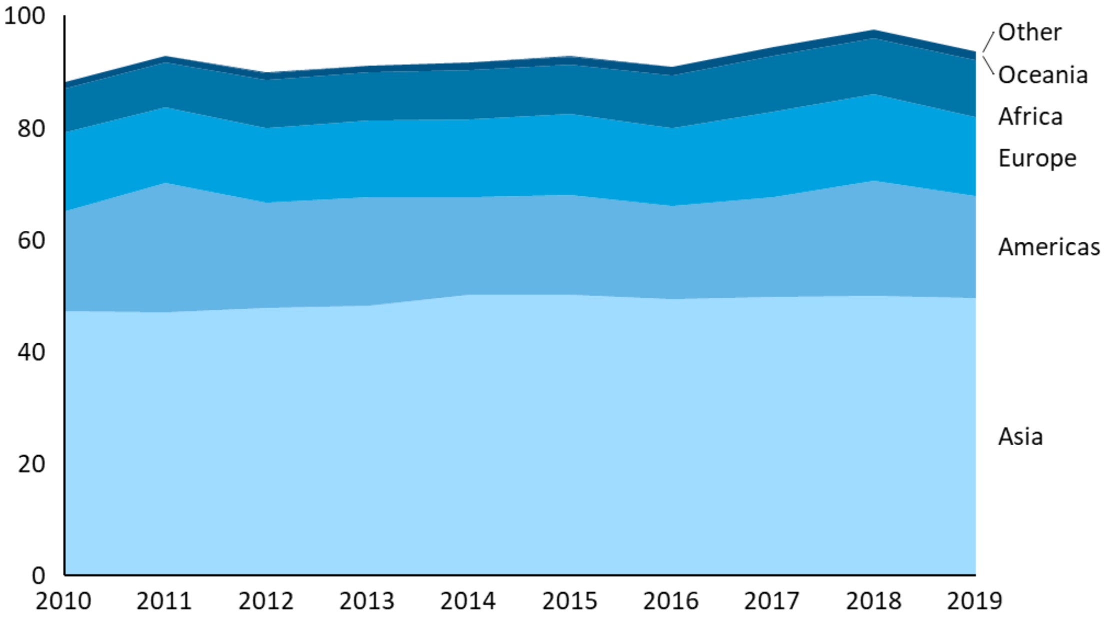
Yield: the catch, i.e. fish taken out of the water through fishing. Usually measured in tonnes.

Maximum sustainable yield: the largest yield (catch) that can be harvested yearly from a specific fish stock over an indefinite period under constant environmental conditions. Usually measured in tonnes.

Biomass: the body weight of all fish of one specific stock in the water. It does not differentiate age, gender or other similar attributes. Usually measured in tonnes.

Globally, the fisheries sector produces almost 100 million tonnes of product each year. More than half of this quantity comes from Asia, with China, Indonesia and India being the main producers. These numbers have been constant over the last 10 years (see figure below). The 10 most fished species in 2021 worldwide are tuna, salmon, cod, tilapia, sardines, catfish, grass carp, pangasius, anchovies, and kingfish.657 US statistics also indicate that the 10 most popular fish styles make up 90% of the total volume.658 In Europe, more than half of the 2019 Aquaculture production has been fish, with salmon accounting for 30% of the overall European aquaculture and 54% of the fish production (see figure below).

Figure 5.2 World fishing by area, in million tonnes



Source: FAOStat

[656] Ocean 2012, https://www.pewtrusts.org/-/media/assets/2015/03/turning_the_tide_msy_explained.pdf

[657] https://www.tuko.co.ke/406008-top-10-consumed-fish-world-2021-photos.html

[658] https://progressivegrocer.com/10-most-popular-fish-make-90-volume

Within Asia, the biggest contributors can be found in the figure below.

Figure 5.3 Fishing quantity in Asia by country (million tonnes)

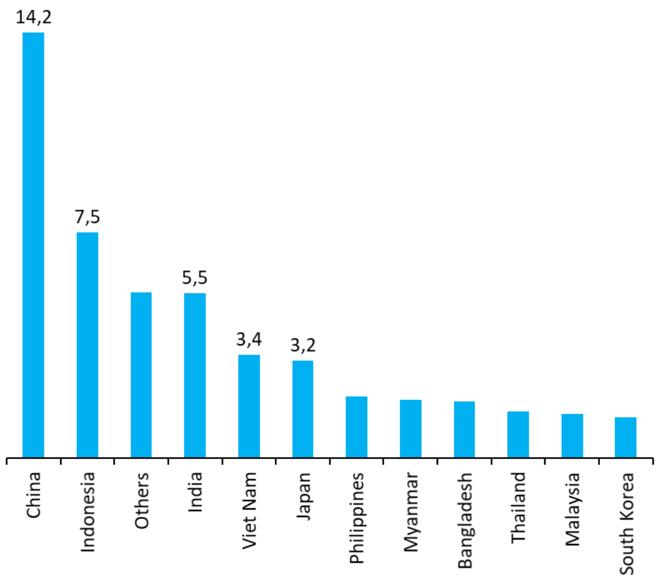
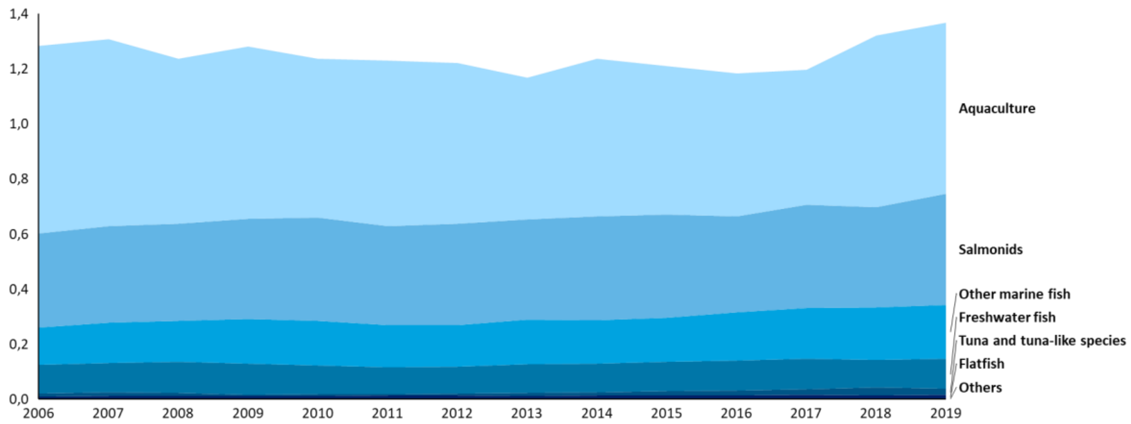


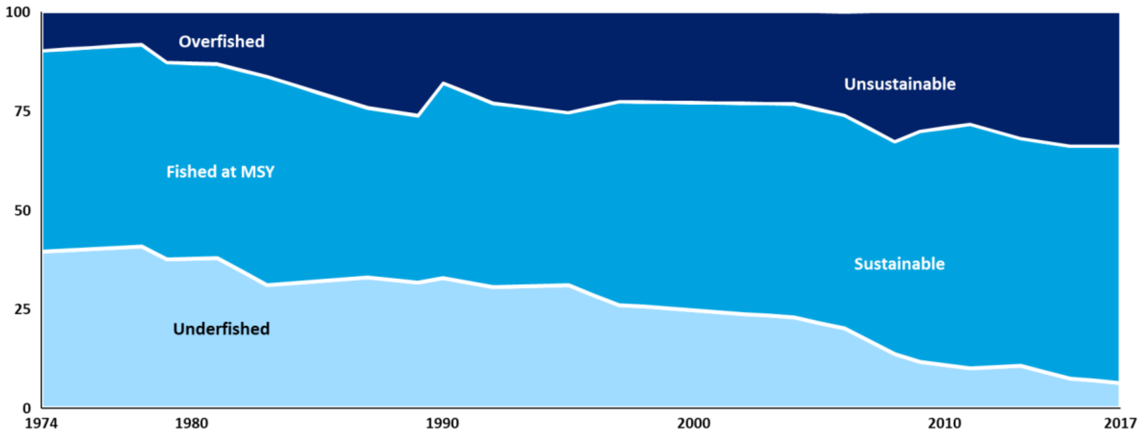
Figure 5.4 EU Aquaculture, in million tonnes



Source: EUMOFA

In a report published in 2020, the FAO assessed that 34% of the world's marine fish stocks were overfished. This percentage has been increasing over the past 30 years, whilst the percentage of underfished stocks has been steadily approaching zero.

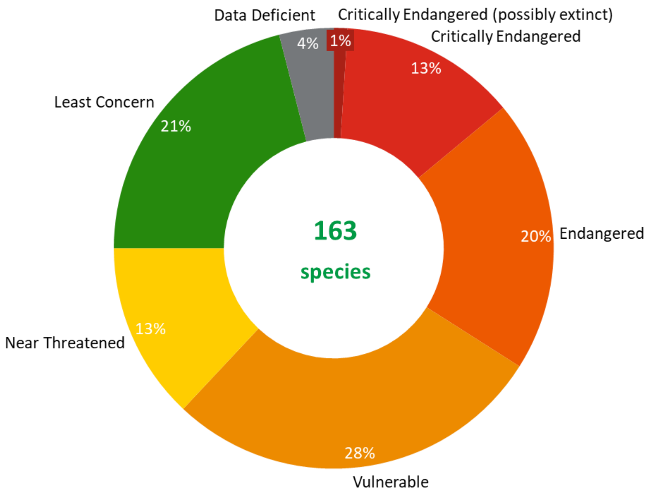
Figure 5.5 Global trends in the state of the world's marine fish stocks, 1974-2017, in %



Source: The Food and Agriculture Organization (FAO) of the United Nations, The State of World Fisheries and Aquaculture 2020, Sustainability in Action.

When taking a closer look at individual species, most can be considered classified as of 2021. Each year, the IUCN publishes a Red List species assessment, in which, in 2021, 63% of the 163 assessed fish and shark species were classified as threatened.[659] A more detailed breakdown of the species can be found in the figure below.

Figure 5.6 IUCN Red List species assessment, 2021

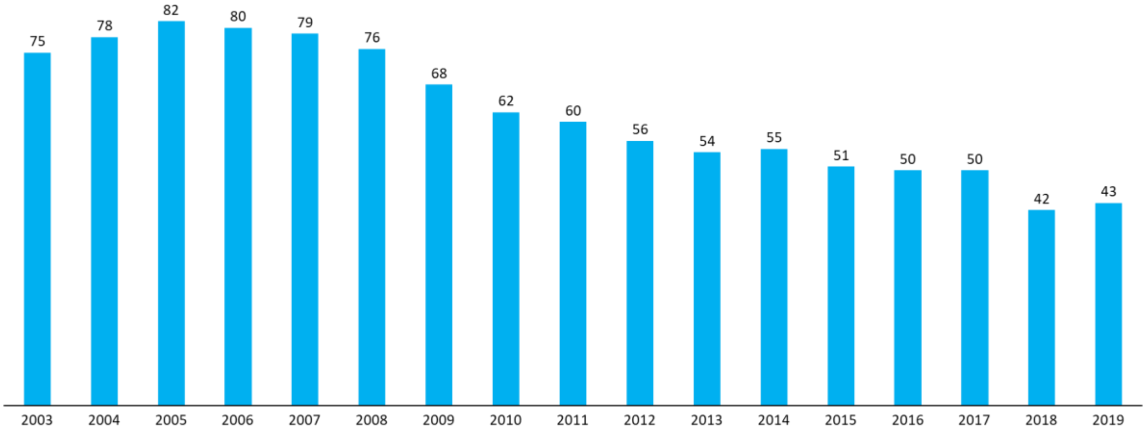


Source: IUCN

However, there are local efforts to mitigate some of these effects. The EU, for instance, assesses fish stocks every year and implements species-specific quotas, aiming for fully sustainable fishing by 2030. Over the last 15 years, this has led to a reduction of almost 40% in the share of overfished stocks.

[659] Species are referred to as threatened if they are assessed as Critically Endangered, Endangered or Vulnerable

Figure 5.7 Percentage of overfished stocks, Europe



Source: Eurostat

Ocean governance can help make the fisheries sector more sustainable. By limiting the allowed quantity of fish, it ensures the longevity of the sector and it allows for long-term gains from fishing.

6.1.1 Description of methodology for monetisation incl. indicators used and data sources

Monetisation for this service is operationalised on the basis of fish as a food service. In order to assess the economic impact of fishing, we examine the value-added of the fisheries sector to the economy by analysing two scenarios:

- comparing the long-term effects of "business as usual" and
- a "scale up" of ocean governance efforts leading to fishing activity at MSY

The "business as usual" scenario uses historical trends to forecast catch developments in the fisheries sector, whilst the "scaled up efforts" scenario estimates the maximum sustainable yield per fish species, in order to ensure long-term production possibilities.

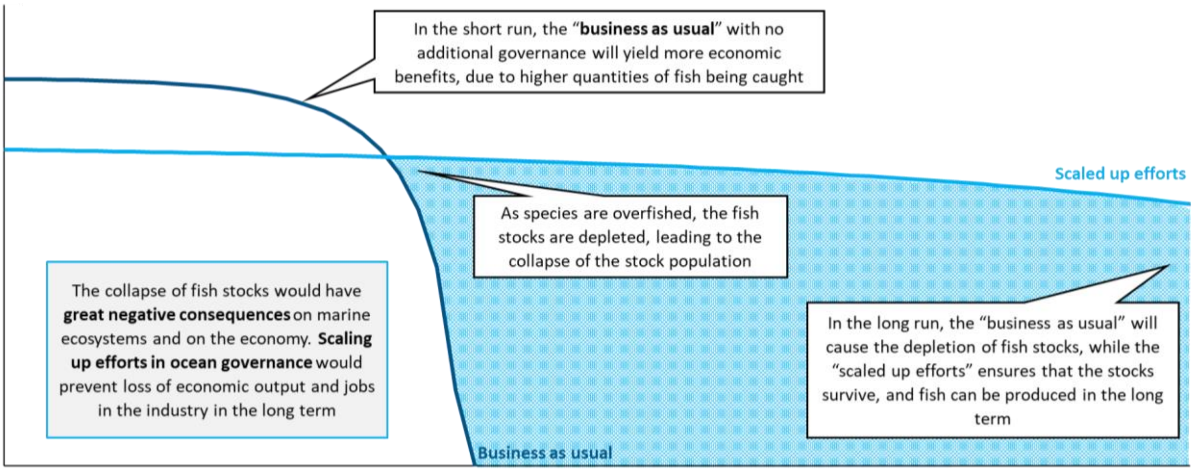
The main data source used for the assessment is the RAM Legacy Stock Assessment Database, which can be accessed at https://www.ramlegacy.org/[660] and https://ourworldindata.org/. The dataset contains indicators, including biomass, total catch, and catch relative to maximum sustainable yield (MSY), for over 1.300 fish species. These indicators are used to predict the "business as usual" scenario and to assess necessary changes in order to achieve a sustainable method of fishing.

In order to assess the economic impact of ocean governance on the fisheries sector, the input-output (I-O) model has been employed. The basis of the model is the linkage and inter-connection of economic sectors. I-O tables compile industrial activity across sectors in a matrix of monetary transactions.[661] These tables are published at national level by the local government or are aggregated at the European level.

[660] The primary publication describing the RAM Legacy Stock Assessment Database is Ricard, D., Minto, C., Jensen, O.P. and Baum, J.K. (2012) Evaluating the knowledge base and status of commercially exploited marine species with the RAM Legacy Stock Assessment Database. Fish and Fisheries 13 (4) 380-398. DOI: 10.1111/j.1467-2979.2011.00435.x

[661] See: https://www.researchgate.net/publication/261175197_Input-Output_Models

Figure 5.8 Conceptual figure of predicted economic value of fisheries under two scenarios (in €)



The driving factor of the model is the concept that currency spent in one sector will be later re-distributed to other sectors, re-entering the economy and creating more value-add as a multiplier to the initial spending.

The I-O table used for the purpose of this model represents the EU27 economy in 2019 and it has been extracted from Eurostat. It has been chosen as it is one of the most recent available datasets and covers a wide spectrum of economies providing a reliable estimate for the worldwide spectrum, in absence of a global (I-O) matrix.

Scope of the assessment

A global assessment of ocean governance covering all species is, however, not feasible given the scope of the study and the difficulties encountered. Firstly, existing data on fishing and stocks is insufficient, as 80% of captures occur in countries with little to no systematic data collection.[662] The IUCN publishes a Red List annually, assessing the stocks of various species which are threatened and the severity of the threats. According to their estimate, the marine realm covered in the Red List is less than 15% of the species assessed.[663] Furthermore, aggregating the biomass of all species would be misleading. As some fish stocks are depleted, others will thrive, for instance, due to a decrease in natural predators. As such, the total biomass can potentially remain constant, while some species may risk population collapse.

Furthermore, there is an important distinction between pelagic and benthic species of fish. The former, including species such as herring and sardines, form schools. As some individuals are removed from the oceans, the remaining ones will join the next available schools. As such, it is possible that prolonged overfishing could fully eradicate the species. On the other hand, benthic species, such as tuna, are more solitary and occupy as much space as is available. When some fish are removed from the ocean, the remaining ones spread out to individually cover a larger territory. This causes difficulties in catching more fish of these species beyond a certain point. It would be economically infeasible to continue trying to catch large quantities after the stock declines.

As such, ocean governance policies concerning fisheries, such as fishing quotas, should be implemented on a species basis. Following this, this report will use specific species of fish, such

[662] https://datatopics.worldbank.org/sdgatlas/archive/2017/SDG-14-life-below-water.html

[663] https://www.iucnredlist.org/about/barometer-of-life

as tuna, in order to illustrate the effects of ocean governance on the sector. The choice of species is made based on the global relevance of these fish stocks and the availability of data.

6.1.2 Assessment of reliability and robustness of methodology and data sources

Robustness in the context of the analysis refers to the degree of reliability of the end results based on the variance in inputs. Robustness issues in the analysis predominantly stem from the time frame covered by the data. While recent catch statistics are available for some locations and species, biomass and MSY data are only available from 2014 to 2018 in the RAM Database. Thus, the data may not capture recent policies and changes across the world, while the identification of these policies exhaustively, is infeasible due to the scope of the research.

Similarly, there are data gaps across indicators, which further complicate the quantification of the proposed scenarios. For instance, data concerning the biomass of fish stocks or the MSY is lacking for some large components, thus causing the estimates to be less reliable than desired.

On the other hand, the MSY approach has been widely accepted as an objective for fisheries management, with references to it being traced back to the United Nations Convention on the Law of the Sea of 1982,664 in which the MSY approach was made mandatory for fisheries in the exclusive economic zones (EEZs) of its signatories, which were obliged to include the MSY concept into national or regional fisheries legislation.[665] Therefore, it has been used as the benchmark of the effort scale-up scenario. Nevertheless, it has, until recently, been viewed more as a theoretical aim, due to the difficulties in calculating it. The MSY is ever-changing and depends on the health of the ecosystem. As the ecosystem changes, the MSY would need to be re-assessed for each species, which is infeasible from a policy standpoint. Specifically, if the ecosystem state worsens, fewer volumes of each species can be sustainably fished. Therefore, most available MSY figures are approximates based on good ecosystem health.

The data sources for the analysis have been carefully reviewed and selected. The RAM Legacy Stock Assessment is based on a highly cited paper, published in a journal with an impact score of 6.90, whilst the I-O matrix was retrieved from Eurostat. Any additional assumptions or inputs, such as exchange rates or prices, were accessed, whenever possible, from reports published by reliable sources, such as FAO or WWF. A list of these reports can be found in the box below.

Box 5.2 List of references for this assessment

Andersen et al. (2018). When is a fish stock collapsed? doi:10.1101/329979

Halpern, B. S. (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. Nat. Commun. 6:7615 doi: 10.1038/ncomms8615, doi: 10.1038/ncomms8615.

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High Level Panel for a Sustainable Ocean Economy. (2020). The Future of Food from the Sea. Retrieved from https://oceanpanel.org/sites/default/files/2020-09/The%20Future%20of%20Food%20from%20the%20Sea.pdf

[664] WWF, 2011 http://awsassets.panda.org/downloads/wwf_msy_oct2011_final.pdf

[665] Mace 2001, A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management

ISSF. (October 2019). Status of the World Fisheries for Tuna. Retrieved from https://www.issuelab.org/resources/35751/35751.pdf?download=true

Mace, P. M. (2001). A new role for MSY in single-species and ecosystem approaches to fisheries stock assessment and management. Fish and Fisheries, 2-32.

Ocean 2012; Transforming Suropean Fisheries. (April 2012). MSY - Maximum Sustainability Yiekd.

WWF. (2014). Cumulative Effects in Marine Ecosystems: Scientific Perspective on its Challenges and Solutions. Retrieved from https://cos.sites.stanford.edu/sites/g/files/sbiybj13371/f/cumulative_effects_in_marine_ecosystems_scientific_perspectives_on_its_challenges_and_solutions_0.pdf

6.1.3 Case studies

6.1.3.1 Species selection

The species have been selected based on their importance in world consumption.

Tuna is one of the most commonly consumed types of fish worldwide, known for its health benefits[666] and very prominent in Asian cuisine. Different types of tuna have different textures, colours, and tastes and they are used for different purposes. Skipjack tuna, for instance, is the most common canned tuna, representing 70% of the US canned tuna market.[667] Albacore tuna is also commonly used in cans, but as larger chunks, and is typically more expensive. Yellowfin is commonly used for steaks and can be found in supermarkets, while Bigeye and Bluefin are used raw, for sushi. Bluefins are the most expensive types of tuna and are almost exclusively served raw.

Sardines are the fifth species of fish most consumed in 2021. They are an important source of food, also used for oil and fish meal. The most common way of consumption of sardines is canned, but they are also eaten dried, salted, or smoked.

Including both tuna and sardines also allows for the analysis of two types of fish exhibiting different behaviours, namely benthic and pelagic species respectively.

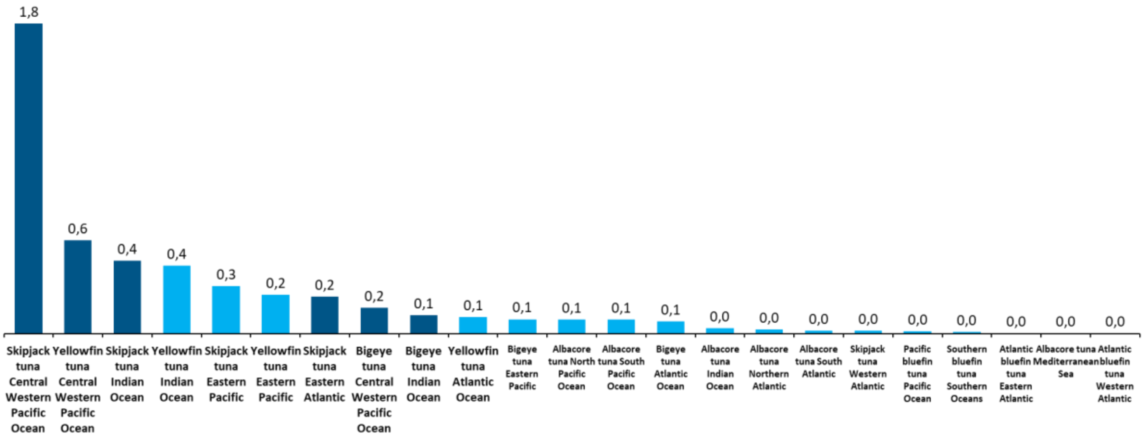
6.1.3.2 Description of the baseline (method and results)

Tuna was identified as one of the fish species for the analysis. The reviewed dataset identifies 23 species of tuna across global oceans. Almost 40% of the global catch consists of Skipjack tuna from the Central Western Pacific Ocean (CWPO), while the first 10 species cover 90% of the global tuna volume. The analysis thus focuses on these 10 species. Four out of the 10 selected species were not included in the analysis due to lack of data, either concerning biomass or MSY, leaving six species of tuna to be assessed. These species represent 70% of the total catch in the latest available years. An overview of the species and the potential reason for their exclusion can be found in the figure below.

[666] https://www.webmd.com/diet/health-benefits-tuna#1

[667] https://fishingbooker.com/blog/types-of-tuna-food/

Figure 5.9 Total catch per tuna species, 2013, in million tonnes, light blue: not included in the analysis, dark blue: included in the analysis



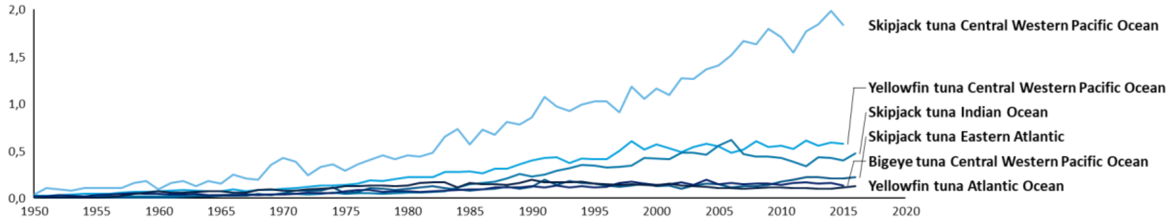
Source: RAM Legacy Stock Assessment Database

Table 5.1 Top 10 tuna species (by capture quantity), in alphabetical order

Species	Notes
Bigeye tuna Central Western Pacific Ocean	assessed
Bigeye tuna Indian Ocean	dismissed due to lack of biomass data
Skipjack tuna Central Western Pacific Ocean	assessed
Skipjack tuna Eastern Atlantic	assessed
Skipjack tuna Eastern Pacific	dismissed due to lack of MSY data
Skipjack tuna Indian Ocean	assessed
Yellowfin tuna Atlantic Ocean	assessed
Yellowfin tuna Central Western Pacific Ocean	assessed
Yellowfin tuna Eastern Pacific	dismissed due to lack of biomass data
Yellowfin tuna Indian Ocean	dismissed due to lack of biomass data

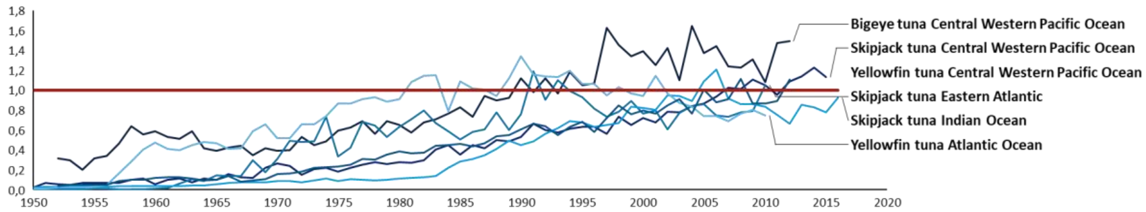
The trend of each of the tuna species has been observed to be steadily increasing throughout the observed period. While catches of most of the selected stocks have stabilised since the 1990s, captures of Skipjack tuna (CWPO) have more than doubled since 1990 and have increased by over 60% between 2000 and 2016. These trends can be seen in Figure 5.10. The stabilisation coincides with global efforts to fish for tuna more sustainably, due to concerns about the long-term prospects of the species. Figure 5.11 shows the trend of the catch to MSY ratio. The dark red line corresponds to a ratio of 1, where tuna is fished exactly at MSY. Above this line, tuna is overfished, while under the line there is still room for growth in fishing. In the past, the ratio was increasing rapidly, however, as the capture growth slowed, the rate of growth of catch to MSY ratio also reduced. Notably, however, Bigeye tuna (CWPO) and Skipjack tuna (CWPO) are above MSY level and do not show signs of returning as of 2016.

Figure 5.10 Total catch per tuna species, in million tonnes



Source: RAM Legacy Stock Assessment Database

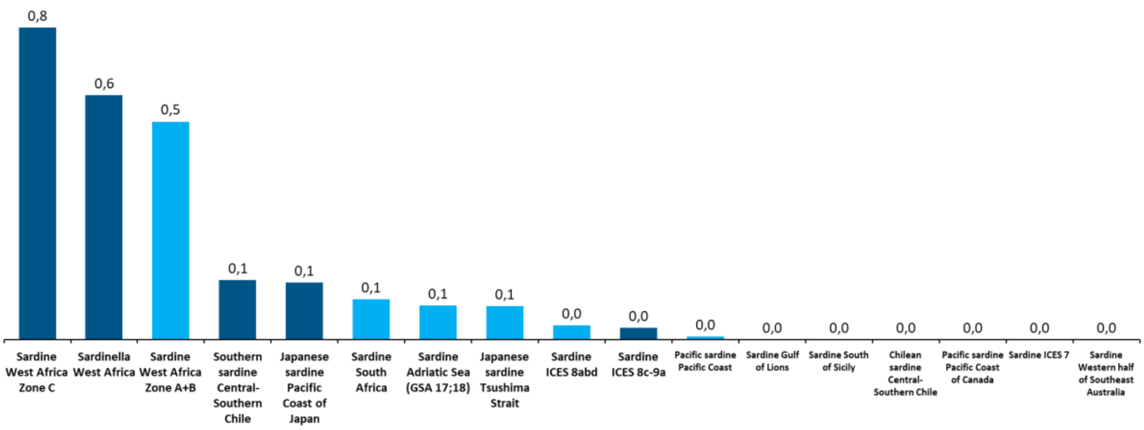
Figure 5.11 Catch to MSY ratio per tuna species



Source: RAM Legacy Stock Assessment Database

Sardines represent an important species for global consumption. The reviewed dataset identifies 17 species of sardines and sardinella (a sub-type of sardines) across global oceans. Almost 30% of the global catch consists of sardines from Zone C of West Africa, while the first 10 species cover almost 97% of the global sardine volume. The analysis thus focuses on these 10 species. Five out of the 10 selected species were not included in the analysis due to lack of data, in particular on MSY, leaving five species of sardines to be assessed. These species represent 67% of the total catch in the latest available years. An overview of the species and the potential reason for their exclusion can be found in the figure below.

Figure 5.12 Total catch per sardine species, 2014, in million tonnes, light blue: not included in the analysis, dark blue: included in the analysis



Source: RAM Legacy Stock Assessment Database

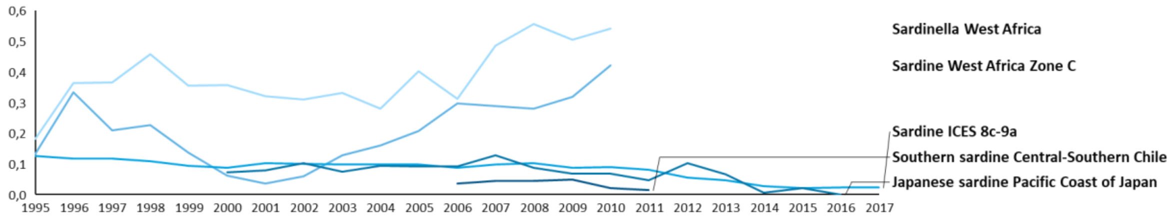
Table 5.2 Top 10 sardine species (by capture quantity), in ranking order

Species	Notes
Japanese sardine Pacific Coast of Japan	assessed
Pacific sardine Pacific Coast	eliminated due to lack of MSY data
Sardine Adriatic Sea (GSA 17;18)	eliminated due to lack of MSY data
Sardine ICES 8abd	eliminated due to lack of MSY data
Sardine ICES 8c-9a	assessed
Sardine South Africa	eliminated due to lack of MSY data
Sardine West Africa Zone A+B	eliminated due to lack of MSY data
Sardine West Africa Zone C	assessed
Sardinella West Africa	assessed
Southern sardine Central-Southern Chile	assessed

Each of the selected species of sardines has been following different trends. Sardines and Sardinella from the West Arica zones have been fished at an increasing rate up until 2010, whilst the other three species at lower rates. The latter trends correspond to a decrease in biomass relative to the MSY value, implying that they are caused by a depletion of the fish stock.

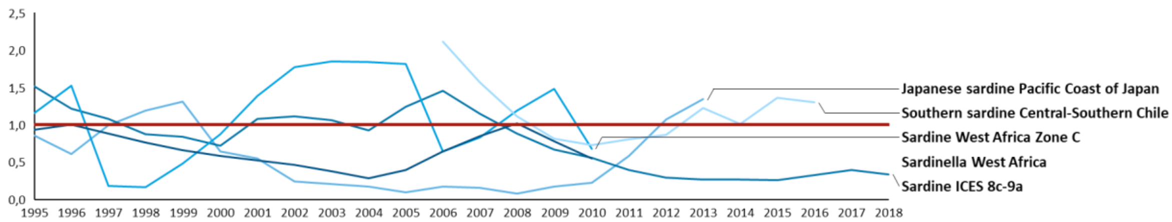
In terms of biomass, a particularly worrying trend can be observed for sardines from the ICES 8c-9a areas. Since 2008, the biomass has dropped below its MSY values, decreasing each year. This indicates the threat of species collapsing in the near future. On the other hand, the biomass of Japanese sardines has risen since 2010, corresponding to a decrease in the total catch of the species. This indicates a recovery of the species, although already a relatively small stock.

Figure 5.13 Total catch per sardine species, in million tonnes



Source: RAM Legacy Stock Assessment Database

Figure 5.14 Biomass to MSY ratio per sardine species



Source: RAM Legacy Stock Assessment Database

6.1.3.3 *Description of the" business as usual" scenario (method and results)*

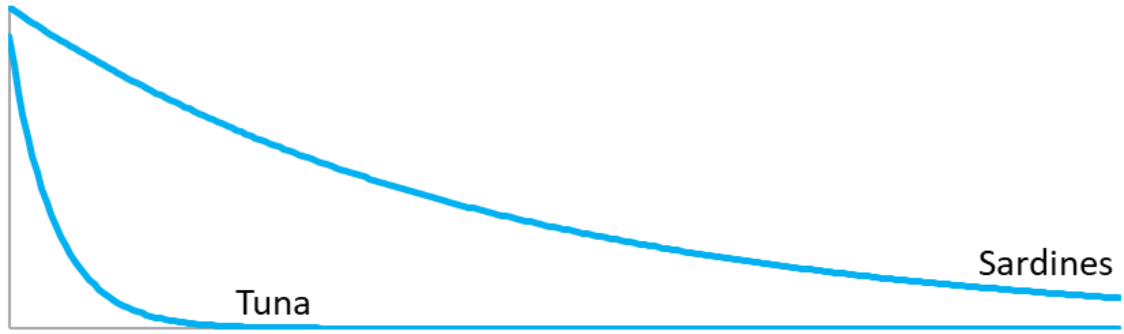
The business as usual scenario uses the total catch trends to forecast the development of the sector without any additional interventions. However, as the catch quantities increase, some fish stocks are observed to decline. Based on current trends and using historical data on the biomass of tuna and sardine species, the model estimates the trends in the table below.

Table 5.3 Biomass predictions for the business as usual scenario

Business as usual	Description
Bigeye tuna Central Western Pacific Ocean	will run out of fish in 2074
Skipjack tuna Central Western Pacific Ocean	will run out of fish in 2660
Skipjack tuna Eastern Atlantic	fished around MSY
Skipjack tuna Indian Ocean	will run out of fish in 2214
Yellowfin tuna Atlantic Ocean	fished around MSY
Yellowfin tuna Central Western Pacific Ocean	will run out of fish in 2050
Japanese sardine Pacific Coast of Japan	fished around MSY
Sardine ICES 8c-9a	will run out of fish in 2038
Sardine West Africa Zone C	will run out of fish in 2026
Sardinella West Africa	will run out of fish in 2056
Southern sardine Central-Southern Chile	fished around MSY

Although total catch trends indicate growth, the decrease in biomass will limit the quantity that can be fished over time. In the case of benthic species, such as tuna, the decrease in biomass causes the fish to disperse across the ocean floor, thus becoming exponentially more difficult to catch, given fishing efforts. Pelagic species such as sardines, on the other hand, school with the remaining fish, once part of their former school has been removed from the ocean. Once the stock has been sufficiently depleted, the instances of "meeting" the species drop in frequency. In either case, it is economically infeasible to further increase the fishing effort to attain the desired catch volume. To capture these effects, the following functions have been introduced in order to adjust the total catch prediction.

Table 5.4 Total catch adjustment function per fish type



However, the decrease in total catch possibilities only occurs after the species is sufficiently depleted. In order to calculate this threshold, we find the MSY value of the catch to biomass ratio for each species. These ratios can be found in the table below. We assume that, once the catch to biomass ratio exceeds that at MSY, the stocks begin decreasing and it becomes increasingly more difficult to sustain the predicted catch. This is thus the threshold beyond which the above adjustments are enforced.

Table 5.5 Catch to biomass ratio at MSY

Species	Catch/biomass ratio
Bigeye tuna CWPO	8%
Skipjack tuna CWPO	45%
Skipjack tuna Eastern Atlantic	44%
Skipjack tuna Indian Ocean	43%
Yellowfin tuna Atlantic Ocean	23%
Yellowfin tuna CWPO	25%
Sardinella West Africa	32%
Sardine West Africa Zone C	5%
Sardine ICES 8c-9a	23%
Japanese sardine Pacific Coast of Japan	22%
Southern sardine Central-Southern Chile	28%

Note: The relative percentages are consistent with previous literature.

Based on the catch to biomass rates, the tipping points of when populations of fish could decrease can be estimated and computed. In the table below, these tipping points are depicted. While for some species these tipping points are still to come, several species can be considered to already have reached a tipping point. However, inconsistencies have been observed due to the availability of data that stem from 2016. At the time of writing, the data is 6 years old and, in the meantime, regulations have been introduced to counter overfishing. Therefore, the actual tipping points will be influenced positively compared to the overview provided here, hence tipping points will lie further in the future than is sketched in this subsection.

Table 5.6 Tipping points of fish species

Species	Tipping point
Bigeye tuna CWPO	2015
Skipjack tuna CWPO	2018
Skipjack tuna Eastern Atlantic	2035
Skipjack tuna Indian Ocean	2013
Yellowfin tuna Atlantic Ocean	2039
Yellowfin tuna CWPO	2018
Sardinella West Africa	No indication of crossing tipping point in the estimated period
Sardine West Africa Zone C	Already past tipping point
Sardine ICES 8c-9a	Already past tipping point
Japanese sardine Pacific Coast of Japan	Already past tipping point
Southern sardine Central-Southern Chile	No indication of crossing tipping point in the estimated period

6.1.3.4 Description of the "scaled up efforts" scenario (method and results)

Box 5.3 Specific considerations for calculating the "scaled up efforts" scenario

The "scaled-up efforts" scenario is based on the goal of reaching and sustaining MSY across all species. Given a constant, "good" ecosystem health, the MSY per species would be constant. Increasing MSY catch trends in the panel data indicate errors in the documentation. However, this is not unexpected given the novelty of the methodology and the difficulties in assessing the MSY each year.

The "scaled-up efforts" scenario implies fishing of each species at MSY over time. To identify the sustainable volume of catch per species, we divide the "total catch" by the "catch to MSY ratio" variable. If the catch to MSY ratio is not available, as is the case with sardines, we instead use the biomass to MSY ratio. It can be assumed that, in years where this ratio was equal to 1, the catch also equalled its MSY value. Finding one or more such instances would provide an approximation of sustainable catch volumes.

Once these have been identified, if the trend of the MSY values is constant or increasing, we use an average value for the forecast.668 If the trend is decreasing, we follow that trend to forecast future MSY values. This is done to capture some of the effects of the worsening of the ecosystem health. Whilst policies targeting fish stocks would help preserve them, there are many other factors negatively affecting marine ecosystems. It is thus expected that all MSY values would decrease over time, without the implementation of further measures targeting the ecosystem.

6.1.3.5 *Comparison of results from the two scenarios*

Comparing the two scenarios, we see that scaling up efforts for ocean governance will come at a short-term reduction of economic value added from the sector. However, in the long term, following the "business as usual" scenario with no additional interventions will lead to a depletion of stocks. Taking action for sustainable fishing will ensure that the species can continue to be consumed for a much longer period of time. To illustrate, Figure 5.15 Figure 5.16 show the predicted trends of the economic value of the fisheries sector. An important note is that the MSY catch value (tonnes) is constant or decreasing per fish species. The upward slope of the "scaled up efforts" scenario in the charts is caused by inflation. Moreover, the upper and lower confidence bounds are estimated based on variations in predicted biomass developments.

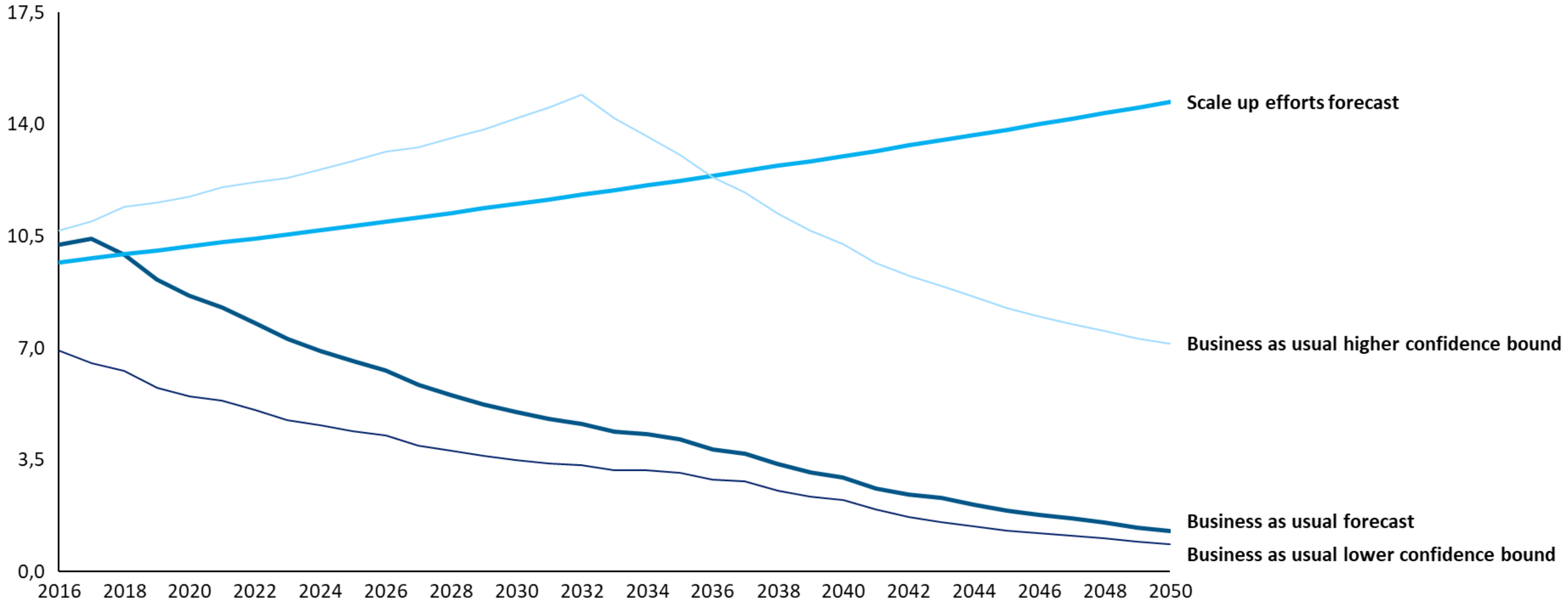
In the case of tuna, the available data indicates that value is already being lost. However, there have been global policies in place during the last years, targeting the recovery of tuna fish stocks, which could not be captured by the data. Thus the "business as usual" scenario is likely closer to the "scaled up efforts" scenario than depicted. Furthermore, the upper confidence bound is far greater than the forecast due to optimistic biomass forecasts in all species, while many become depleted in the forecast. Given recent developments, it is thus likely that the real scenario takes place somewhere between the forecast and the upper confidence bound.

For sardines, we see a sudden dip in the "business as usual" forecast in the near future. This corresponds to a simultaneous collapse of three of the five assessed sardine stocks.

These trends are very similar to those of the fish stocks, as seen in Figure 5.17 and Figure 5.18. The differences stem from the predicted yearly inflation over future years. Firstly, once the total catch volumes have been identified for both scenarios, they are multiplied by the average price of tuna and sardines respectively, in order to find the direct spending in the sector. Using the I-O model, we compute how much value is indirectly produced in the economy due to the sale of these fish. Specifically, using the 2019 Eurostat I-O table, the multiplier is 2.41. The resulting yearly values are adjusted for inflation, using the average inflation rate of 1.41%, as computed based on 2009 to 2020 data from Eurostat.

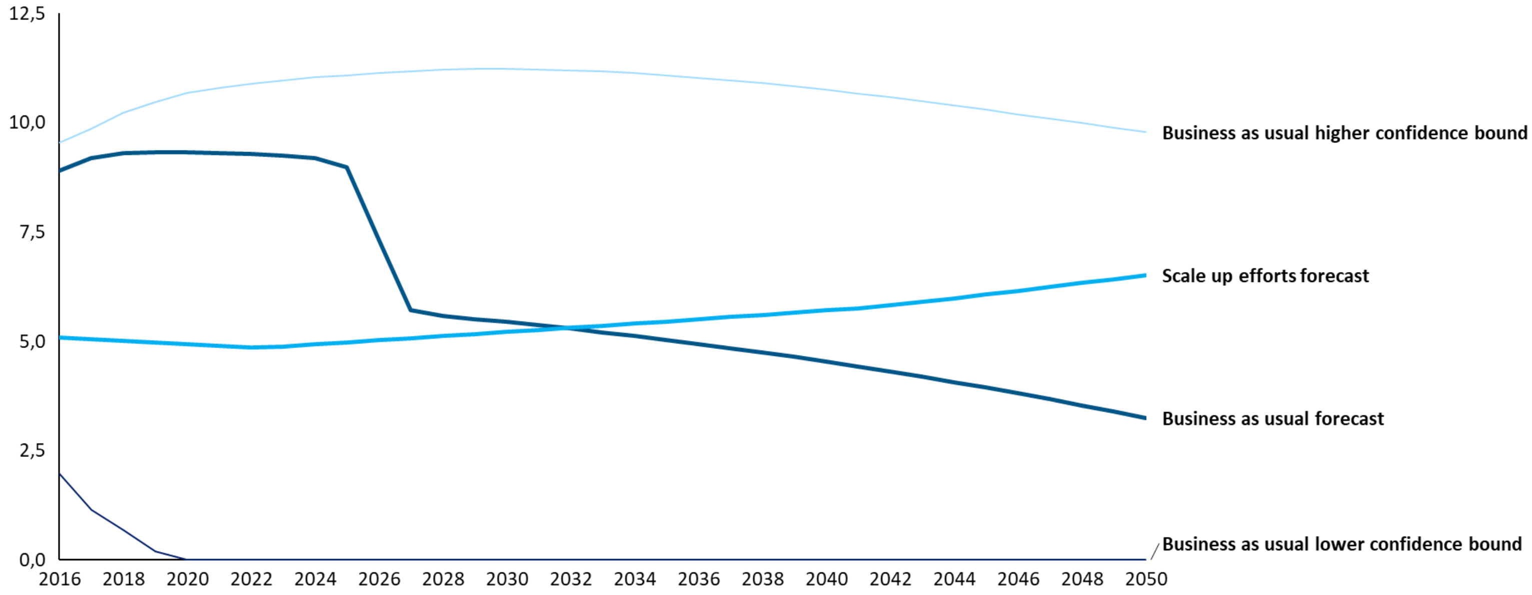
[668] An increasing trend indicates errors in the dataset. Taking an average value mitigates some of these issues.

Figure 5.15 Forecast economic value of tuna, in € billion



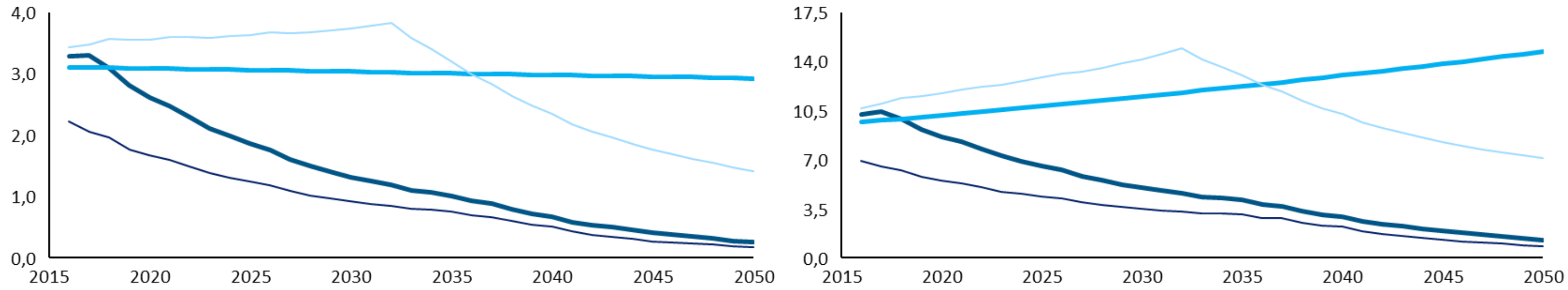
Source: Own computations

Figure 5.16 Forecast economic value of sardines, in € billion



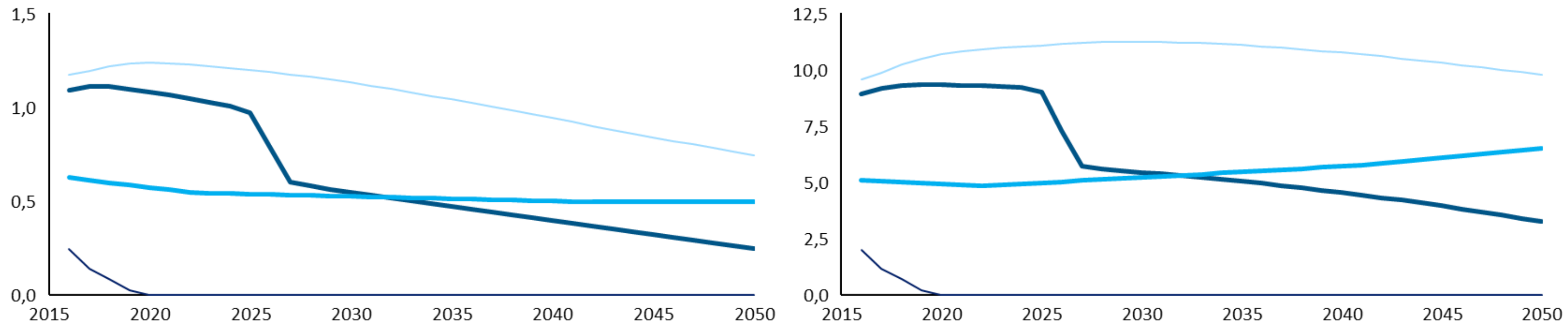
Source: Own computations

Figure 5.17 Tuna, total catch (in million tonnes) and economic impact (in billion €)



Source: own computations

Figure 5.18 Sardines, total catch (in million tonnes) and economic impact (in billion €)



Source: Own computations

6.2 Aquaculture Provisioning Services

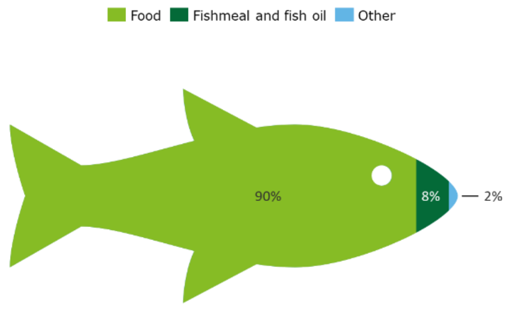
6.2.1 Description of Ecosystem Service / Benefit and Impact

The SEEA-EA defines aquaculture provisioning services as the 'ecosystem contributions to the growth of animals and plants in aquaculture facilities that are harvested by economic units for various uses'.

Aquaculture is possible in freshwater, brackish water and saltwater, and cultivates populations under controlled or semi-natural conditions. Within the context of this study, the focus is made on mariculture: aquaculture activities carried out in the ocean and coastal areas, which can include farming of fish, crustaceans, molluscs, algae and other organisms of value such as seaweeds.

Aquaculture can provide a wide range of products, e.g. food, basis for feed (e.g. fish meal, fish oil), fuel and raw materials for the pharmaceutical and cosmetics industry. Next to provisioning services, aquaculture provides regulating services; directly by cleaning the water, but also by preventing pollution of more harmful species such as CO2 pollution. Especially filter feeders, like mussels and oysters, can clean water, to improve the water quality.669 Given that approximately 90% of the total seafood production is consumed as food, 8% is reduced to fishmeal and fish oil, and the remaining 2% is used for other non-food appliances, this section focuses on aquaculture dedicated to food production[670,671].

Figure 5.19 Division of provisioning services derived from aquaculture



Source: own illustration

In this report, the use of the word 'seafood' indicates fish, crustaceans, molluscs and other aquatic animals, but excludes aquatic mammals, crocodiles, caimans, alligators and aquatic plants[672,673]. Seafood can be sourced from aquaculture and wild fishing activities. While the term

[669] Hu et al. (2021) Development of fisheries in China, Reproduction and Breeding. See: https://www.sciencedirect.com/science/article/pii/S2667071221000089

[670] Naylor et al (2021) A 20-year retrospective review of global aquaculture. See: https://www.nature.com/articles/s41586-021-03308-6

[671] OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030. See: https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm

[672] See: https://oceanservice.noaa.gov/facts/aquaculture.html

[673] OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en. (https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm)

'seafood' suggests that seafood comes from the sea, also food from animals living in freshwater like trout are falling under this name in this case study.

Substitutes to seafood

Current alternatives to seafood are mainly animal-based protein-rich food sources which involve sheep meat, beef/veal meat, pork meat, and poultry meat. The value of proteins delivered by aquaculture production is taken as a proxy for aquaculture provisioning services, and we compare this with protein delivered by terrestrial farming. In this section, it is hypothesised that seafood can substitute meat from land-based animals to prevent the higher impact that terrestrial animals have on the environment. For instance, during an outbreak of African swine fever in China, the price of pork increased, and as a consequence, the demand for seafood increased as a substitute for pork[674].

6.2.2 Description of methodology for monetisation incl. indicators used and data sources

The structure of this case study follows three distinguished steps. First, the baseline in 2020 is estimated. Then, a business as usual (BAU) scenario for the period until 2050 is elaborated on, and lastly, the scaled-up efforts (SUE) scenario is presented for the period until 2050.

A baseline will be sketched to picture the current status of consumption of animal-based protein-rich food sources. Based on the data of consumption for 2020, the inhabitants of the EU in 2020, and the prices per kilogramme of a specific food source, the benefits of selling protein sources can be calculated. The consumption of food in different geographical regions is reported by the Food and Agriculture Organization of the United Nations (FAO). FAO publishes the trends in the consumption of different categories of food and also projects the development of food prices[675.] Besides the benefits, the impact of food sources on the environment can be derived. These environmental impacts are split into CO2 emissions and land use. Based on a report written by the PBL Netherlands Environmental Assessment Agency, we can derive the environmental impact by multiplying the CO2 emissions and land-use per kilogramme with the total volume of the consumption of food sources in 2020 in the EU.

After the baseline is sketched, the developments in consumption, prices and costs of animal-based protein-rich food sources are projected. The BAU scenario assumes that the current trends are pursued and no additional governance is introduced. Relying on FAO data and taking into account the volume of consumption of food, the prices of food and the growth of population over time, a business as usual scenario (BAU) is defined for the consumption demand of protein-based sources. Based on the consumption of the foods, benefits and costs can be calculated. The benefits are calculated by multiplying the prices of food with the total consumption of food. Regarding the costs side, three different costs are accounted for in this case study: production, CO2 emission, and land-use costs. The production costs are calculated with help of the consumption and the production costs per kilogramme. As we are attempting to interpret global data for cost and economic values, inconsistencies are observed due to the limited availability of production costs as it is competitor sensitive information. It is tried to address this by using

[674] See: https://www.reuters.com/world/china/surging-chinese-fish-prices-stir-up-food-supplies-2021-09-10/

[675] OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en. (https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm)

multiple different sources [676, 677, 678, 679, 680, 681]. The analysis of environmental costs is based on land use and greenhouse gas emission per kg of meat and seafood, based on statistics provided by the PBL Netherlands Environmental Assessment Agency[682]. Multiplying these values with the volume of consumption, the total carbon emissions and land use can be derived. To express these in economic terms, the CO2 emissions are converted by using the EU Emissions Trading System (ETS) carbon prices[683]. The costs of land-use are transferred in euros based on the eco-costs of land-use for agricultural products[684].

Environmentally and economically, the BAU scenario is expected to be sub-optimal to meet the consumption demand while ensuring that the world meets the current targets set by the 26th session of the Conference of the Parties (COP26)[685]. Based on the research by Wageningen University ("Impact of the EU's Green Deal on the livestock sector")[686], the EU's livestock should decrease by 10 to 15% in 2030. A quantitative analysis enables us to understand this figure and acts as a basis to discuss the benefits and limitations of stimulating mariculture. Mariculture is expected to have a lower environmental impact. This will be discussed in the scaled-up efforts (SUE) scenario. In this part of the case study, it is suggested to replace some categories of terrestrial meat with seafood from mariculture at a realistic rate. Assuming this is realistic, the same calculations can be done as in the BAU scenario, e.g. the benefits of selling protein-rich foods, and the total costs of producing these are computed. Moreover, it is discussed what means are necessary considering Ocean Governance to make this transition possible.

Having both a BAU and SUE scenario, the two can be compared to conclude which direction to head in.

6.2.3 Assessment of reliability and robustness of methodology and data sources

The data is sourced from reputable stakeholders such as the FAO, the PBL Netherlands Environmental Assessment Agency, and Wageningen University & Research. While projections bring uncertainties, drawing from historical data for the presented forecasts in the analysis helps bring reliability to the analysis.

676 https://meatpromotion.wales/en/industry-resources/sheep-management/cost-of-production

677 https://www.gov.mb.ca/agriculture/farm-management/production-economics/pubs/cop-beef-300-cow-calf.pdf

678 https://ahdb.org.uk/pork-cost-of-production-and-net-margins

679 https://projectblue.blob.core.windows.net/media/Default/Pork/Documents/CostOfPigProduction_20193995-WEB2.pdf

680 Wageningen Economic Research Report 2020-2027

681 Audun Iversen, Frank Asche, Øystein Hermansen, Ragnar Nystøyl, Production cost and competitiveness in major salmon farming countries 2003–2018, Aquaculture, Volume 522, 2020, 735089, ISSN 0044-8486, https://doi.org/10.1016/j.aquaculture.2020.735089. (https://www.sciencedirect.com/science/article/pii/S0044848619300638)

682 Nijdam, Durk & Rood, Geertruida & Westhoek, Henk. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy. 37. 760–770. 10.1016/j.foodpol.2012.08.002. (https://www.sciencedirect.com/science/article/abs/pii/S0306919212000942)

683 https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_nl

684 https://www.ecocostsvalue.com/eco-costs/eco-costs-land-use/

685 https://ukcop26.org/wp-content/uploads/2021/11/COP26-Presidency-Outcomes-The-Climate-Pact.pdf

686 Jongeneel, R., Silvis, H., Martinez, A. G., & Jager, J. (2021). The Green Deal: An assessment of impacts of the Farm to Fork and Biodiversity Strategies on the EU livestock sector. (https://www.wur.nl/en/show/Impact-of-the-EUs-Green-Deal-on-the-livestock-sector-1.htm#:~:text=%2D%20Achieving%20the%20EU's%20Green%20Deal,Balance%20(GNB)%20surpluses)

6.2.4 Description of the baseline (method and results)

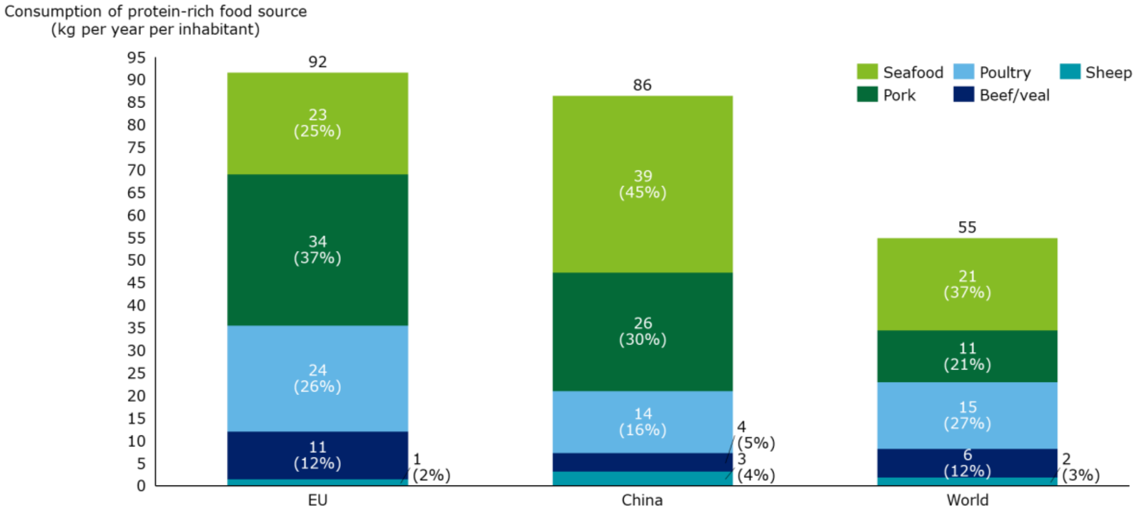
An overview of the baseline considering seafood and meat is sketched in this subsection. First, the baseline consumption of conventional proteins and seafood production is sketched in this sub-section. Subsequently, different protein source categories are quantified in relation to three aspects: economic benefits, land use, and carbon footprint. These three factors are used throughout this subsection to compare the effects of different animal-based protein-rich food sources quantitatively.

Consumption of animal-based protein-rich food sources in the EU, China and the world

It is observed in the baseline analysis that considerable differences exist between the consumption of seafood and meat in different countries which may be caused by rising incomes that translate into more money spent on meat and seafood[687]. A correlation can be observed between the wealth of a society and its animal-based protein consumption.

Currently, the consumption of protein-rich food sources in the World, EU, and China are as depicted in Figure 5.20. Notable facts are that, in comparison to seafood, relatively more meat is consumed in the EU compared to China or the World. The total consumption of seafood and meat accumulated is also the highest in the EU[688]. The share of seafood consumption in the diets of the geographical areas varies, observing that an average EU inhabitant consumes in percentage the least seafood compared to an inhabitant of China and in general the world. The reason is not that the EU population eat less fish, but because they eat more terrestrial meat.

Figure 5.20 Consumption of protein-rich food sources per geographical area in 2020 (kg per year per inhabitant).



Source: FAO

[687] https://www.bbc.com/news/health-47057341

[688] OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en. (https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm)

Consumption of seafood originating from aquaculture

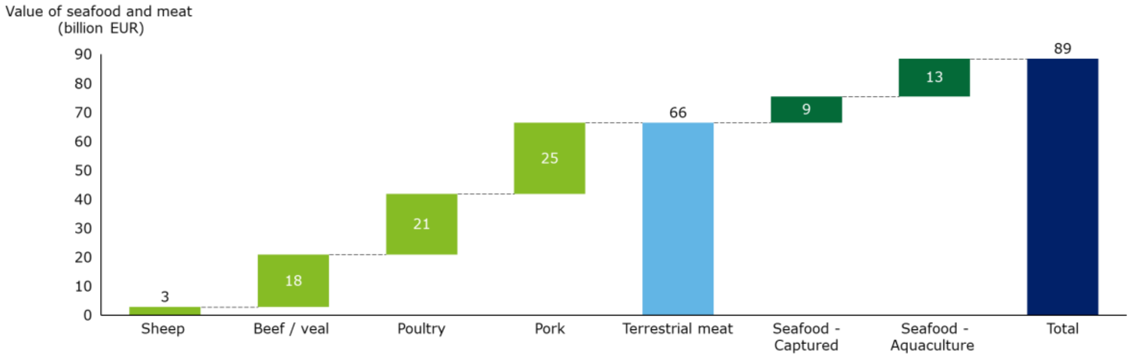
In the period from 2018 to 2020, the contribution of aquaculture to the global production of seafood was approximately 47%[689], while the contribution of aquaculture to the EU's production of seafood was 20% in 2018, a share that was similar to that in 2008. Six species account for 90% of the volume of aquaculture: salmon, trout, oysters, European seabass, seabream and mussels. The economic value of aquaculture in the EU is 41% of the total value of the EU's total production of fishery products. In 2008, this number was seven percentage points lower, accounting for 34% of the total production of seafood[690].

In 2019, the EU's aquaculture sector represents 2% of the world's value of aquaculture. The EU's (including the United Kingdom) aquaculture was valued at 5 billion euros, while the world's aquaculture had a worth of more than 245 billion approximately euros[691].

Value of animal-based protein-rich food sources

The value of animal-based protein-rich food sources is computed by the volume consumed multiplied by the selling price. In Figure 5.21 the total consumption in the European Union of protein-rich sources is divided into categories. The value of animal-based protein-rich food within the European Union was estimated at 89 billion EUR (98 billion USD[692]) in 2020, of which pork (28%), seafood (26%), and poultry (23%) contribute relatively the most.

Figure 5.21 Value of seafood and meat in the European Union in 2020 (billion EUR)



Source: FAO

Land-use and ecological footprint of food sources

Farming requires the use of land, feeding of animals and generates greenhouse gas emissions. Using a life cycle assessment (LCA) approach, the carbon footprint and land-use of animal-based protein-rich food products per kilogramme is estimated[693] from cradle to retail. Multiplying these estimates with the total consumption of the specific type of meat or seafood,

[689] Annex C.7, OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en. (https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm)

[690] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20191015-2

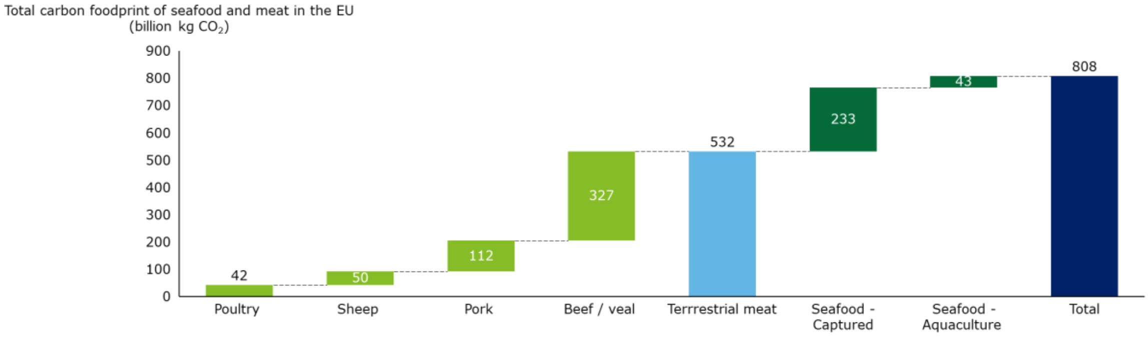
[691] https://www.eumofa.eu/data

[692] Throughout the report, a constant EUR/USD of 0.9 is adopted.

[693] Nijdam, Durk & Rood, Geertruida & Westhoek, Henk. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy. 37. 760–770. 10.1016/j.foodpol.2012.08.002. (https://www.sciencedirect.com/science/article/abs/pii/S0306919212000942)

the total CO2 emissions and land-use are obtained. Overviews of the values per meat / seafood category and totals are represented in Figure 5.22 and Figure 5.23.

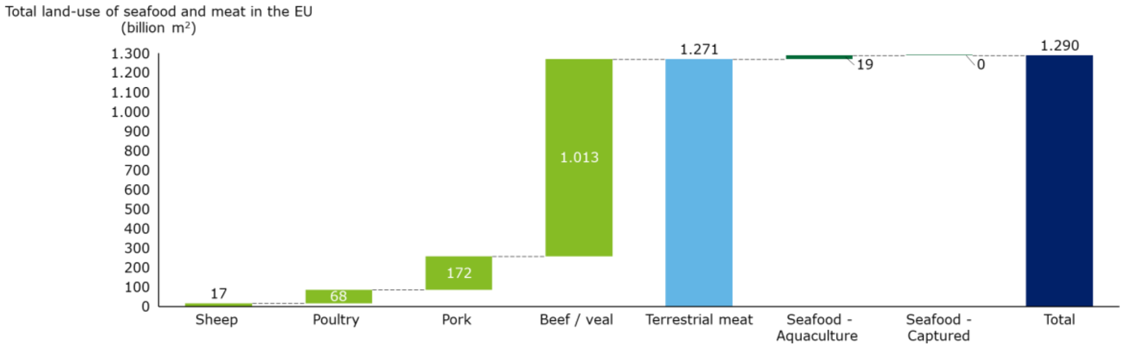
Figure 5.22 Carbon footprint of protein-rich food in the EU in 2020 (billion kg CO2).



Source: Deloitte analysis, FAO and PBL Netherlands Environmental Assessment Agency

While the absolute consumption of captured seafood and beef/veal is relatively modest in the EU (approximately 25%), the carbon footprint of the sector accounts for almost 70% of that of all land-based meat production. Potentially, captured seafood has a large carbon footprint due to the use of vessels that sail on fossil fuels, while cows, needed for the production of beef / veal meat, produce a high amount of methane[694].

Figure 5.23 Land use of animal-based protein-rich food in the EU in 2020 (billion m2)



Source: Deloitte analysis, FAO and PBL Netherlands Environmental Assessment Agency

Although beef/veal only accounted for approximately 12% of the total consumption of protein-rich food source in the EU in 2020, it represented approximately 78% of the total land used in comparison to other forms of protein production. The land use per kilogramme of beef/veal meat is, therefore, significantly higher than the other forms of animal-based protein-rich food production. Seafood is not farmed on land, therefore, the land-use component consists only of the land used for plant-based feed.

[694] theguardian.com/environment/2021/oct/27/whats-the-beef-with-cows-and-the-climate-crisis

6.2.5 Description of the" business as usual" (BAU) scenario (method and results)

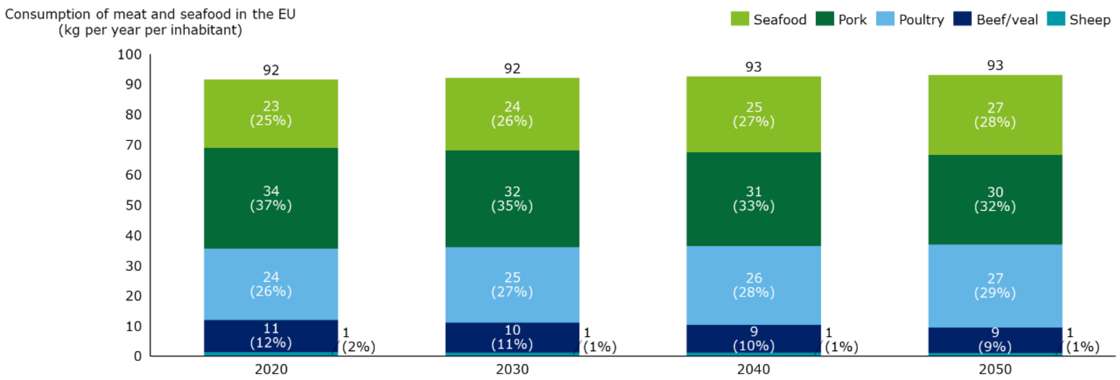
This subsection portrays the situation when no additional governance is implemented by local, regional, national or international governmental bodies. History does not forecast the future, meaning that long-term projections are subject to uncertainty.

Firstly, the economic impact of animal-based protein-rich food is determined via the benefits of selling the foods on the market. Secondly, an overview is provided of the costs associated with production, carbon footprint and land-use of meat/seafood. At the end of this subsection, the benefits and costs are compared and overviews of profits are provided. Using statistics and forecasts developed by the FAO up until 2030, and by extrapolating these numbers for the period from 2030 to 2050, reliable projections can be made[695]. It is assumed that the consumption of seafood by inhabitants of the EU follows the global trend (47% of seafood from aquaculture in 2020, and 52% in 2030). To have a basis on which we compare evenly, the benefits and costs are expressed in euros.

Value of animal-based protein-rich food sources

Under the BAU scenario, consumption of animal-based protein-rich food sources would remain almost stable over the next decades, as shown in Figure 5.24, however, the share of terrestrial meat would decrease, with poultry as an exception. The share of consumption of seafood would increase from 25% to 28%. While it is expected that the share of volume seafood production of aquaculture remains equal to approximately 20% in the EU, the global volume contribution of aquaculture will increase to 52% in 2030696. The motivations of consumers driving the changes in their diet could be related to sustainability and health concerns697.

Figure 5.24 Predicted consumption of meat and seafood in the EU in the period 2020-2050 (kg per year per inhabitant).



Source: Deloitte analysis and FAO

[695] OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en. (https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm)

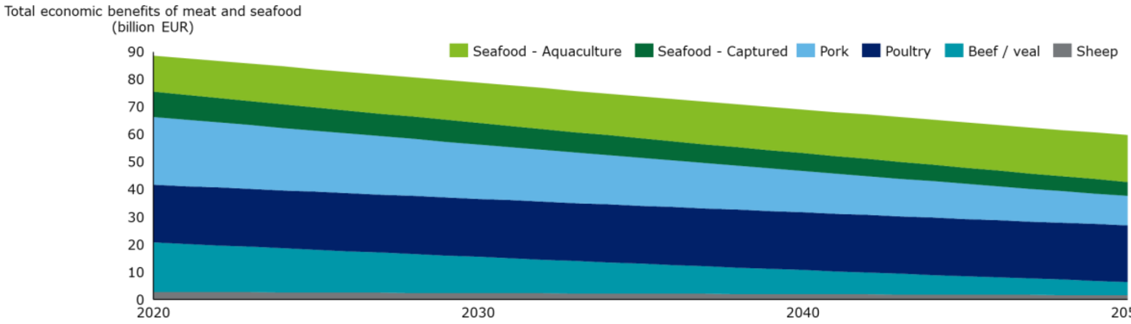
[696] Annex C.7, OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en. (https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm)

[697] Joop de Boer, Harry Aiking, Do EU consumers think about meat reduction when considering to eat a healthy, sustainable diet and to have a role in food system change?, Appetite, Volume 170, 2022, 105880, ISSN 0195-6663, https://doi.org/10.1016/j.appet.2021.105880. (https://www.sciencedirect.com/science/article/pii/S019566632100787X)

Figure 5.25 translates the volume of consumption of the protein-rich food sources into economic value, showing that the total value of animal-based protein sources would decrease from more than 88 billion EUR to slightly less than 60 billion EUR698. The value of the total sold animal-based protein-rich food sources is computed by multiplying the projected consumption of meat/seafood with the expected number of inhabitants in the European Union. Subsequently, this resulting total volume of meat/seafood consumption in the EU can be multiplied by the forecasted meat/seafood prices. The result is the total meat/seafood value in the EU. It is assumed that the percentage of consumption of seafood from aquaculture compared to the overall in the EU corresponds to the global consumption of seafood, thus having a share of 47% in 2020, and a share of 52% in 2030.

The loss in the total value of animal-based protein sources is anticipated to be driven by a significant price cut in pork (more than 50%) and beef/veal (more than 66%).699 The decrease in prices of meat and seafood is driven by projected productivity gains and slowing demand growth or even shrinking of the demand. The long-term price projections are subject to uncertainty and do not remove the reality of short-term price spikes and volatility.

Figure 5.25 Economic contributions of different kinds of protein-rich foods in the EU in the period 2020-2050 (billion EUR, BAU).



Source: Deloitte analysis and FAO

Costs of meat and seafood

Considering the costs side of the production of meat and seafood, three categories are distinguished: production, carbon footprint, and land-use costs. The first step to compute these costs is to obtain the EU's total volume of meat/seafood. As already described in this subsection, these are calculated by multiplying the projected meat/seafood consumption per person by the expected inhabitants in the EU. Based on the volume and the production costs per kilogramme, the total production costs can be derived. The CO2 and land-use costs can be calculated by multiplying the total consumed volume of meat/seafood by the CO2 emitted per kilogramme of meat/seafood and the land-use per kilogramme of meat/seafood. The result is the total CO2 emissions and the total land used in the EU. To have an equal basis of comparison, the costs are translated to euros. CO2 emissions are converted to euros by using the EU Emissions Trading System (ETS) carbon prices.[700] The costs of land-use are based on the eco-costs of land-use for agricultural products.[701]

[698] Throughout the report, a constant EUR/USD of 0.9 is adopted

[699] Extrapolating the data from https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm

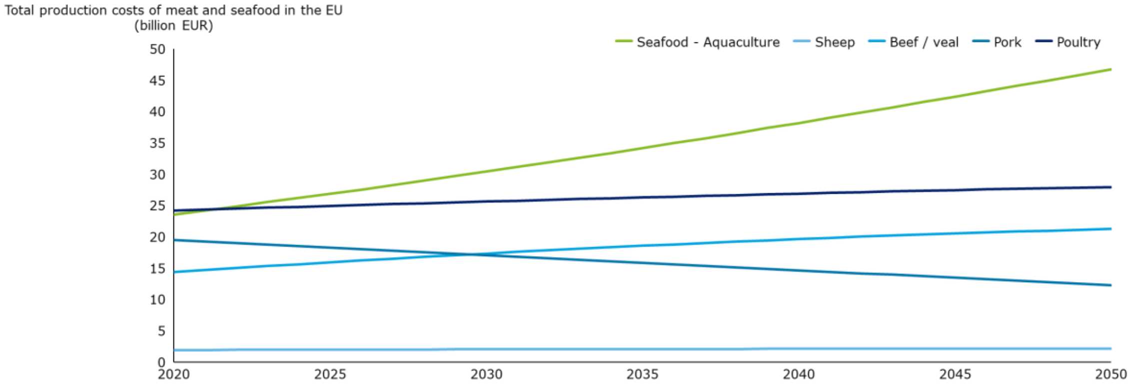
[700] https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_nl

[701] https://www.ecocostsvalue.com/eco-costs/eco-costs-land-use/

Production costs of meat and seafood

The production of meat and seafood depends mainly on labour, feed, medicines, power, and machinery. In Figure 5.26, the predicted costs for production over time are outlined. The production costs are calculated in two steps. Firstly, the total volume of consumed meat/seafood is calculated by multiplying the projected meat/seafood consumption per person by the expected inhabitants in the EU. Based on the volume and the production costs per kilogramme, the total production costs can be derived. Comparing the Figure above, which denote the benefits of the food categories and the production costs respectively, the production costs are sometimes higher. Different factors cause the negative profit margin, non-exhaustively they include heavy competition, amortization of assets, imports, and subsidies [702, 703, 704, 705, 706, 707, 708]. Sheep and beef/veal production costs per kilogramme increase over time, while the production costs of poultry per kilogramme are expected to remain equal. The production costs of pork per kilogramme decrease over time. Lastly, the production costs of seafood from aquaculture per kilogramme will increase, possibly due to the increased number of species that will be suitable for aquaculture. These species could be more costly to breed. While the consumption of beef/veal decreases, the production costs increase due to fact that the production prices per kilogramme increase relatively more than the decrease in consumption.

Figure 5.26 Production costs of animal-based protein-rich food in the EU in 2020-2050 (billion EUR, BAU).



Source: Deloitte analysis, various production price sources, FAO

Cost of carbon emission associated with meat and seafood production

Projections for the costs of carbon emissions for all types of meat and seafood are discussed in this subsection. The CO2 emissions per meat/seafood category are not represented here but are directly converted into economic terms. The CO2 emissions per animal-based protein-rich

702 https://ahdb.org.uk/lamb-international-comparisons

703 https://meatpromotion.wales/en/industry-resources/sheep-management/cost-of-production

704 https://www.gov.mb.ca/agriculture/farm-management/production-economics/pubs/cop-beef-300-cow-calf.pdf

705 https://ahdb.org.uk/pork-cost-of-production-and-net-margins

706 https://projectblue.blob.core.windows.net/media/Default/Pork/Documents/CostOfPigProduction_20193995-WEB2.pdf

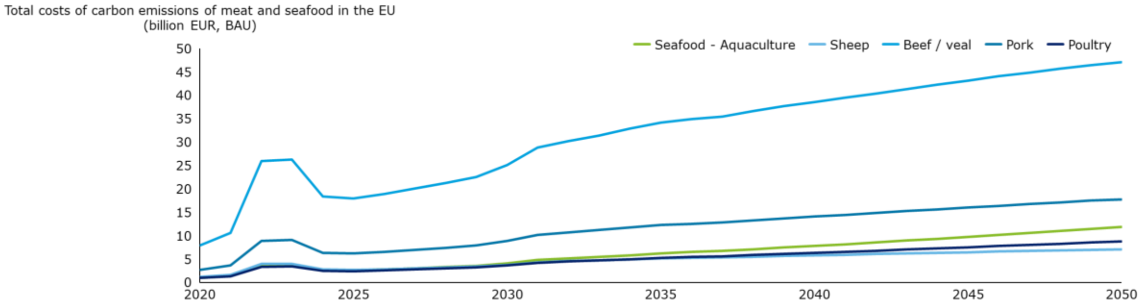
707 Wageningen Economic Research Report 2020-2027

708 Audun Iversen, Frank Asche, Øystein Hermansen, Ragnar Nystøyl, Production cost and competitiveness in major salmon farming countries 2003–2018, Aquaculture, Volume 522, 2020, 735089, ISSN 0044-8486, https://doi.org/10.1016/j.aquaculture.2020.735089. (https://www.sciencedirect.com/science/article/pii/S0044848619300638)

source are calculated by multiplying the expected population growth in the EU[709] by the expected consumption of the protein source discussed earlier, multiplying this by the CO2 emissions per kg of meat or seafood[710], and multiplying this by the expected CO2 costs per kg. The CO2 emissions per kg of meat or seafood are based on the cradle to retail lifecycle, excluding packaging as this is of minor importance. [711]

Converting CO2 emissions to economical costs is done using the EU Emissions Trading System (ETS) carbon prices. The values from 2005 to 2022 are used to predict ETS carbon prices in the period from 2022 to 2050[712,713]. The prediction of CO2 prices corresponds with International Energy Agency's (IEA) prediction for 2025 and is presuming a higher price for ETS than the IEA in 2040 (136 EUR vs. 112 EUR expected by the IEA).[714] It can be expected that when the EU tightens the climate target from 40% to 55% (37.5% decrease) in 2030, the ETS price will rise to 129 EUR per tonne CO2 in 2030.[715] Adhering to the scenario as proposed by the EU's Green Deel at the moment of writing (April 2022), the expectation of our model of carbon prices is around 30% lower than proposed in the article by Pietzcker et al. and can, therefore, be seen as realistic. Using the ETS prices, the emissions of obtaining protein-rich animal-based food are economised. The result can be seen in the figure below.

Figure 5.27 Costs of carbon emissions of animal-based protein-rich food in the EU in 2020-2050 (billion EUR, BAU).



Source: Deloitte analysis, FAO and PBL Netherlands Environmental Assessment Agency

In general, the costs of carbon emissions are predicted to increase in line with the IEA and EU ETS. The contribution of beef/veal is significant, even though its predicted consumption is relatively small in comparison to the other sources. The costs associated with carbon emissions from seafood and poultry production are predicted to increase due to the expected consumption

[709] https://data.oecd.org/pop/population.htm and https://stats.oecd.org/Index.aspx?DataSetCode=POPPROJ#

[710] Nijdam, Durk & Rood, Geertruida & Westhoek, Henk. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy. 37. 760–770. 10.1016/j.foodpol.2012.08.002. (https://www.sciencedirect.com/science/article/abs/pii/S0306919212000942)

[711] Nijdam, Durk & Rood, Geertruida & Westhoek, Henk. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy. 37. 760–770. 10.1016/j.foodpol.2012.08.002. (https://www.sciencedirect.com/science/article/abs/pii/S0306919212000942)

[712] https://tradingeconomics.com/commodity/carbon

[713] https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_nl

[714] https://www.oxfordenergy.org/wpcms/wp-content/uploads/2021/05/The-Challenges-and-Prospects-for-Carbon-Pricing-in-Europe-NG-168.pdf

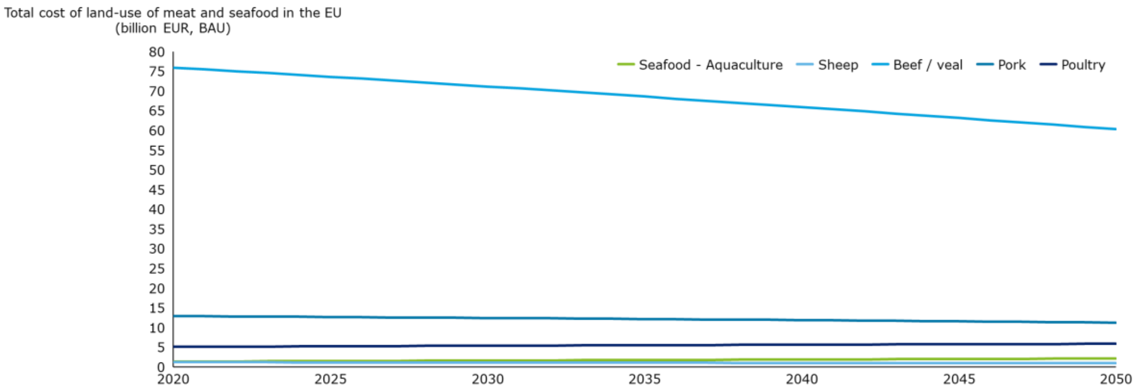
[715] Audun Iversen, Frank Asche, Øystein Hermansen, Ragnar Nystøyl, Production cost and competitiveness in major salmon farming countries 2003–2018, Aquaculture, Volume 522, 2020, 735089, ISSN 0044-8486, https://doi.org/10.1016/j.aquaculture.2020.735089. (https://www.sciencedirect.com/science/article/pii/S0044848619300638)

growth. Notably is that there is a peak in 2022 due to an extremity; oil and gas were expensive at this point in time, which made coal-powered plants economically feasible to start up again. This caused a chain reaction of increased demand for emission permits, and consequently an increase in the price of ETS.

Cost of land-use associated with meat and seafood production

Land-use costs are calculated by multiplying the predicted consumption of a given product with the estimated land-use per kg of the animal (cradle to retail)[716]. This amount is multiplied by the eco-costs of land-use for agricultural products.717. Mean values of the land-use per kilogramme of meat/seafood in the report are taken. Seafood is not farmed on land, therefore, the land-use component consists only of the land used for plant-based feed. Since the cost of land use per m2 is insusceptible to a specific species, the category which uses the most land is the costliest. Beef/veal consumption is predicted to decrease over time, so the costs for land use would also be anticipated to decrease. The total costs for land use are depicted in the figure below.

Figure 5.28 Total cost of land-use in the EU in the period 2020 – 2050 (billion EUR, BAU).



Source: Deloitte analysis, FAO and PBL Netherlands Environmental Assessment Agency

Cows that provide beef/veal demand the most land of all categories of protein sources. Per kilogramme, veal/beef uses more than 50 times the land that fish from aquaculture requires. The development of land-use costs of the other protein sources varies linearly with the consumption.

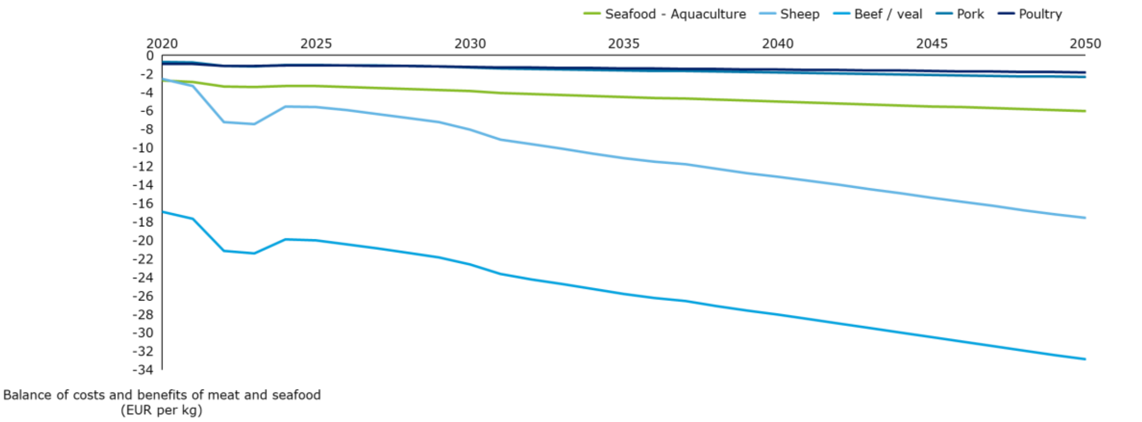
Balance of costs and benefits of meat and seafood

In this subsection, the findings of previous subsections are merged. Figure 5.29 combines both cost and benefits per kilogramme of product per year, showing that all types of products are net negative per kilogramme produced if we compare the benefits of selling meat/seafood, and the production, land-use, and carbon emission costs. However, poultry, pork and seafood from aquaculture come closest to a positive balance per kilogramme.

716 Nijdam, Durk & Rood, Geertruida & Westhoek, Henk. (2012). The price of protein: Review of land use and carbon footprints from life cycle assessments of animal food products and their substitutes. Food Policy. 37. 760–770. 10.1016/j.foodpol.2012.08.002. (https://www.sciencedirect.com/science/article/abs/pii/S0306919212000942)

717 https://www.ecocostsvalue.com/eco-costs/eco-costs-land-use/

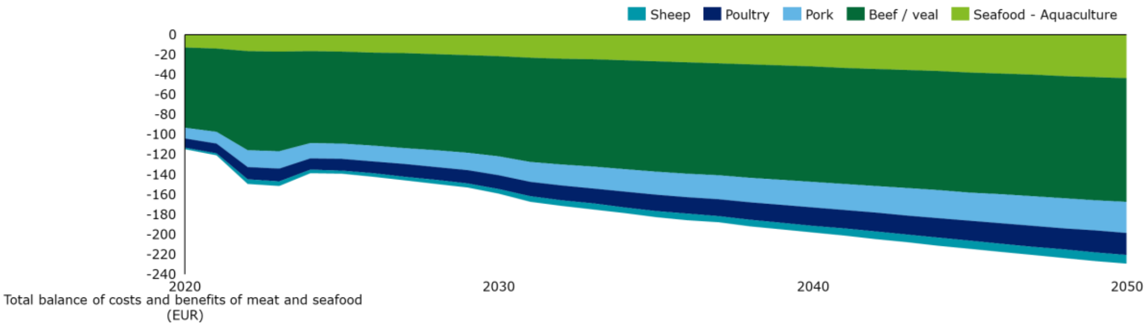
Figure 5.29 Balance of costs and benefits regarding animal-based protein-rich food sources (EUR per kg)



Source: Deloitte analysis

Multiplying the total consumption of the different protein sources by the costs and benefits per kilogramme, the total balance can be calculated. The total balance of the animal-based protein-rich food sources under a business-as-usual (BAU) scenario is depicted in the figure below, denoting that the biggest contributor to the negative contribution of protein-rich food sources is veal/beef, primarily due to the impact the production of veal/beef has on the environment.

Figure 5.30 Total profits of the animal-based protein-rich food sources from 2020-2050 in the business as usual scenario (billion EUR)



Source: Deloitte analysis

6.2.6 Description of the "scaled up efforts" scenario (method and results)

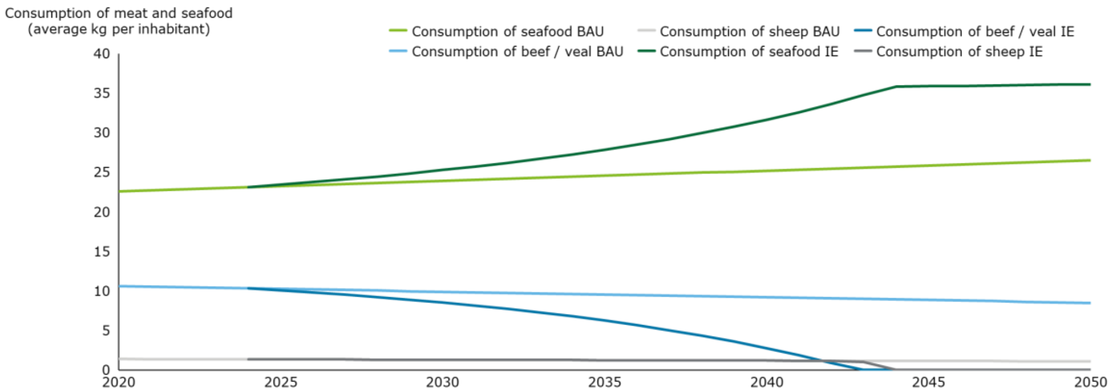
Based on the analysis conducted in the BAU scenario, it is observed that the costs of protein-rich animal-based protein sources outweigh the benefits. Ocean Governance can tip the balance towards a more favourable scenario. Since Ocean Governance applies only to mariculture, the scaled-up efforts (SUE) will only apply to mariculture, the part of aquaculture which is located in the sea. The scaled-up effort (SUE) scenario presented here assumes that beef/veal, and sheep meat production can be replaced by seafood from mariculture to decrease costs in general, but also to use land more efficiently and pollute less CO2. Realising that mariculture cannot replace meadows where cows are held, the gain in the land that will result from the decreased demand in veal/beef, can be used for other purposes such as nature, infrastructure or buildings. As already can be concluded from the BAU scenario, the production of meat/seafood will never be net positive. The SUE scenario provides insights into how possibly costs (both financially and environmentally) can be avoided.

Taking a step back, to determine whether growth in mariculture is possible and with which rate, comparable countries have been investigated. China is a frontrunner in aquaculture and looking specifically to China, the development of mariculture grew from 525,000 t (35% of total aquaculture production) in 1992 to 2.04 million t (40% of total aquaculture production) in 2019, which is an increase in mariculture activity of more than 10% per year.[718]

Reflecting to our analysis, it is assumed that seafood from mariculture can realistically replace meat from sheep and veal/beef with a rate of 10% per year starting from 2025, and that seafood from mariculture will first replace the less favourable meat source (beef/veal). Furthermore, it is assumed that the EU's total aquaculture in 2019 has a value of 1.36 million tonnes in the EU. Approximately 20% of this is accounted for by the UK, and 75% of the total aquaculture concerns saltwater species. In 2019, the volume of the EU-27's mariculture is thus slightly more than 0.8 million tonnes.[719] These volumes remained approximately equal in the period from 2010-2019720, and, therefore, will be considered equal in the BAU scenario.

With this assumption of increased mariculture in the EU, the trend of food distribution under the SUE scenario is presented in the figure below. For this analysis, pork, poultry and seafood from wild catch are not taken into consideration, because no change in consumption is expected concerning the BAU scenario in these categories, purely from an economic standpoint. Seafood from aquaculture will namely only replace beef/veal and sheep, in comparison with the BAU scenario.

Figure 5.31 Consumption of animal-based protein sources (average kg/inhabitant) regarding the scaled-up efforts (SUE) and business as usual (BAU) scenarios



Source: Deloitte analysis

Under this SUE scenario, the total contribution of seafood, both from wild catch and aquaculture, to the diet of EU inhabitants is expected to be almost 39% of the total consumption of animal-based protein-rich food sources in 2050. This number is a reliable estimate as the total contribution of seafood to the diets of Chinese inhabitants was 45% in 2020.721 As can be seen, the total consumption of both beef/veal and sheep will decrease to zero. After 18 years,

[718] Hu et al., Development of fisheries in China, Reproduction and Breeding, Volume 1, Issue 1, 2021, Pages 64-79, ISSN 2667-0712, https://doi.org/10.1016/j.repbre.2021.03.003. (https://www.sciencedirect.com/science/article/pii/S2667071221000089)

[719] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/edn-20191015-2

[720] https://www.eumofa.eu/documents/20178/477018/EN_The+EU+fish+market_2021.pdf/27a6d912-a758-6065-c973-c1146ac93d30

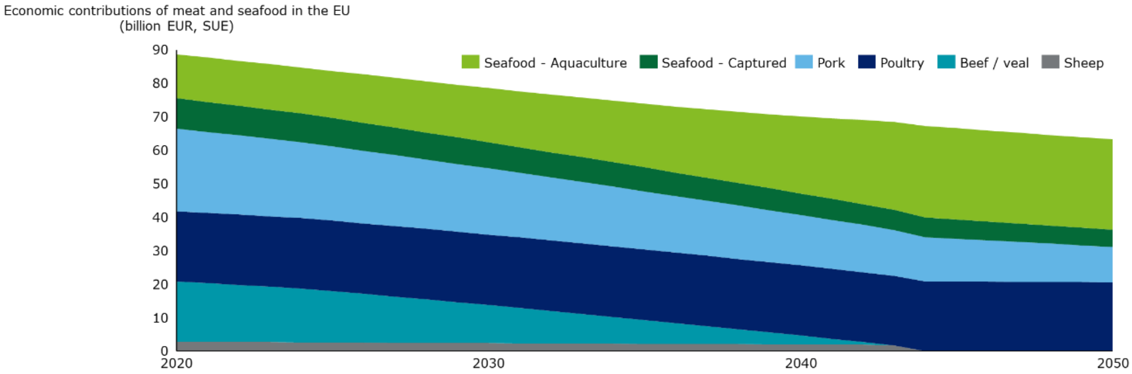
[721] OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en. (https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm)

seafood from mariculture in the EU can have fully replaced beef/veal and after 19 years, also sheep can be substituted by seafood from mariculture in the EU.

Value of animal-based protein-rich food sources

Under this SUE scenario, the economic contribution of protein-rich foods in the EU would see an increase in the consumption of seafood, as shown in the figure below. The benefits of the different protein sources are computed by multiplying the expected consumption of food sources by the projected price of the food source. Since the volume of consumption decreases of beef/veal and sheep, the benefits of beef/veal and sheep decrease. Pork, poultry and seafood from wild capture follow the same trend as the BAU scenario.

Figure 5.32 Economic contributions of different kinds of protein-rich foods in the EU in the period 2020-2050 (billion EUR, SUE)



Source: Deloitte analysis

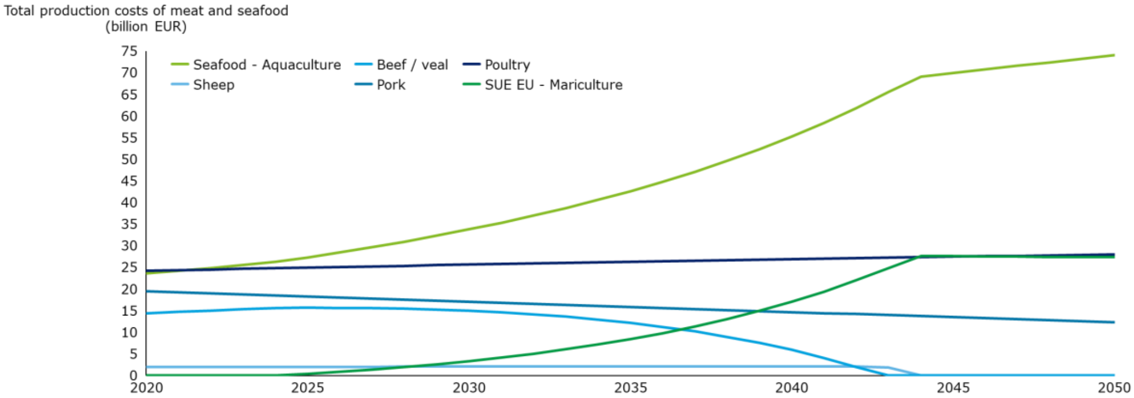
Costs of meat and seafood

The costs associated with production, CO2 pollution and land-use are represented in Figure 5.33, Figure 5.34 and Figure 5.35 respectively. The contribution of the scaled-up efforts is depicted in dark green in these figures.

The production costs of seafood from aquaculture rise, because more seafood is produced and consumed, as a replacement for veal/beef, and sheep. Due to economies of scale, it is expected that the production costs of meat from veal/beef and sheep will decrease. However, many different species of fish exist, but are not ready yet to be farmed. An increase in farming of species that are more expensive to nurture is foreseen by the FAO.[722] Poultry, sheep and pork follow the same trend in production costs as is described in the BAU subsection.

[722] OECD/FAO (2021), OECD-FAO Agricultural Outlook 2021-2030, OECD Publishing, Paris, https://doi.org/10.1787/19428846-en. (https://www.oecd.org/publications/oecd-fao-agricultural-outlook-19991142.htm)

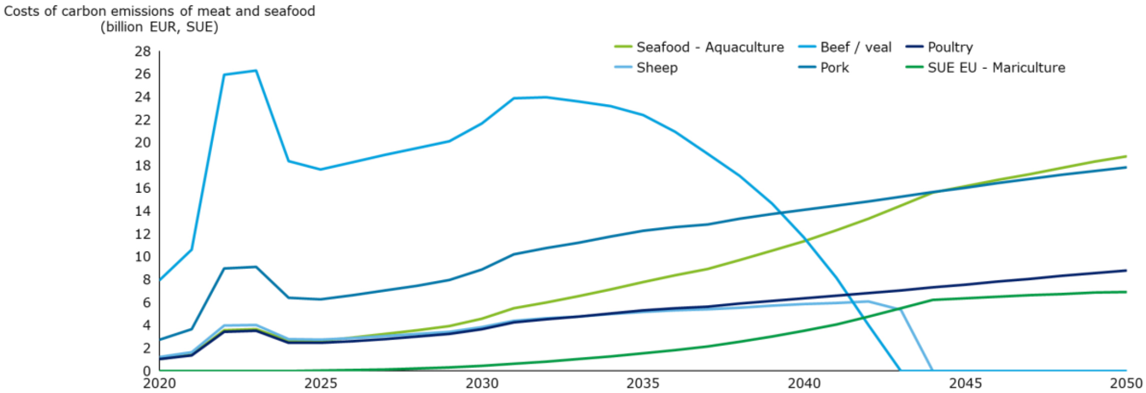
Figure 5.33 Production costs of animal-based protein-rich food in the EU in 2020-2050 (billion EUR, SUE)



Source: Deloitte analysis

The carbon footprint of aquaculture would increase, and, therefore also the costs for carbon emissions. However, it is expected that the effect is not so drastically as the carbon emissions from the production of veal/beef. Economically and environmentally, it is, thus, a wise plan to replace sheep and beef/veal, with seafood from aquaculture considering carbon emissions. The costs of carbon emissions for pork and poultry do not change with respect to the BAU scenario.

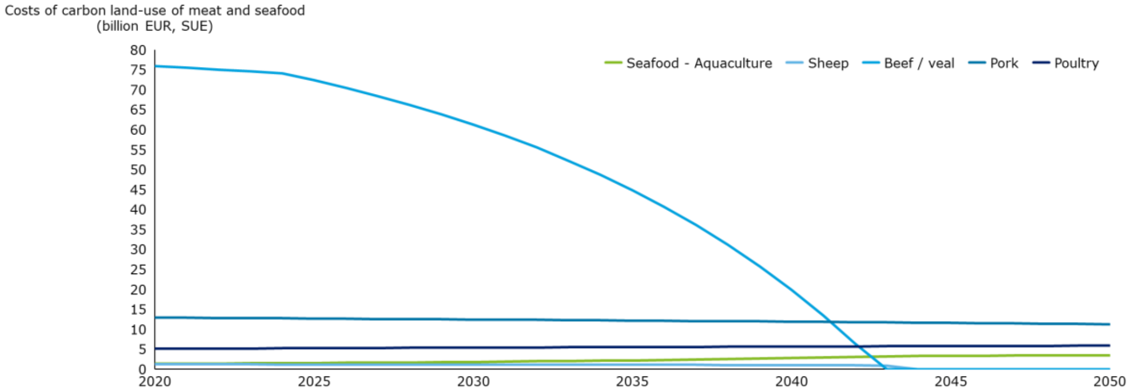
Figure 5.34 Total costs of carbon emissions in the EU in the period 2020 – 2050 (billion EUR, SUE)



Source: Deloitte analysis

Land-use costs associated with aquaculture would increase marginally. After all, aquaculture requires only land to produce fish feed. In the SUE case, the land-use for the production of veal/beef would decrease drastically due to the fall in consumption.

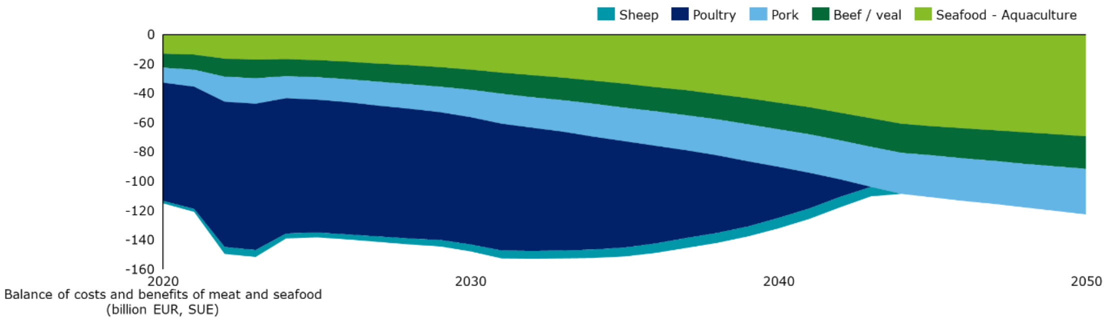
Figure 5.35 Total cost of land-use in the EU in the period 2020 – 2050 (billion EUR, SUE)



Source: Deloitte analysis

The balance between benefits and costs of the SUE case is presented in the figure below. While the balance is still net negative, it is less negative than in the BAU scenario due to the shift of consumption from veal/beef and sheep to seafood from mariculture.

Figure 5.36 Total profits of animal-based protein-rich food sources in the period 2020-2050 (billion EUR, SUE)



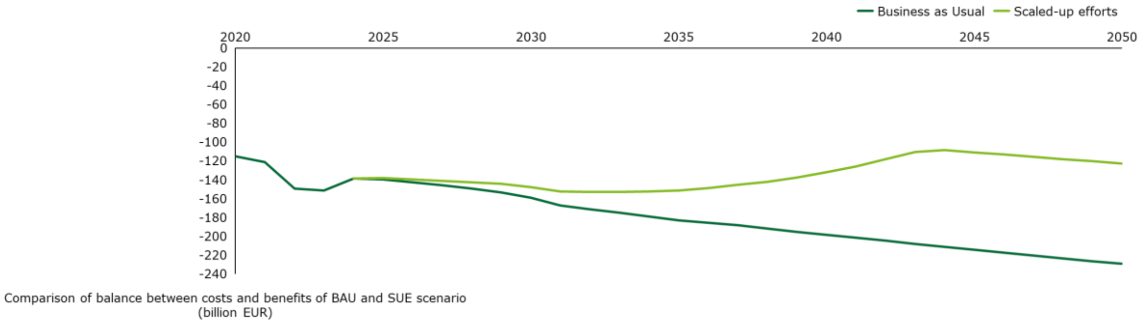
Source: Deloitte analysis

6.2.7 Comparison of results from the two scenarios

Seafood from Mariculture replaces meat from agriculture partly

The balance of producing animal-based protein-rich foods is never economically positive, but by implementing Ocean Governance to stimulate mariculture, a more positive balance can be achieved in the long term. When seafood from mariculture will replace beef/veal, and sheep, the economic comparison in the figure below is obtained.

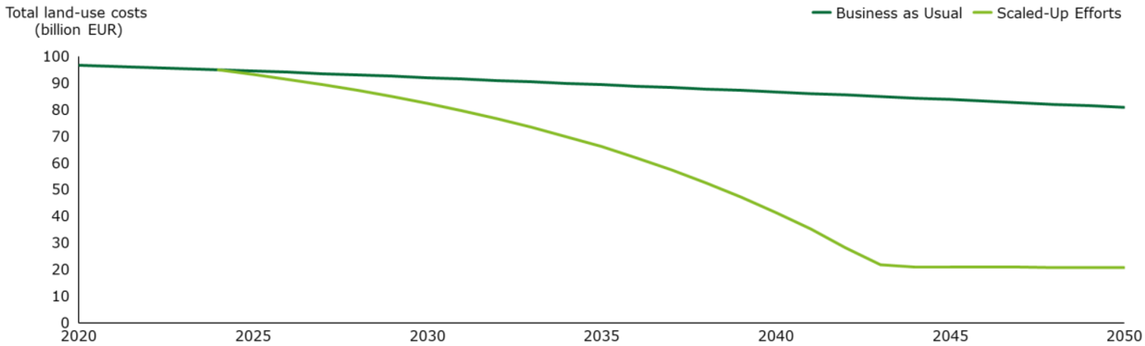
Figure 5.37 Comparison of BAU and SUE situation comparing costs and benefits (billion EUR)



Source: Deloitte analysis

The balance is more favourable in the scaled-up efforts (SUE) than the business as usual (BAU) scenario, due to the decreased environmental costs: land-use, and carbon emission costs. This can be observed in the figures below.

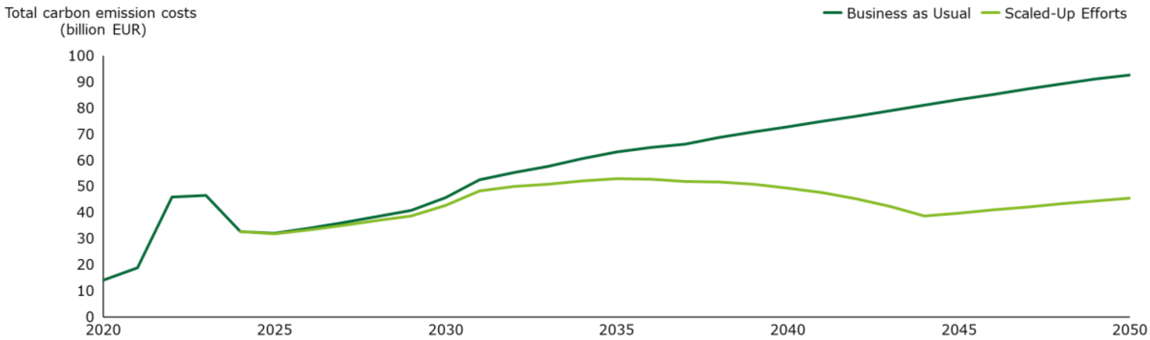
Figure 5.38 Comparison of BAU and SUE situation regarding land-use costs (billion EUR)



Source: Deloitte analysis

The figure below presents a comparison between the BAU and SUE scenarios, with regards to carbon emission costs.

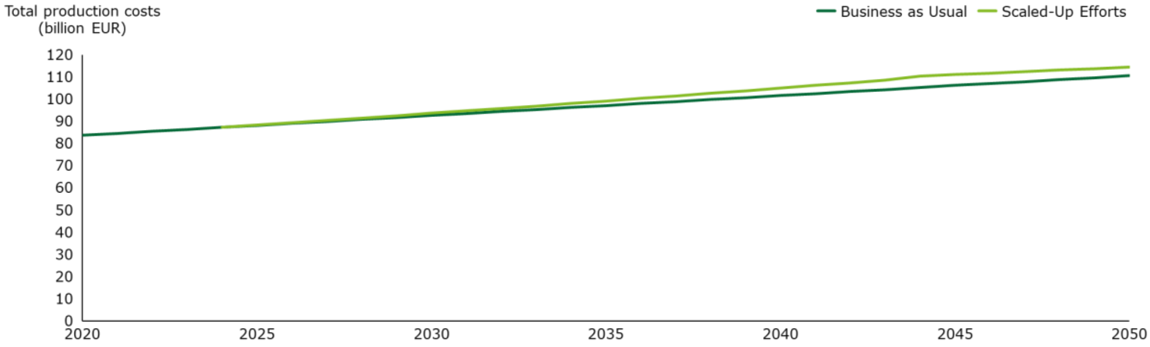
Figure 5.39 Comparison of BAU and SUE situation regarding carbon emission costs (billion EUR)



Source: Deloitte analysis

The production costs of the increased efforts scenario are expected to increase concerning the business as usual scenario, as can be seen in the figure below. The reason for this is that aquaculture is more expensive than agriculture.

Figure 5.40 Comparison of BAU and SUE situation regarding production costs (billion EUR)



Source: Deloitte analysis

Considerations throughout the report

- Cows for milk and meat are different from a farm perspective. The animals which provide meat, are not providing other provisioning services like milk or eggs.
- Preferences of customers are not taken into consideration.
- Seafood from the wild catch is disregarded in parts of the report because, in both BAU and SUE scenarios, the total amount of seafood from the wild catch will be considered equal.
- The consumption of the EU is considered. However, a large part of the meat comes from imports outside the EU. The overview which is provided, gives an overview of the impact of inhabitants of the EU on different aspects. It does not consider the animals in the EU, but all the animals globally which are consumed by EU inhabitants.

6.3 Genetic Material Services

6.3.1 Description of Ecosystem Service / Benefit and Impact

The SEEA-EA framework defines genetic material services as 'ecosystem contributions from all biota (including seed, spore or gamete production) that are used by economic units, for example (i) to develop new animal and plant breeds; (ii) in gene synthesis; or (iii) in product development directly using genetic material.

Marine genetic diversity determines the abundance and resilience of ecosystems, and therefore supports a number of ecosystem services provided by these, such as water quality regulation, climate regulation or wild fish provisioning among others (acting as an intermediate service)[723,724]. However, marine genetic material also includes substances directly isolated from

[723] Marlow, J.J., Harden-Davies, H., Snelgrove, P.V.R., Jaspars, M., Blasiak, R., 2019. The full value of marine genetic resources. Deep-Ocean Stewardship Initiative. Policy Brief March 2019. Available at: https://www.researchgate.net

[724] Blasiak, R., Wynberg, R., Grorud-Colvert, K., Thambisetty, S., 2020. The Ocean Genome: Conservation and the Fair, Equitable and Sustainable Use of Marine Genetic Resources. Washington, DC: World Resources Institute. Available online at www.oceanpanel.org

marine organisms and their derivatives (*in/ex situ* and *in vitro*), which can then be synthesised by chemical, biotechnological or engineering approaches for a number of applications.

For the purposes of this study, the value of marine genetic resources is considered in relation to their commercial use, which can include three main applications[725]:

- Pharmaceutical applications, most of which have been developed for anticancer chemotherapy, derived from sponges and tunicates mainly;
- Cosmeceutical[726] applications, mostly derived from macroalgae and microalgae, as well as microorganisms[727];
- Food and feed applications, such as fatty-acids from fish or macroalgae used for feed and biofuel.

6.3.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Marine genetic resources and the marine biodiversity these underpin are vulnerable to a number of pressures, including habitat loss and degradation, pollution, invasive species or climate change effects[728] among others, with many valuable species constraint to climate-sensitive environments, such as Arctic Waters[741].

A challenge widely reviewed in literature is the protection of marine genetic resources in international waters, where no universally accepted legal framework exists to protect and regulate the exploitation of marine genetic resources, and the unresolved issues on patenting and access benefit sharing of products[729,730].

The exploration of marine biodiversity for commercially valuable genetic and biochemical resources is carried out through marine bioprospecting, which can involve[731]:

- Search, collection, gathering of biological resources, generally using research vessels with collection equipment including deep-water winches, corers and remotely operated vehicles[732];
- Screening, isolation, characterisation of commercially useful compounds;
- Testing and trials; and
- Further application and development of the isolated compounds for commercial purposes upon regulatory approval, which may require large-scale collection or development of mass culture techniques.

Screening of many species is often required for the identification of genes and natural products and, in some cases, the desired natural products are present in such low concentrations that large amounts of the source organism are required, which has potential to lead to over-

[725] Royal Society, 2017. Future ocean resources: Metal-rich minerals and genetics – evidence pack. Available at: https://royalsociety.org

[726] Cosmetics with pharmaceutical properties

[727] Guillerme, J.B., Couteau, C., Coiffard, L., 2017. Applications for marine resources in cosmetics. Cosmetics 4 (35) doi:10.3390/cosmetics4030035

[728] See footnote 724

[729] See footnote 724

[730] Arrieta, J.M., Arnaud-Haond, S., Duarte, C.M., 2010. What lies underneath: Conserving the oceans' genetic resources. Proceedings of the National Academy of Sciences of the United States of America 107 (43) 18318 - 18324. https://doi.org/10.1073/pnas.0911897107. Available at: https://www.pnas.org

[731] Arico, S. and Salpin, C., 2005. Bioprospecting of genetic resources in the deep seabed: scientific, legal and policy aspects. United Nations University – Institute of Advanced Studies. Available at: https://www.cbd.int

[732] See footnote 725

exploitation[733]. Most activity is, however, concentrated around development stages through to clinical trials, for which generally kilograms rather than tonnes of a material are needed[734], and accordingly, Environmental Impact Assessments (EIAs) are rarely required, unless vulnerable habitats are targeted[735]. Disturbance of habitats and species associated with bioprospecting activities and technology used has also been identified as a potential environmental impact[736].

6.3.3 Description of methodology for monetisation incl. indicators used and data sources

The discovery-based nature of marine genetic resources makes the potential market size inherently difficult to assess[737]. This includes the commercial potential and market application of marine genetic resources in Areas Beyond National Jurisdiction (ABNJ), which are considered to be largely speculative[738]. Accordingly, an overview of current value estimates based on published literature is provided. Two different scenarios to qualitatively describe the consequences of inaction are used:

- comparing the long-term effects of "business as usual" (BAU scenario); and
- a "scale up" of ocean governance efforts (SUE scenario)

6.3.4 Description of the baseline (method and results)

Although biota-derived genes and natural products of terrestrial origin are still a majority[739], over 34,000 marine natural products have been described to date[740], with recent discovery rates reaching more than 1,000 compounds each year[741]. The main sources of new compounds are marine invertebrates (e.g. sea sponges, corals), marine algae (e.g. *chlorella*, *spirulina*) and microorganisms (e.g. bacteria, phytoplankton)[742,743], although genetic sequences from marine mammals and fish have also been the focus of bioprospecting activities[744]. In addition, approximately 11% of marine genetic resources associated with patent applications are found in deep-sea and hydrothermal vent communities, reflecting increased research in remote and extreme ocean environments.

[733] Daniotti, S. and Re, I., 2021. Marine biotechnology: Challenges and development market trends for the enhancement of biotic resources in industrial pharmaceutical and food applications. A statistical analysis of scientific literature and business models. Marine drugs 19 (2) https://doi.org/10.3390/md19020061

[734] See footnote 725

[735] Broggiato, A., Vanagt, T., Lallier, L.E., Jaspars, M., Burton, G., Muyldermans, D., 2018. Mare Geneticum: balancing governance of marine genetic resources in international waters. The International Journal of Marine and Coastal Law 33 (1). Available at: https://brill.com

[736] See footnote 727

[737] See footnote 725

[738] Spiteri, C., Senechal, T., Hazin, C., Hampton, S., Greyling, L., Boteler, B., 2021. Study on the Socio-Economic Importance of Areas Beyond National Jurisdiction in the Southeast Atlantic Region. STRONG High Seas Project. Available at: https://www.prog-ocean.org

[739] See footnote 725

[740] MarinLit, 2020. A Database of Marine Natural Products Literature. Available at: http://pubs.rsc.org/marinlit

[741] United Nations, 2021. The Second World Ocean Assessment. Available at: https://www.un.org

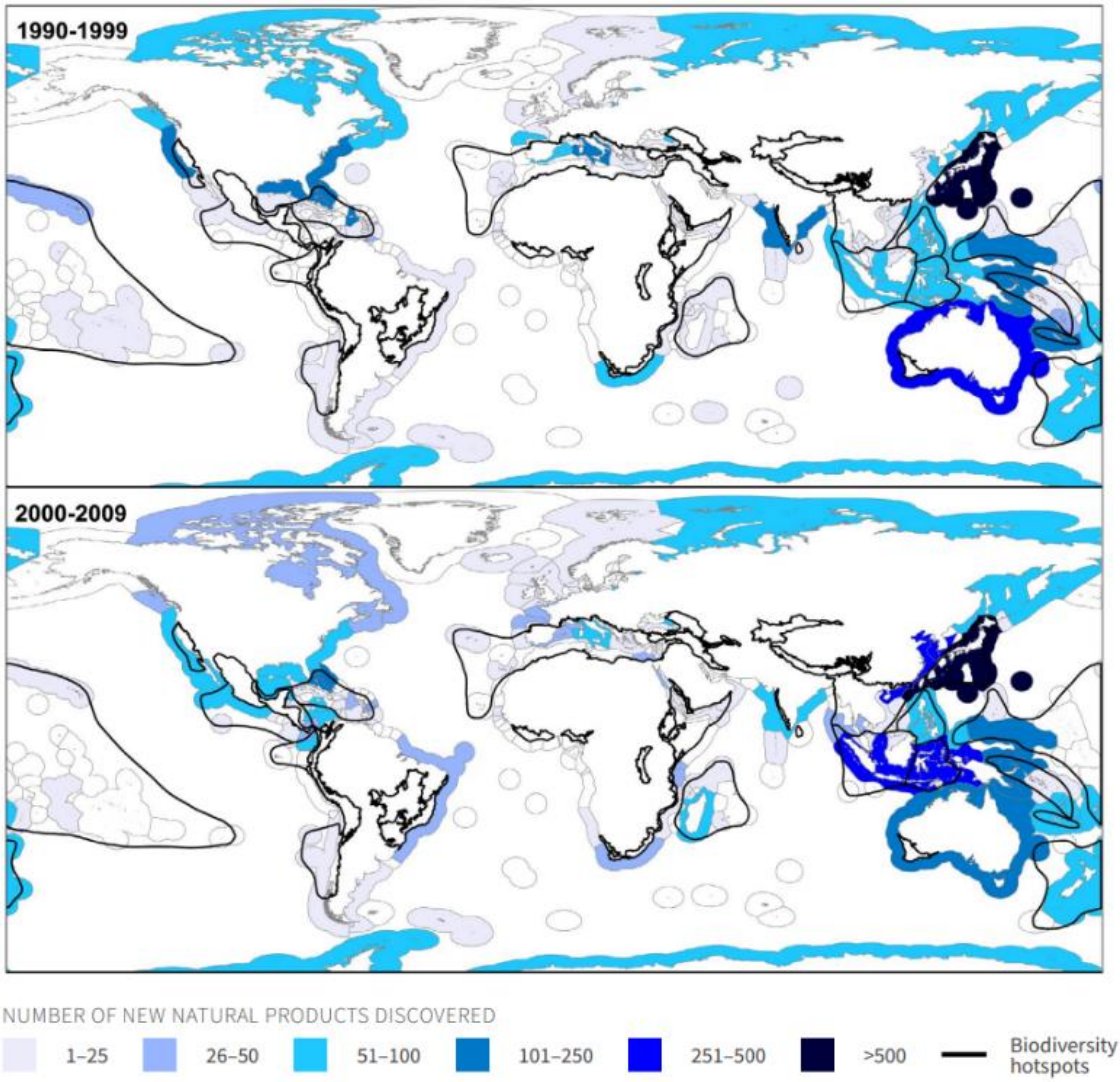
[742] See footnote 733

[743] Oldham, P; Hall, S; Barnes, C; Oldham, C; Cutter, AM; Burns, N; Kindness, L (2014) Valuing the Deep: Marine Genetic Resources in Areas Beyond National Jurisdiction. DEFRA Contract MB0128. London: DEFRA. DOI: 10.13140/2.1.2612.5605. Available at: https://bookdown.org

[744] Blasiak, R., Jouffray, J.B., Wabnitz, C.C.C., Sundstrom, E., Osterblom, H., 2018. Corporate control and global governance of marine genetic resources. Science Advances 4 (6). DOI: 10.1126/sciadv.aar5237. Available at: https://www.science.org

Commercial activity is known to be concentrated in a small number of high-income countries, with almost 75% of patents based on marine genetic resources based in Germany (49%), the United States (13%) and Japan (12%)[744], which responds to the considerable costs associated with bioprospecting activities, as well as the technology and expertise required[745]. However, a review of marine invertebrate bioprospecting activities in the 1990s and 2000s, found that sampling is mostly conducted in low- or middle-income tropical countries, and Australasia in particular[746], as illustrated in Figure 5.41.

Figure 5.41: Number of new natural products from marine invertebrates found in exclusive economic zones during the 1990s and 2000s, as well as boundaries of biodiversity hotspots.



Source: Leal et al. 2012

[745] See footnote 735

[746] Leal, M.C., Puga, J., Serôdio, J., Gomes, N.C.M., and Calado, R., 2012. Trends in the Discovery of New Marine Natural Products from Invertebrates over the Last Two Decades – Where and What Are We Bioprospecting?" PLOS ONE 7 (1): e30580. https://doi.org/10.1371/journal.pone.0030580

In 2020, the global market of marine biotechnology was estimated at €3.3 billion[747], representing ~1% of the whole biotechnology market[748]. Medical and pharmaceutical applications are considered to hold the largest share (approx. 25%).

Despite its current value, bioprospecting for marine-derived products has a very low success rate. At present, there are only ten approved drugs and seven types of cosmeceutical ingredients derived from marine resources and commercialised[749]. The benefits of marine genetic services, however, extend beyond the successful development of a product and its economic commercialisation, as the development process leads to training opportunities, promoting research and development activities, and building of biological repositories[735750] that can eventually feed into conservation policies and action.

The Nagoya Protocol on Access to Genetic Resources and Benefit Sharing[751] currently provides a legal framework aimed at creating transparency for those interested in the production and exploitation of genetic materials within territorial waters and exclusive economic zones (EEZs). Most patent applications, however, do not disclose information on species provenance and marine genetic resources origins, limiting transparency and insights into the extent to which organisms derive from ABNJ.

6.3.5 Description of the" business as usual" (BAU) scenario (method and results)

As the oceans are the largest and least explored ecosystem on Earth, with exceptionally high biological diversity, they provide significant opportunities to discover new life forms and novel marine genetic resources. In 2020, the global market for marine biotechnology was estimated to potentially reach €3.93 billion by 2026[752].

Spiteri *et al.* (2021)[738] forecast that under a BAU scenario:

- new vaccines and other medicines from marine species would continue to be discovered;
- commercial interest in marine genetic resources would continue to increase at a global level;
- the majority of patents (84%) would be registered by keystone actors (221 solo companies based in northern Europe and the USA), with almost half of patents claimed by a single transnational actor (BASF);
- gaps on the nature and scale of the commercial interest, specially within ABNJ would continue to increase;
- upfront costs in generating capacities and access to marine genetic resources would continue to increase, with potentially longer returns and higher risks on investment; and
- uncertainties on future monetary and non-monetary benefits would continue to exist.

[747] Conversion from 2019 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846, based *on figures extracted from* Abstract of Global Marine Biotechnology for Industry – Global Industry Analysts (February 2022). Available at: https://www.reportlinker.com

[748] Rotter, A., Bacu, A., Barbier, M., Bertoni, F., Bones, A., Cancela, L., Carlsson, J., Carvalho, M., Ceglowska, M., Dalay, M., Dailianis, T., Deniz, I., Drakulovic, D., Dubnika, A., Einarsson, H., Erdogan, A., Eroldogan, T., Ezra, D., Fazi, S., ... Vasquez, M. (2020). A new network for the advancement of marine biotechnology in Europe and beyond. Frontiers in Marine Science, 2020(7), [278]. https://doi.org/10.3389/fmars.2020.00278

[749] Martins, A., Vieira, H., Gaspar, h., Santos, S., 2014. Marketed marine natural products in the pharmaceutical and cosmeceutical industries: Tips for success. Marine drugs 12 (2). doi: 10.3390/md12021066

[750] See footnote 735

[751] Available at: https://www.cbd.int

[752] Conversion from 2020 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846, based *on figures extracted from* Abstract of Global Marine Biotechnology for Industry – Global Industry Analysts (February 2022). Available at: https://www.reportlinker.com. See also footnote 747

Spiteri *et al.* (2021) also look into likely socio-economic interest trends of the sector within the Southeast Atlantic Region in more detail, highlighting that under a BAU scenario, the Southeast Atlantic Region would:

- have access to a comparatively low level of research capacity, research infrastructure, legal and technical expertise on marine genetic resources; and
- opportunities to access and utilize marine genetic resources would continue to be limited and reduce, exposed to significant risks of exclusion from access to marine genetic resources driven by patents and private enterprises in wealthy countries.

6.3.6 Description of the "scaled up efforts" scenario (method and results)

A SUE scenario in relation to marine genetic resources and the services they provide could assume that:

- significant efforts are implemented to ensure that genetic diversity in areas outside marine protected areas (MPAs) and other effective area-based conservation measures (OECMs) is conserved. This would include ensuring the sustainable use of resources; preventing habitat degradation; cautiously using previously unexploited places; and protecting rare, threatened and endangered species and populations;
- more equitable, responsible and inclusive research partnerships between industrialised and developing countries—and between users and providers of marine genetic resources, centred on scientific capacity, technology transfer[731] and adequate finance, is promoted / supported; and
- the new legally binding international treaty on biodiversity in ABNJ (BBNJ)[753] is agreed and adopted by as many state parties as possible, including agreement on the implementation of a global multilateral benefit-sharing mechanism that is subject to benefit-sharing obligations in ABNJ, comprising[754]:
- Access to marine genetic resources through notifications managed by an international organisation, with the condition that any non-monetary (e.g. eventually releasing samples and data through openly accessible biological repositories and databases) and monetary benefits from the use of marine genetic resources are shared. This would form the starting point of a track-trace system;
- Benefit-sharing through multi-lateral agreements that bridge the gap between countries that hold knowledge, marine genetic resources and technologies and those that don't
- Compliance and enforcement of benefit-sharing obligations through the centralised track-trace system.

Spiteri *et al.* (2021)[738] forecast that under a SUE scenario:

- benefits from the use of marine genetic resources would be fairly and equitably shared;
- capacity building opportunities for developing States to access and utilize marine genetic resources would be enhanced;
- generation of knowledge and technological innovations would be enhanced;
- development and transfer of marine technology would be subject to all legitimate interests, including the rights and duties of holders, suppliers and recipients of marine technology;
- collaboration on marine scientific research would increase;
- new instruments on intellectual property rights and the public domain approach; benefit-sharing obligations; and the building of common pools of resource would be implemented; and

[753] See: https://www.un.org/bbnj/

[754] See footnote 735

- a Clearing House Mechanism for scientific data access would be established through the "track and trace" proposed under the BBNJ framework.

7. Regulation and Maintenance ecosystem services

7.1 Carbon Sequestration Services

7.1.1 Description of Ecosystem Service / Benefit and Impact

Marine environments provide an essential ecosystem service by capturing and storing carbon at significantly higher rates than other natural environments on land such as forests[755]. This is particularly true for coastal ecosystems with the presence of aquatic vegetation such as mangroves, salt marshes, and seagrass meadows, which act as short- and long-term natural carbon sinks and are now referred to as Blue Carbon[756]. The Intergovernmental Panel on Climate Change (IPCC) defines Blue Carbon as "all biologically driven carbon fluxes and storage in marine systems that are amenable to management". Coastal ecosystems like tidal marshes and mangrove forests in particular have high carbon burial rates on a per unit basis and accumulate carbon in their soil and sediments[757]. Effectively, they act as nature-based carbon removal solutions, and account for half of the total carbon burial in the ocean[758]. Blue Carbon has attracted the attention of numerous actors due to its potential to mitigate climate change as well as providing additional co-benefits, including serving as feeding and nursery grounds for fish and shellfish, protection of coastal infrastructure from storm surge and flooding, and water filtration.

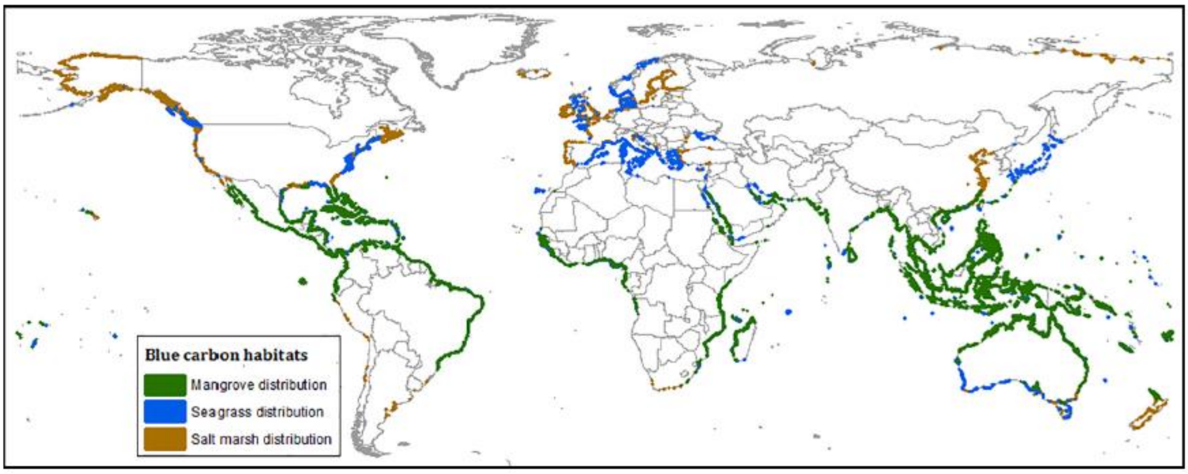
[755] Mcleod et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Front. Ecol. Environ. 9, 552-560.

[756] Macreadie et al. (2019). The future of Blue Carbon science. Nature Communications volume 10, Article number: 3998.

[757] Hilmi et al. (2021). The role of Blue Carbon in climate change mitigation and carbon stock conservation. Front. Clim. 3:710546.

[758] Duarte et al. (2005). Major rôle of marine vegetation on the oceanic carbon cycle. Biogeosciences 2 (1), 1-8.

Figure 5.42 Global distribution of Blue Carbon ecosystems



Source: Himes-Cornell et al. (2018).

Besides coastal environments, open ocean ecosystems also play a role in sequestering and storing carbon dioxide thanks to the microorganismal activity of bacteria and microalgae. Ocean waters store dissolved carbon stocks which are significantly larger than global terrestrial soils, at least of an order of magnitude[759]. Marine phytoplankton, basically photosynthetic algae and bacteria, fix dissolved carbon which is mostly consumed and stored in the biomass of other organisms and ends up in deep water masses. The rate of sinking and degradation of carbon from phytoplankton are affected by cell size, morphology and chemical composition[760].

7.1.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Blue Carbon coastal ecosystems are exposed to many potential threatening human activities. Expanding population and urbanisation of coastal areas has adversely affected vegetated coastal habitats across the world, especially due to the impacts on the marine coastal environments of fisheries, aquaculture, pollution and sedimentation[761]. Many studies have showed that large amounts of these ecosystems have been and are still currently being destroyed. Between 2000 and 2016, over 62% of mangrove forests worldwide were lost[762], with also a parallel reduction of salt marshes and seagrass meadows, reversing the carbon cycle and transforming these ecosystems into natural sources of CO_2 and methane (CH_4). Seagrasses are affected by phenomena such as eutrophication, overharvesting, coastal developments, aquaculture, climate change and sea level rise, while salt marshes are also being impacted by marsh reclamation, pollution, biological invasion and altered hydrological regimes[763]. Overharvesting for firewood and upstream soil loss are also affecting mangrove forests.

[759] Hilmi et al. (2021). The role of Blue Carbon in climate change mitigation and carbon stock conservation. Front. Clim. 3:710546.

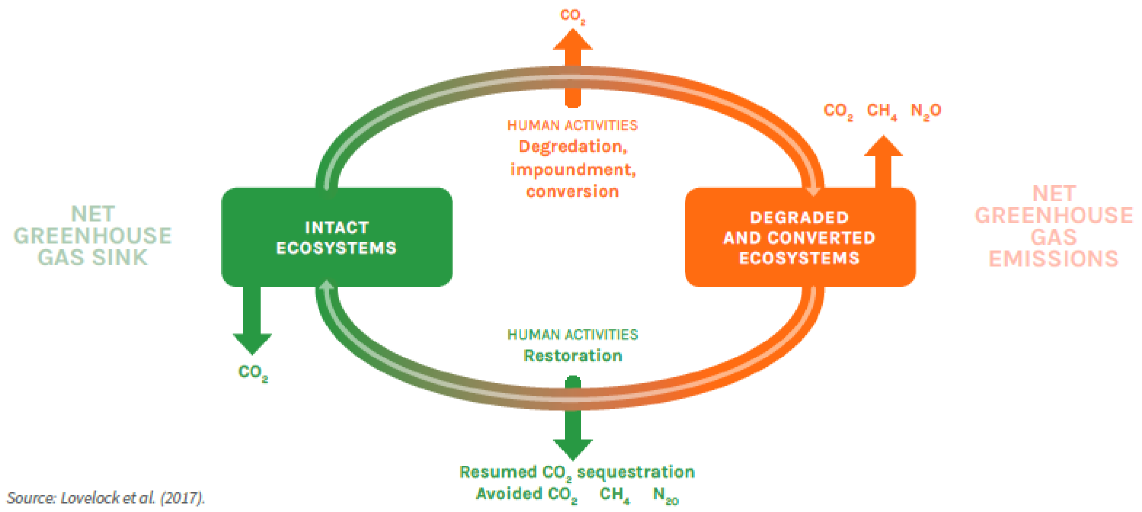
[760] Bach et al. (2019). The influence of plankton community structure on sinking velocity and remineralization rate of marine aggregates. Global Biogeochem. Cycles 33, 971-994.

[761] Gullström et al. (2021). Coastal Blue Carbon stocks in Tanzania and Mozambique. IUCN Global Marine and Polar Programme.

[762] Goldberg et al. (2020). Global declines in human-driven mangrove loss. Glob. Chang. Biol. 26, 5844-5855.

[763] Himes-Cornell et al. (2018). Valuing ecosystem services from blue forests: A systematic review valuation of salt marshes, sea grass beds and mangrove forests. Ecosystem Services 30, 36-48.

Figure 5.43 The carbon cycle in coastal and marine ecosystems



Source: Lovelock et al. (2017)

Regarding open ocean ecosystems, the already visible ocean warming is affecting the ability of marine ecosystems to remove CO_2 from the atmosphere as warmer waters absorb less CO_2. It has also been estimated that ocean warming, and acidification will progressively slow down the sinking of particulate organic carbon to the deep seafloor by approximately 10-15% by 2100 if significant release of CO_2 in the atmosphere continues[764].

Carbon is also stored by marine animals, so extracting fish from the oceans is also contributing to the release of additional carbon[765].

7.1.3 Description of methodology for monetisation incl. indicators used and data sources

Estimating the monetary value of the carbon sequestration service provided by the oceans and coastal environments requires an extensive preliminary data collection exercise. This can be summarised in the following steps:

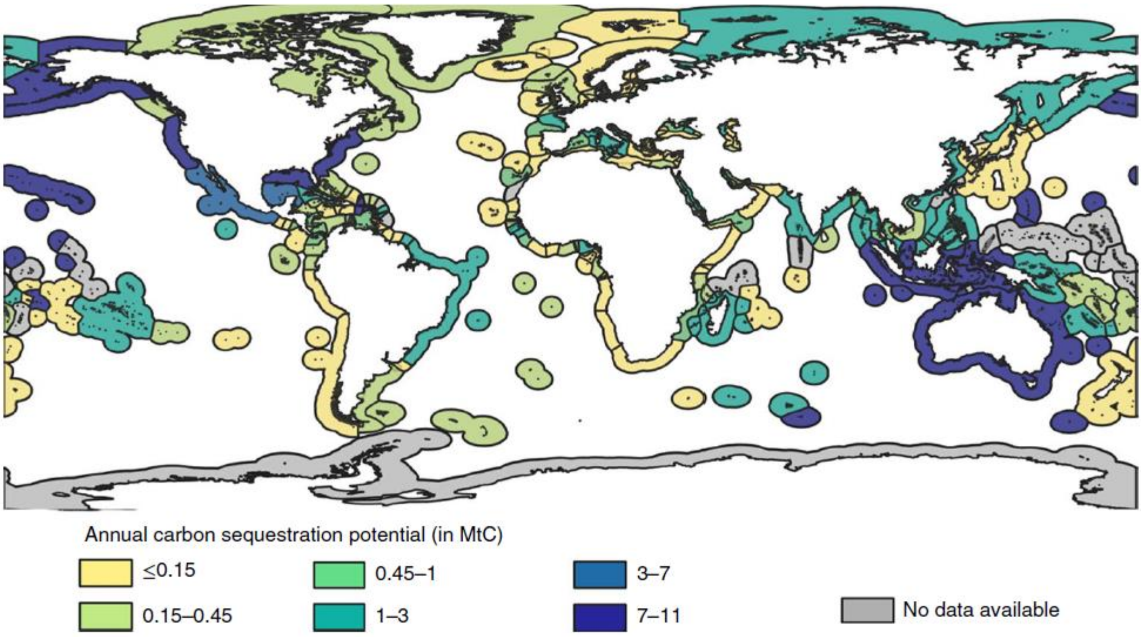
- Estimate the carbon sequestration rate of marine ecosystems in terms of e.g. Tons of CO_2 / year;
- Estimate the value of the carbon stored in these ecosystems in terms of e.g. EUR per Ton of stored CO_2, i.e. assessment of the blue wealth;
- Calculate the current annual monetary value of the carbon sequestration service provide by the oceans at the global level;
- Define a set of assumptions to project how the provision of this service will change in the future in the business as usual (BAU) and scaled up efforts (SUE) scenarios;
- Calculate the future annual monetary value of the carbon sequestration service at the global level in the BAU and SUE scenarios.

The next sections describe in detail the sources used to gather the required information, the methodology and its limitations, as well as how the two scenarios were constructed.

[764] Bindoff et al. (2019). Changing ocean, marine ecosystems, and dependent communities. IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.

[765] Mariani et al. (2020). Let more big fish sink: fisheries prevent blue carbon sequestration – half in unprofitable areas. Sci. Adv. 6 :abb4848.

Figure 5.44 Mean annual carbon sequestration potentials for vegetated coastal habitats by country



Source: Bertram et al. (2021).

7.1.4 Assessment of reliability and robustness of methodology and data sources

The data has been collected from secondary sources, specifically scientific papers and reports that investigated the climate mitigation potential of marine environments and estimate the value of carbon sequestration ecosystem services in certain regions of the planet. These are based on a number of assumptions and have associated limitations, fully described in the respective studies.

While the methodology for quantification has been based on the most recent scientific literature, it is important to recognise that the methods applied present limitations. These can be summarised as follows:

- The social cost of carbon represents a commonly adopted and relatively robust approach to estimate the monetary value of carbon sequestration services i.e. based on the present value of climate damages caused by an additional tCO_2 emitted in the atmosphere, but it is not the only method. It also suffers from inherent uncertainty as it is hard to estimate how much the cost could be in the future, and in this case, a unique cost is applied across the entire globe;
- While the most up-to-date reviews were considered, uncertainty persists on the effective carbon sequestration rates of the considered ecosystems, which can be influenced by numerous factors and can change across geographical contexts and time. Such influencing factors were not taken into account here.
- It is likely that the social cost of carbon will increase in the future as the impacts of climate change exacerbate; our approach however is based on a constant social cost of carbon as uncertainty on future costs cannot be completely reduced.
- We do not assume future changes in the carbon sequestration rates of the different ecosystems, while it is likely that climate change and e.g. the warming of oceanic waters, will negatively impact the carbon sequestration potential of marine environments. This is

due to lack of data and scientific knowledge on how much the sequestration rate could effectively diminish in the future.

7.1.5 Description of the baseline (method and results)

To assess the carbon sequestration potential of the oceans, annual sequestration rates were collected by ecosystem type, including not only coastal ecosystems but also the deep sea. These are reported in the table below.

The reported carbon sequestration rates for vegetated habitats were calculated using the mean values expressed in terms of yearly tCO_2 captured per km^2, originally sourced from Alongi (2009, 2012)[766,767], Ouyang and Lee (2014)[768], and Mcleod et al. (2011)[769], multiplied by the most recent estimates on the current extension of mangroves, salt marshes, and seagrass meadows. This data was sourced from Bertram et al. (2021).

Table 5.7 Annual carbon sequestration rates by ecosystem type

Component	Ecosystem	Annual carbon sequestration ($Tg\ y^{-1}$)[770]	Source
Vegetated habitats	Mangroves	23.96	Calculated from Bertrand et al. (2021)
	Salt marshes	13.39	
	Seagrass meadows	43.86	
Depositional areas	Estuaries	81.00	Duarte et al. (2005)
	Shelf	45.20	Duarte et al. (2005)
Deep sea burial	Deep sea	6.00	Duarte et al. (2005)

As a second step, we relied on the global social cost of carbon to assess how much monetary value can be attributed to the carbon sequestration services of oceans. The social cost of carbon represents the present value of all climate change damage across the world caused by the emission of an additional tonne of CO_2 in the atmosphere[771]. This value was calculated as the sum of the country-specific social costs of carbon as reported in Bertram et al. (2021), corresponding to about 640.26 USD per tCO_2 or 541.66 EUR per tCO_2[772].

Given the information on the carbon sequestration rates and on the global social cost of carbon, we calculated an annual global value of carbon sequestration services equal to 115.60bn EUR, considering both coastal and open ocean marine ecosystems.

[766] Alongi (2009) Carbon cycling and storage in mangrove forests. Annu. Rev. Mar. Sci. 6, 195-219.

[767] Alongi (2012) Carbon sequestration in mangrove forests. Carbon Manag. 3, 313-322.

[768] Ouyang and Lee (2014). Updated estimates of carbon accumulation rates in coastal marsh sediments.

[769] Mcleod et al. (2011). A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Front. Ecol. Environ. 9, 552-560.

[770] Teragrams of carbon or 10^{12} grams of carbon.

[771] Arrow et al. (2003). Evaluating projects and assessing sustainable development in imperfect economies. Environ. Resour. Econ. 26, 647-685.

[772] Expressed in 2021 real terms. Yearly average 2021 exchange rate from: https://www.irs.gov/individuals/international-taxpayers/yearly-average-currency-exchange-rates.

7.1.6 Description of the" business as usual" (BAU) scenario (method and results)

In the BAU scenario it is assumed that the level of pressure exerted by anthropogenic activities on marine ecosystems does not change from recent trends. This has clear implications on the projected ability of coastal environments to sequester CO_2 from the atmosphere, as it is assumed that the extension of ecosystems such as mangroves and salt marshes will continue to decline in line with recent trends. Hoegh-Guldberg et al. (2019)[773] provides an overview of the rates of loss and degradation of coastal ecosystems in the latest years, and these are reported in the table below.

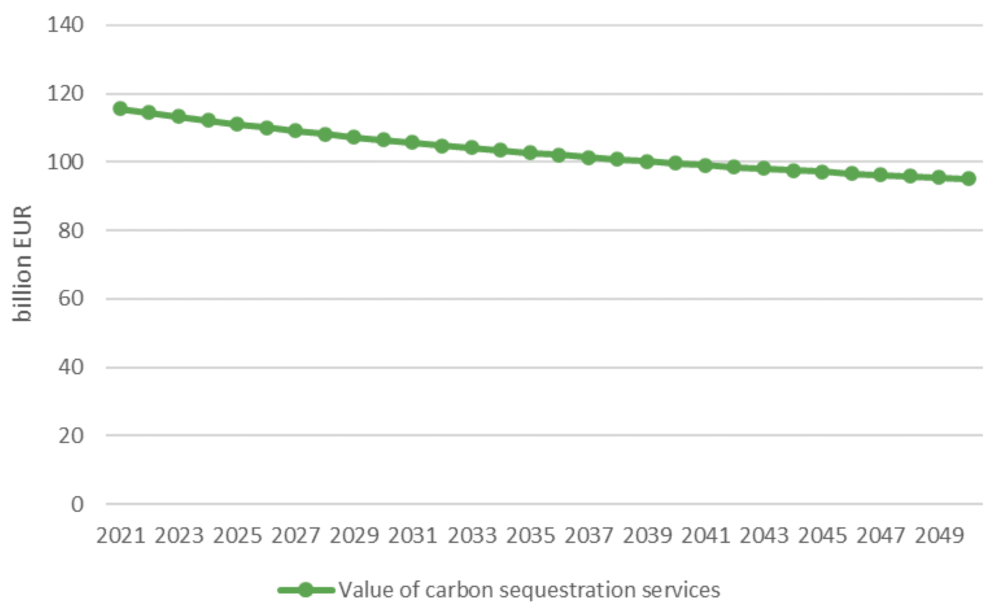
Table 5.8 Rates of loss and degradation of coastal ecosystems

Ecosystem	Rates of loss and degradation	Original source
Mangrove	0.11 %/year	Bunting et al. (2018)
Salt marshes	1 to 2 %/year	Pendleton et al. (2012)
Seagrass meadows	2 to 7 r	Waycott et al. (2009)

Given these recent rates of loss and assuming that they will continue up to the year 2050, we calculated the projected extension of the coastal environments and the corresponding decline in annual CO_2 captured and stored. Notice that no change was assumed for the annual amount of CO_2 captured by estuaries, shelf, and deep sea, due to lack of data.

The next chart shows the obtained projections of the estimated global annual value of the carbon sequestration ecosystem services.

Figure 5.45 Estimated global annual value of carbon sequestration services in the BAU scenario



Source: own analysis

[773] Hoegh-Guldberg et al. (2019). The ocean as a solution to climate change: five opportunities for action. Report. Washington, DC: World Resource Institute.

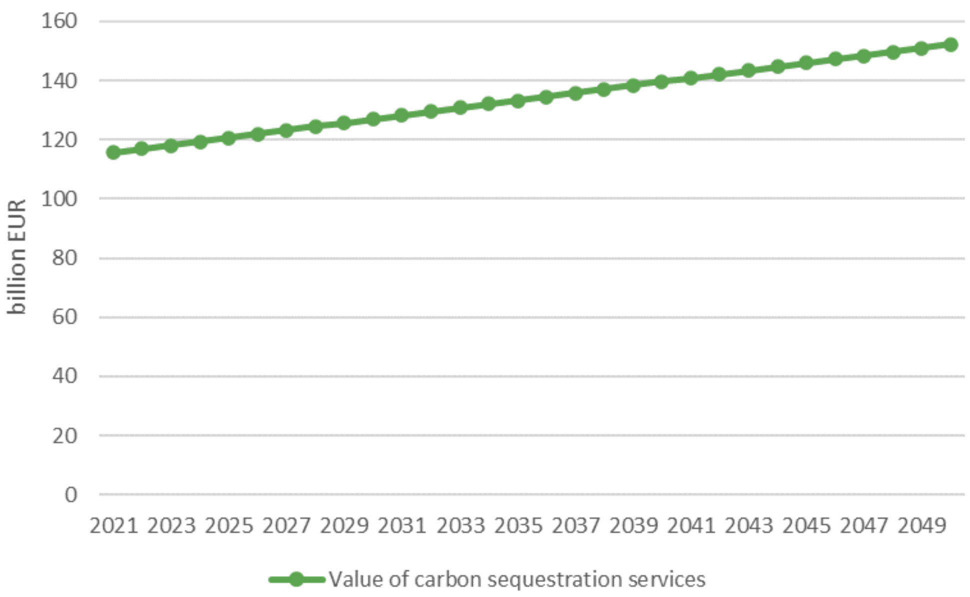
7.1.7 Description of the "scaled up efforts" scenario (method and results)

In the SUE scenario, it is assumed that mechanisms are put in place to conserve, protect, restore and expand degraded blue carbon coastal ecosystems, for example via halting the conversion of mangrove forests to aquaculture or rice cultivation. Clearly, the range of potential mitigation that can be achieved in such a scenario varies with the level of effort and investment. Hoegh-Guldberg et al. (2019) provides two scenarios and their respective mitigation potentials:

- A moderate restoration effort recovering 40 percent of historical ecosystem cover by 2050;
- An aggressive scenario of complete restoration of pre-1980s cover.
- In this case, we decided to follow the most ambitious scenario achieving the following mitigation potentials by 2030 and by 2050:
- Mangroves: 0.08 $GtCO_2e$/year in 2030 and 0.25 $GtCO_2e$/year in 2050, with an extension of 225,000 km^2;
- Salt marshes: 0.01 $GtCO_2e$/year in 2030 and 0.03 $GtCO_2e$/year in 2050, with an extension of 110,000 km^2;
- Seagrass meadows: 0.02 $GtCO_2e$/year in 2030 and 0.05 $GtCO_2e$/year in 2050, with an extension of 600,000 km^2.

Given these assumptions, we calculated the projected change in the global annual value of the carbon sequestration ecosystem services as depicted in the figure below.

Figure 5.46 Estimated global annual value of carbon sequestration services in the SEU scenario

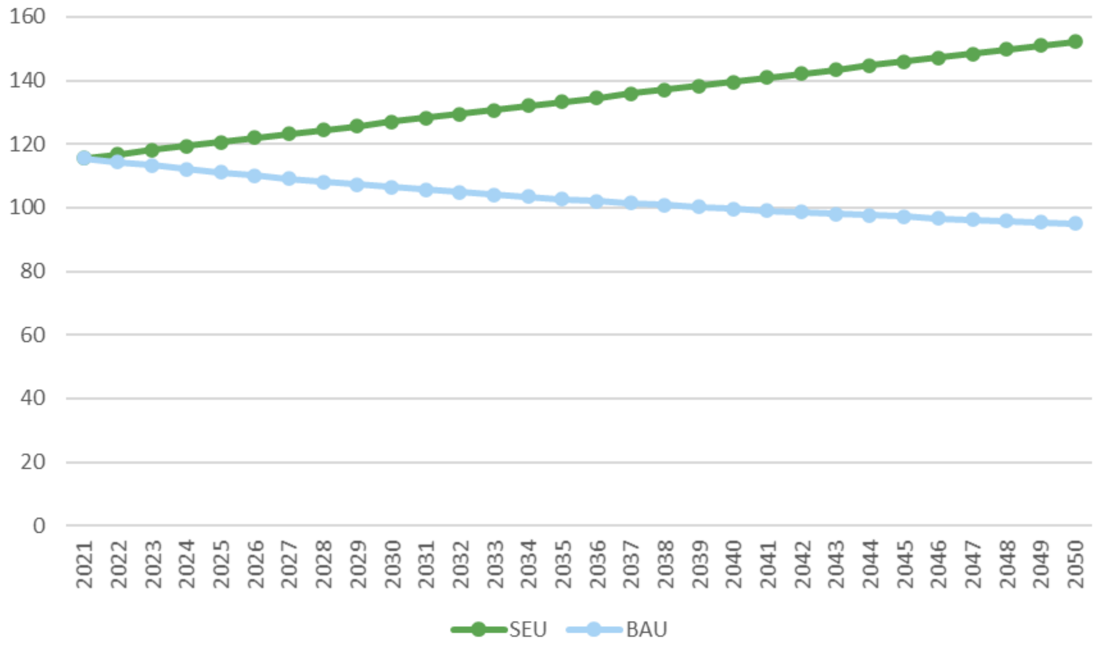


Source: own analysis

7.1.8 Comparison of results from the two scenarios

When comparing the BAU and SEU scenarios, it clearly emerges how increase efforts aimed at not only conserving, but also restoring natural coastal ecosystems which are natural carbon sinks would yield substantial monetary benefits, in the order of 57bn EUR per year in 2050. This would also translate into cumulative savings of about 1,689 $MtCO_2$ between today and the year 2050.

Figure 5.47 Comparison of the estimated global annual value of carbon sequestration services in the BAU and SEU scenarios in billion EUR



Source: own analysis

7.2 Coastal Protection Services

7.2.1 Description of Ecosystem Service / Benefit and Impact

Approximately 40% of the global population is settled in coastal areas (within 100 km from the coast)[774], with 90% concentrated in coastal cities with populations of over 1 million, particularly common in East, South and South-East Asia[775]. There are also a number of smaller coastal communities around the world, some for which population estimates are not available[775]. The vulnerability of coastal communities to the impacts of climate change is of increasing concern, where the risks of coastal erosion and coastal flooding, among others, are projected to increase[776].

There are four different regulation and maintenance ecosystem services distinguished in the SEEA-EA framework that are provided by coastal ecosystems and that are closely interrelated

[774] Center for International Earth Science Information Network - CIESIN - Columbia University, 2012. National Aggregates of Geospatial Data Collection: Population, Landscape, And Climate Estimates, Version 3 (PLACE III). Palisades, NY: NASA Socioeconomic Data and Applications Center (SEDAC). http://dx.doi.org/10.7927/H4F769GP. Accessed through Resource Watch, (16/02/2022). www.resourcewatch.org.

[775] United Nations, 2021. The Second World Ocean Assessment. Available at: https://www.un.org

[776] IPCC, 2021. Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press. Available at: https://www.ipcc.ch

and have, accordingly, been considered in combination as 'coastal protection services' for the purposes of this study, these are defined in the SEEA-EA framework as follows:

- Soil erosion control services, related to the stabilising effects of ecosystems that reduce the loss of soil and sediment and support the use of the environment, protecting our coastline;
- Peak flow mitigation services, related to the regulation effects of ecosystems on marine currents and wave action, which can also provide the benefit of coastal protection;
- Coastal protection services, related to the protection of the shore by ecosystems that mitigate the impact of tidal surges and storms; and
- Storm mitigation services, related to the contribution of coastal ecosystems in mitigating the impacts of wind, sand and other storms.

Coastal protection services are therefore the result of three common processes supported by coastal ecosystems[777,778]:

- Wave attenuation, coastal ecosystems have a complex tangle of shoots, roots, shells or coral skeletons that can cause friction, rapidly diminishing waves' energy, minimising coastal erosion effects;
- Storm surge attenuation, coastal ecosystems can also provide resistance to the landward flow of a storm surge, i.e. a rise in the water level caused by storms, minimising coastal erosion and flooding effects; and
- Maintaining shoreline elevation, coastal ecosystems can become self-maintaining barriers and coastal defences, as these can "grow" vertically, providing for sediment capture or raising the elevation of the seabed or land on which they are growing.

7.2.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Coastal ecosystems that can contribute to coastal protection include intertidal wetlands (e.g. mangroves, salt marshes) and reefs (coral and shellfish)[779], as well as seagrass beds, beach and dune systems[780].

Changes to these ecosystems can affect the extent to which they are capable of maintaining the integrity of coastal areas and protecting coastal communities from flooding and storm events.

These coastal ecosystems are particularly vulnerable to poorly planned coastal development and climate change effects. Estuarine and coastal ecosystems are some of the most heavily used and threatened natural systems, and their deterioration due to human activities is intense and increasing[781]. At the same time, some of these ecosystems face opportunities for

[777] The Nature Conservancy. Mapping Ocean Wealth - Coastal protection. Available at: https://oceanwealth.org

[778] Spalding, M.D., Ruffo, S., Lacambra, C., Meliane, I., Hale, L.Z., Shepard, C.C., Beck, M.W., 2014. The role of ecosystems in coastal protection: Adapting to climate change and coastal hazards. Ocean & Coastal Management, 90, 50-57. https://doi.org/10.1016/j.ocecoaman.2013.09.007.

[779] See footnote 778

[780] Mehvar, S., Filatova, T., Dastgheib, A., Van Steveninck, E.R., Ranasinghe, R., 2018. Quantifying economic value of coastal ecosystem services. A review. Journal of Marine Sicence and Engineering 6, 5. https://doi.org/10.3390/jmse6010005

[781] Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. Ecological Monographs 81 (2), 169-193. Available at: https://esajournals.onlinelibrary.wiley.com

expansion, as they are increasingly being considered as part of nature-based solutions (NBS) to increase coastal resilience in climate change mitigation strategies[782,783].

7.2.3 Description of methodology for monetisation incl. indicators used and data sources

In order to assess the economic value of these services, two previous studies that estimate the value of coastal protection provided by coastal ecosystems have been reviewed / combined:

- The 2021 Changing Wealth of Nations (CWON)[784,785], which estimates the value of mangrove ecosystems for coastal protection for 62 nations covering approximately 700,000 km of tropical and subtropical coastline; and
- Mapping Ocean Wealth[786,787], which estimates the value of coral reefs for coastal protection across 71,000 km of reef coastlines.

These studies apply the "avoided damage" valuation approach, which uses the cost of damages prevented by a given ecosystem to estimate the value of the resulting benefits, in this case coastal protection.

Two different scenarios are used to calculate the cost of inaction (estimated as the difference between them):

- comparing the long-term effects of "business as usual" (BAU scenario); and
- a "scale up" of ocean governance efforts (SUE scenario)

7.2.4 Assessment of reliability and robustness of methodology and data sources

The baseline has been defined using secondary sources, studies that estimate the global value of coastal protection from mangroves and coastal reefs. These are based on a number of assumptions and have associated limitations, fully described in respective studies, including some lack of data and therefore consideration of species, age composition or condition, or exclusion of some areas due to their size (e.g. only countries with an estimated area covered by mangroves > 100 ha were considered).

The approach used to define the BAU scenarios is limited to applying an annual loss rate through to 2050 for mangroves, and to assume the vertical loss of up to 1 m for coral reefs caused by climate change effects, as modelled by Beck *et al*. 2018[788].

[782] Browder, G., Ozment, S., Rehberger Bescos, I., Gartner, T., Lange, G.M, 2019. Integrating Green and Gray, Creating Next Generation Infrastructure. World Bank Group and World Resources Institute. Available at: https://www.wri.org

[783] Lecerf, M., Herr D., Thomas, T., Elverum, C., Delrieu, E. and Picourt, L., 2021. Coastal and marine ecosystems as Nature-based Solutions in new or updated Nationally Determined Contributions, Ocean & Climate Platform, Conservation International, IUCN, GIZ, Rare, The Nature Conservancy and WWF. Available at: https://ocean-climate.org

[784] World Bank, 2021. The Changing Wealth of Nations 2021: Managing Assets for the Future. Washington, DC: World Bank. doi:10.1596/978-1-4648-1590-4. License: Creative Commons Attribution CC BY 3.0 IGO. Available at: https://openknowledge.worldbank.org

[785] Beck, M. W., P. Menéndez, S. Narayan, S. Torres-Ortega, S. Abad, and I. J. Losada, 2021. Building Coastal Resilience with Mangroves: The Contribution of Natural Flood Defenses to the Changing Wealth of Nations. CWON 2021 technical report, World Bank, Washington, DC

[786] See footnote 777

[787] Beck, M.W., Losada, I.J., Menéndez, P., Reguero, B.G., Diaz-Simal, P., Fernández, F., 2018. The global Flood protection savings provided by coral reefs. Nature Communications 9, 2186. Available at: https://www.nature.com

[788] See footnote 787

The approach used to define the SUE scenarios is based on the assumption that mangrove cover would increase through restoration efforts, as estimated in literature; and the extent of coral reefs (and their value) would at least be maintained up to 2050 to current levels.

7.2.5 Description of the baseline (method and results)

Direct estimates of the value of coastal protection services provided by mangroves covering the period between 1995 and 2018 were calculated by Beck *et al*. 2021[789] using global mangrove distribution data, which shows that mangroves distribute coastal areas across the world except within Europe and Centra Asia regions. Avoided damage per ha was treated as equivalent to resource rent used to estimate asset value. Results were aggregated by region as shown in the table below.

Table 5.9 Wealth associated with coastal protection provided by mangroves, by region, in 1995 and 2018. Estimated in € millions.

Region	1995	2018	% change
East Asia and Pacific	103,963	367,596	254
Europe and Central Asia	N/A	N/A	N/A
Latin America and the Caribbean	38,360	54,489	42
Middle East and North Africa	9,006	10,170	13
North America	27,463	23,220	-15
South Asia	11,101	34,614	212
Sub-Saharan Africa	3,375	6,927	105
World	**193,267**	**497,016**	**157**

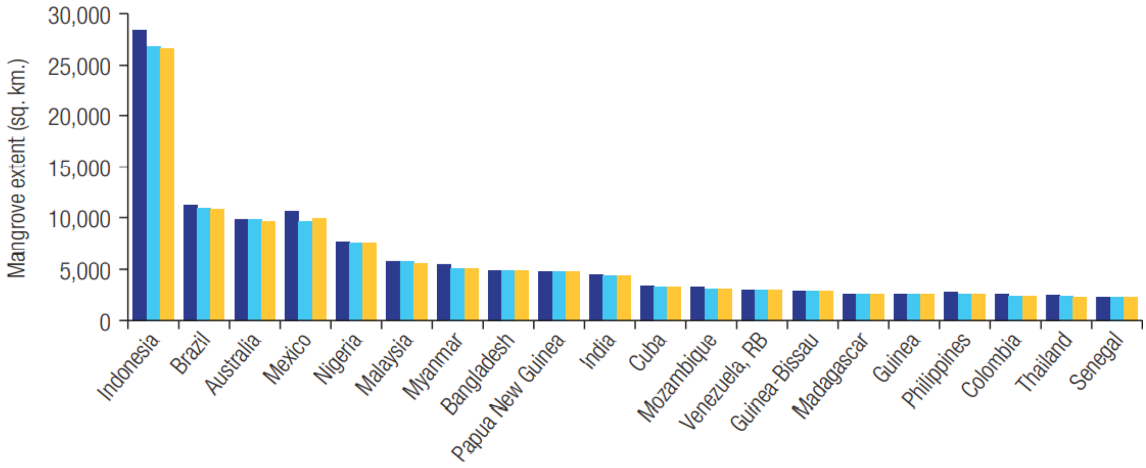
Note - Conversion from 2018 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846
Source: Adapted from World Bank, 2021 Table 6.1

The value of mangroves for coastal protection was noted to depend on different factors, including the extent of mangroves, flood risks and capital at risk from flooding. Accordingly, although the extent of mangrove worldwide may have reduced since 1995 (see the figure below), their overall value for coastal protection has increased substantially because of sharp increases in coastal flood risk driven by the growth in coastal populations and wealth, e.g. from 1995 and 2018, the number of people directly affected by flooding in mangrove areas grew by 66%, and capital stock damages grew by 268%. In 2018, mangroves protected more than 6 million people from annual flooding and prevented additional annual losses of €22 billion of produced capital. The annual benefit per hectare more than doubled between 1995 and 2018, from a global average of €584 to €1,533 per ha[790].

[789] See footnote 785

[790] See footnote 782. Conversion from 2018 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846

Figure 5.48 Mangrove extent in the Top 20 countries, 1996, 2010, and 2015.



Source: World Bank, 2021

A similar approach was used by Beck *et al.* 2018[791], who used process-based flooding models to estimate the annual expected benefit of coral reefs for protecting people and property globally, comparing flooding scenarios and economic impact with and without reefs for four storm return periods. Reefs were estimated to reduce the annual expected damages from storms by more than €3.72 billion, noting that reefs provide more benefit for lower intensity, frequent storms.

Countries identified to receive the most flood protection benefits from reefs are outlined in the table below, showing that in smaller island nations in the Caribbean and the South Pacific, coastal protection from coral reefs is particularly important.

Table 5.10 Annual expected benefit of reefs from coastal protection in terms of annual averted damages to built capital. Estimated in € millions per year and relative Gross Domestic Product.

Annual averted damages (€ millions)		Annual averted damages/GDP	
Indonesia	594	Cayman Islands	0.91
Philippines	548	Belize	0.34
Malaysia	420	Grenada	0.28
Mexico	420	Cuba	0.23
Cuba	373	Bahamas	0.15
Saudi Arabia	128	Jamaica	0.13
Dom. Republic	89	Philippines	0.13
United States	87	Antigua & Barbuda	0.12
Taiwan	57	Dom. Republic	0.10
Jamaica	43	Malaysia	0.08

Note - Conversion from 2017 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846
Source: Extracted from Beck et al. 2018, Table 1

[791] See footnote 787

7.2.6 Description of the" business as usual" (BAU) scenario (method and results)

The loss of mangroves globally has slowed over the past decade, from about 2% per year to less than 0.4% per year between the late twentieth and early twenty-first centuries[792]. The future value of coastal protection services from mangroves through 2050 is likely to be driven by changes in coastal population density and wealth. After 2050, climate change will play a more dominant role, but the complex interplay between these factors makes difficult to predict coastal protection values in the future[785].

The BAU scenario for coastal protection services provided by mangroves assumes that current benefits continue at the same level into the future up to 2050, at an annual 0.11% discount, which assumes a direct relationship between future mangrove loss rates, as estimated by Bunting e*t al.* (2018) reported in Hoegh-Guldberg *et al.* (2019)[793], and their coastal protection value.

Regarding coral reefs, these have experienced a significant decline over the last decade, mainly related to bleaching associated with increasing water temperatures and ocean acidification caused by climate change effects.

The BAU scenario for coastal protection services provided by coral reefs defined by Beck *et al.* 2018[787] assumes that coral reefs degrade, experiencing a vertical loss of 1 m in their profile and roughness across the globe. For comparison purposes, the 50-year storm event modelled estimates, as shown in Beck *et al.* 2018, are also presented.

7.2.7 Description of the "scaled up efforts" scenario (method and results)

The SUE scenario for coastal protection services provided by mangroves assumes an aggressive scenario of complete restoration[794], based on the cover recorded pre-1980s, which would imply a gradual increase in the overall cover of mangroves up to 225,000 km^2 in 2050 (an average of approximately 703,125 ha / year between 2018 and 2050), as estimated by Hoegh-Guldberg *et al.* (2019)[795].

For comparison purposes, the coastal protection value estimated per ha of mangrove in 2018 (€1,533 / ha) is applied to the annual estimated increases in mangrove cover up to 2050, although this is likely to be an underestimation, with factors such as flood risks and capital at risk from flooding likely to vary in the future, see Section 7.2.5.

Regarding coastal protection from coral reefs, the SUE scenario also assumes that the existing distribution of coral reefs is maintained, considering the value of damages under a 50-year storm event as modelled by Beck *et al.* 2018[796].

[792] Friess, D.A., Yando, E.S., Abuchahla, G.M.O., Adams, J.B., Cannicci, S., Canty, S.W.J., Cavanaugh, K.C., Connolly, R.M., Cormier, N., Dahdouh-Guebas, F., Diele, K., Feller, I.C., Fratini, S., Jennerjahn, T.C., Lee, S.Y., Ogurcak, D.E., Ouyang, X., Rogers, K., Rowntree, J.K., Sharma, S., Sloey, T.M., Wee, A.K.S., 2020. Mangroves give cause for conservation optimism, for now. Current Biology, vol. 30, No. 4, pp. R153–R154. Available at: https://www.researchgate.net

[793] Hoegh-Guldberg et al., 2019. The ocean as a solution to climate change: five opportunities for action. Report. Washington, DC: World Resource Institute.

[794] Friess, D.A., Rogers, K., Lovelock, C.E., Krauss, K.W., Hamilton, S.E., Lee, S.Y., Lucas, R., Primavera, J., Rajkaran, A., Shi, S, 2019. The state of the world's mangrove forests: past, present, and future. Annual Review of Environment and Resources, vol. 44, pp. 89–115. Available at: https://www.annualreviews.org

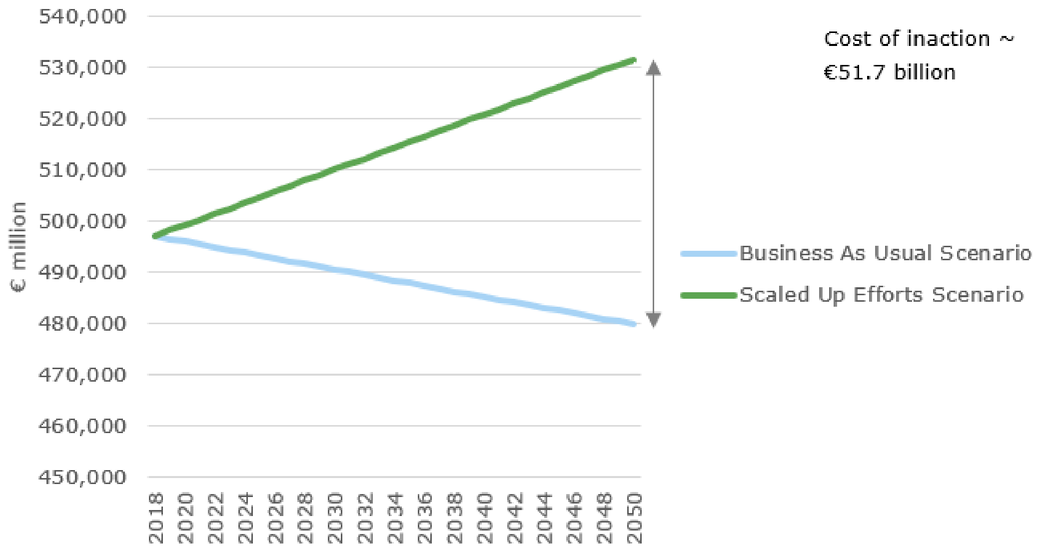
[795] See footnote 793

[796] See footnote 787

7.2.8 Comparison of results from the two scenarios

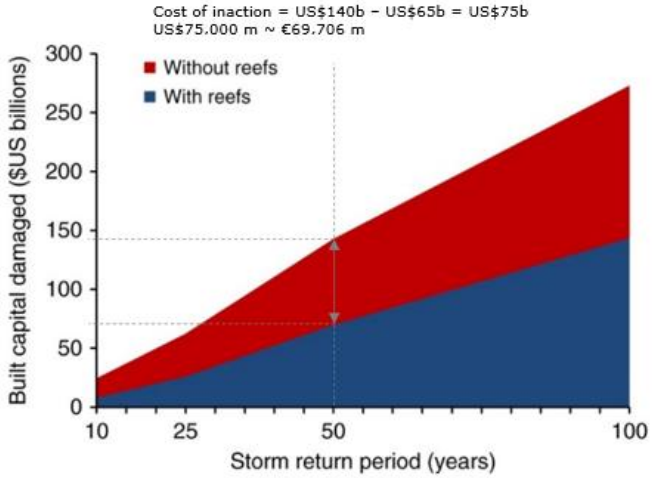
As shown in the figure below, comparison of the BAU and SUE scenarios for coastal protection services from mangroves shows that the cost of inaction corresponds to approximately €51,692 million.

Figure 5.49 Comparison of BAU and SUE scenarios for coastal protection value from mangroves



As illustrated in the figure below, the analysis conducted by Beck *et al.* 2018[797] is used as a proxy to compare the BAU and SUE scenarios for coastal protection services from coral reefs, showing that the cost of inaction corresponds to approximately €69,706 million[798].

Figure 5.50 Comparison of BAU (without reefs, i.e. 1 m vertical loss for a 100-yr storm) and SUE (with reefs) scenarios for coastal protection value from coral reefs.



Source: Adapted from Beck et al. 2018

[797] See footnote 787

[798] Conversion from 2017 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846

The combined estimated cost of inaction on mangrove and coral reef preservation, and in relation to coastal protection services is estimated at €51.7 billion.

7.3 Nursery Population and Habitat Maintenance Services

7.3.1 Description of Ecosystem Service / Benefit and Impact

"Nursery population and habitat maintenance" is one of the most controversial ecosystem services described in the several framework and classifications of ecosystem services. One of the reasons is that this service can be interlinked and correlated to other services that directly rely on it, e.g., fisheries, and is thus considered as an intermediate ecosystem service. Another explanation lies in the fact that it is also referring to biodiversity components and ecosystem functions[799]. For these reasons, considering "nursery population and habitat maintenance" as a service is still being discussed among scholars, and this notably raises the issue of what is the best way to assess it.

The SEEA- EA framework describes "nursery population and habitat maintenance services" as the "ecosystem contributions necessary for sustaining populations of species that economic units ultimately use or enjoy either through the maintenance of habitats (e.g., for nurseries or migration) or the protection of natural gene pools"[800]. According to this definition scholars conclude that the nursery function can be considered an ecosystem service on its own right when it is linked to a concrete human benefit, e.g. the contribution to fish biomass, and not when it is represented with indicators of general biodiversity or ecosystem condition.

A nursery is defined as a habitat where juveniles' density, growth, survival, and/or movement to adult habitats is, on average, greater than in other habitats[801]. The main factors that facilitate the reproduction and recruitment are density, growth and survival of juveniles, movement to adult habitats, or a combination of those[802]. In this sense, studies have demonstrated how the nursery function (i.e. the production of individuals that recruit to adult populations per unit area of juvenile habitat *sensu*) decreases with nursery habitat loss[803] .

For the purpose of this study, the value of nursery population and habitat maintenance services is assessed in relation to the capacity of coastal wetlands (nearshore estuarine and marine ecosystems) to provide suitable habitats and nursery grounds to fish and other marine species to reproduce successfully. The focus on coastal wetlands can be explained by several reasons:

- Coastal zones represent nursery sites for numerous fishes, including commercial species. According to RAMSAR at least two-thirds of all the fish consumed worldwide are dependent

[799] Liquete, C., Cid, N., Lanzanova, D., Grizzetti, B., & Reynaud, A. (2016). Perspectives on the link between ecosystem services and biodiversity: The assessment of the nursery function. *Ecological Indicators*, *63*, 249-257.

[800] United Nations et al. (2021). System of Environmental-Economic Accounting— Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing. Available at: https://seea.un.org/ecosystem-accounting

[801] Beck, M. W., Heck, K. L., Able, K. W., Childers, D. L., Eggleston, D. B., Gillanders, B. M., ... & Weinstein, M. P. (2001). The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates: a better understanding of the habitats that serve as nurseries for marine species and the factors that create site-specific variability in nursery quality will improve conservation and management of these areas. *Bioscience*, *51*(8), 633-641.

[802] Idem

[803] Cheminée, A., Sala, E., Pastor, J., Bodilis, P., Thiriet, P., Mangialajo, L., Cottalorda, J.M. and Francour, P., (2013). Nursery value of Cystoseira forests for Mediterranean rocky reef fishes. *Journal of experimental marine biology and ecology*, *442*, pp.70-79.

on coastal wetlands804. They are sites of important connectivity for marine species and are considered among the world's most productive ecosystems[805].

- The majority of articles and studies that deal with nursery services focuses on the role coastal wetlands play for the maintenance of prosperous fisheries. These coastal habitats are typically structured habitats e.g. salt marshes[806], mangrove forests[807], seagrass meadows803, intertidal flats and tidal freshwater wetlands. Structured habitats are described as such because they have complex three-dimensional shapes that protrude above the benthos (the community of organisms that live on, in, or near the bottom of a sea) compared to unstructured habitats, such as sand and mud, which provide only a relatively flat and two-dimensional surface. Structured habitats are economically and ecologically important as they directly or indirectly provide a variety of ecosystem services, e.g., carbon sequestration, nutrient cycling or shoreline protection[808].
- Coastal systems are some of the most heavily used and threatened natural systems globally due to human activities[809]. In addition they are experiencing to an important extent the adverse impacts of climate change, e.g. sea level rise, sea temperature, more frequent and intense extreme weather events and are highly exposed to these increasing risks. This ultimately leads to habitat destruction and consequently to the alteration of the nursery population and habitat maintenance service.

7.3.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Human settlements leading to coastal development and urbanisation, combined with all types of anthropogenic activities on coastal areas such as fishing, tourism, shipping are the main drivers of change of coastal ecosystems.

Anthropogenic activities impose important pressures on coastal ecosystems, including habitat destruction, chemical pollution, noise pollution etc. Nursery maintenance services are altered as a result of the disruption of connectivity between spawning, nursery and adult-stage habitats[810].

The alteration of suitable habitat/provision of food leads to the loss of the contribution of a particular marine habitat to migratory and resident species' populations, that can eventually lead to population depletion (no critical habitat for feeding, or reproduction and juvenile maturation).

[804] Ramsar. (2021). Realizing the full potential of marine and coastal wetlands: why their restoration matters. Available at : » https://www.ramsar.org/sites/default/files/documents/library/factsheet_wetland_restoration_coastal_e.pdf

[805] Elliott, M., Day, J. W., Ramachandran, R., & Wolanski, E. (2019). A synthesis: what is the future for coasts, estuaries, deltas and other transitional habitats in 2050 and beyond?. In *Coasts and Estuaries* (pp. 1-28). Elsevier.

[806] Boesch, D. F., & Turner, R. E. (1984). Dependence of fishery species on salt marshes: the role of food and refuge. *Estuaries*, *7*(4), 460-468.

[807] Aburto-Oropeza, O., Ezcurra, E., Danemann, G., Valdez, V., Murray, J., & Sala, E. (2008). Mangroves in the Gulf of California increase fishery yields. *Proceedings of the National Academy of Sciences*, *105*(30), 10456-10459.

[808] Lefcheck, J. S., Hughes, B. B., Johnson, A. J., Pfirrmann, B. W., Rasher, D. B., Smyth, A. R., ... & Orth, R. J. (2019). Are coastal habitats important nurseries? A meta-analysis. *Conservation Letters*, *12*(4), e12645.

[809] Doney, S.C., Ruckelshaus, M., Duffy, J.E., Barry, J.P., Chan, F., English, C.A., Galindo, H.M., Grebmeier, J.M., Hollowed, A.B., Knowlton, N., Polovina, J.J., Rabalais, N.N., Sydeman, W.J., Talley, L.D., (2012). Climate change impacts on marine ecosystems. Annual Review of Marine Science 4, 11e37.

[810] McMahon, K. W., Berumen, M. L., & Thorrold, S. R. (2012). Linking habitat mosaics and connectivity in a coral reef seascape. *Proceedings of the National Academy of Sciences*, *109*(38), 15372-15376.

7.3.3 Description of methodology for monetisation incl. indicators used and data sources

Because of its complexity and the fact that is often considered as an intermediate service (i.e. as an ecosystem function), it is difficult to assess the monetary value of nursery population maintenance services, especially at a global scale. For this reason, the literature review disclosed the existence of many more local-specific case studies than global assessment of the monetary value of nursery services. In addition, studies make use of a variety of approaches and economic methods to achieve the valuation, as described in the following paragraphs.

- In the context of ecosystem service valuation, studies that focus on quantifying nursery population and habitat maintenance services use several indicators and proxies that focus on different levels
- Most studies link the nursery population and habitat maintenance service to the delivery of food provision. In this case, proxies focusing on benefits and values focus on estimating the proportion of commercial fisheries that depends on the existence and functioning of a certain nursery habitat. Indicators can be for instance measuring the economic production along the productive mangrove fringe (USD/ha/yr)[811]; measuring the value of commercial fish in seagrass meadows (EUR/ha)[812]; estimating the commercial fishery landings linked to seagrass-associated species (EUR/yr, %)[813].
- Some studies suggest using the same indicators as for biodiversity or ecosystem condition, such as looking at the biodiversity value (species diversity or abundance, endemics or red list species) or at habitat diversity[814].
- Other scholars choose to look at proxies of ecosystem service flow by measuring e.g., the presence or increase of juveniles with commercial or recreational interest within nursery habitats. An example could be looking at the biomass of reef fish in mangrove-rich systems (kg/km2)[815].

With these indicators and proxies, a variety of methods can be applied to achieve the monetisation but are still debated in the literature. Cordier et al. (2014)[816] depict in Figure 5.51 below the framework for ecosystem services valuation, using the example of the nursery service. More specifically, the reason for using different approaches lies in the fact that the nursery population and habitat maintenance service can be valuated at different levels, looking either at its direct use value, its indirect use value or its non-use value:

- Some studies recommend estimating the economic benefits of the nursery services of coastal ecosystems by valuing its direct use value, e.g. the additional benefits for commercial and recreational fisheries. Under this approach, methods include for instance using direct monetary assessment of coastal fisheries through the transformation of fish abundance into

[811] Please see footnote 9.

[812] Tuya, F., Haroun, R., & Espino, F. (2014). Economic assessment of ecosystem services: monetary value of seagrass meadows for coastal fisheries. *Ocean & Coastal Management*, 96, 181-187.

[813] Jackson, E. L., Rees, S. E., Wilding, C., & Attrill, M. J. (2015). Use of a seagrass residency index to apportion commercial fishery landing values and recreation fisheries expenditure to seagrass habitat service. *Conservation Biology*, *29*(3), 899-909.

[814] Maes, J., et al., 2016. An Indicator Framework for Assessing Ecosystem Services in Support of the EU Biodiversity Strategy to 2020. Ecosystem Services 17,14–23. Mangialajo,

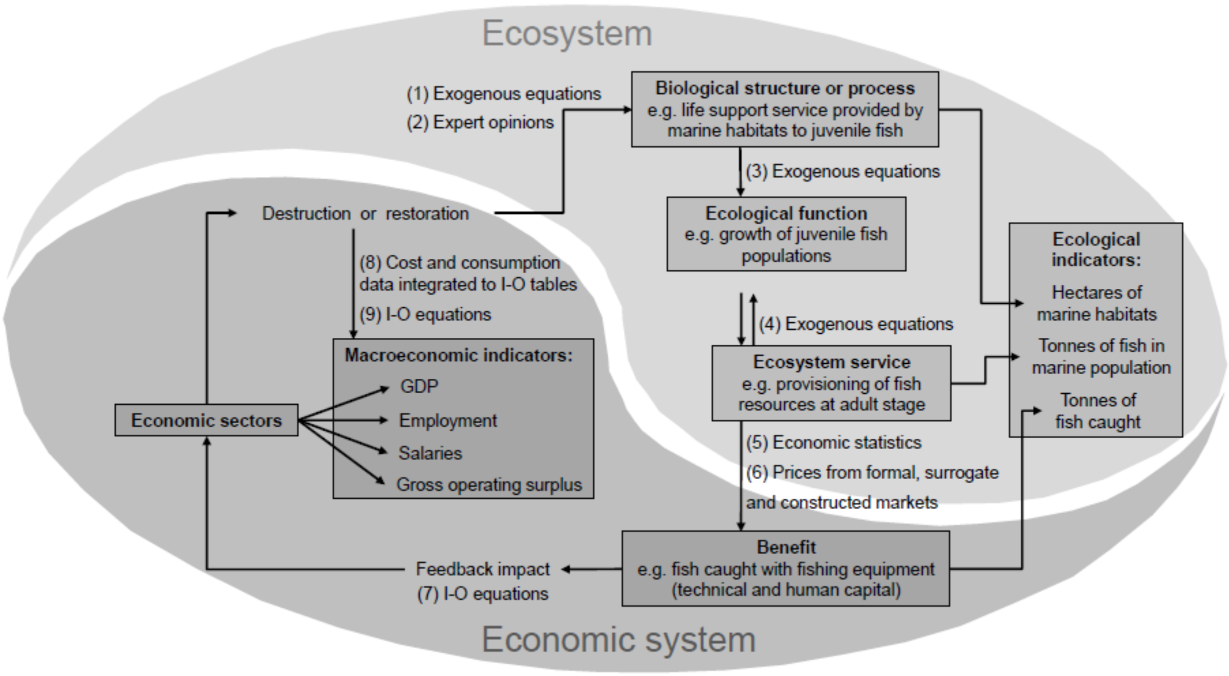
[815] Mumby, P. J., Edwards, A. J., Ernesto Arias-Gonzalez, J., Lindeman, K. C., Blackwell, P. G., Gall, A. & Llewellyn, G. (2004). Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *Nature*, *427*(6974), 533-536.

[816] Cordier, M., Agúndez, J. A. P., Hecq, W., & Hamaide, B. (2014). A guiding framework for ecosystem services monetization in ecological–economic modeling. *Ecosystem Services*, *8*, 86-96.

financial value using standard market-prices with a quantitative estimate of juvenile fishes[817].

- Many scholars argue that the economic benefits derived from the nursery service is a typical example of indirect use values, in other words an example of benefits derived from functional services that support current production and consumption[818]. Monetisation techniques to value indirect use values include methods such as avoided cost methods or production functions[819].
- Finally, the non-use value of nursery services, i.e. the bequest or existence value of nursery and habitat maintenance services, can be estimated by using contingent methods such as the willingness to pay (WTP) approach[820].

Figure 5.51. Quantification of relationships between the four steps of the cascade model (Biological structure and process, Ecological function, Ecosystem service, Benefit) using the example of the impact of the economy on fish nurseries (a marine natural habitat)



Source: Cordier et al. (2014)

Methodology of the present study

The nursery population and habitat maintenance service can thus be monetised. Studies however mainly focus on certain types of biomes – and not on the entire marine systems - to estimate the value of the nursery service. From the literature review it clearly appears that coastal wetlands, such as mangroves or sea grasses, are the most important sites for which

[817] Please see footnote 9.

[818] Barbier, E. B. (2007). Valuing ecosystem services as productive inputs. *Economic policy*, *22*(49), 178-229.

[819] *Ibid.*

[820] Stone, K., Bhat, M., Bhatta, R., & Mathews, A. (2008). Factors influencing community participation in mangroves restoration: A contingent valuation analysis. *Ocean & Coastal Management*, *51*(6), 476-484.

most fish and other marine species' nurseries are found and studied[821],[822]. The present monetisation exercise will thus focus on coastal wetlands and build on existing literature, in particular the global monetary estimation of the value of ecosystems and their services from de Groot et al. (2012)[823]. This study will help us define a baseline and, starting from this, to elaborate two scenarios for 2050. More specifically, the objective will be to:

- compare the long-term effects of "business-as-usual" (BAU scenario), in which coastal wetlands and in particular mangroves and salt marshes continue to be degraded by the combination of impacts originating from both human activities on the seashores and climate change; and
- a "scaled-up" of ocean governance efforts (SUE scenario), in which it is assumed that coastal wetlands and ecosystems are maintained to the current level through halting the degradation of coastal wetlands and through the restoration of damaged wetlands.

7.3.4 Assessment of reliability and robustness of methodology and data sources

In a general way, the methods that can be applied to value nursery population and habitat maintenance services of coastal wetlands present limitations. It is for instance the case for methods to quantify the direct use value of nursery services that make use of proxies such as fish sold on the market. With this approach, the biodiversity of associated commercial fish species is considered in the economic valuation because they can be more directly linked to an economic dimension, even though the biodiversity of invertebrate species and micro-organisms associated to other habitats is significantly greater[824].

In addition, the monetary valuation of nursery services can lead to double counting with the assessment of other ecosystem services, e.g. provision of fish biomass services, or with the assessment of biodiversity itself, particularly when only the ecosystem goods (e.g. fish) and not the processes are valued799. Young and Potschin (2010)[825] consider that, for avoiding double counting, the provisioning ecosystem service of fish resources should be considered as a final service obtained from, among others, the supporting service provided by nursery habitats. In that case, they argue that nursery and habitat maintenance services should not be valued monetarily because their economic value is already included in the benefit obtained from the provisioning ecosystem service of fish resources.

Data sources used to inform this study are sourced from secondary literature only. It should be noted that there remains a range of gaps in the literature on the values of ecosystem services from wetlands and therefore the existing data should be seen as indicative. Of the nursery service value assessment studies that could be found, most were focusing on coastal wetlands, as compared with inland wetlands or other marine biomes. In addition, the extent of valuation assessment information is best for mangroves and salt marshes, which explains the choice to focus specifically on these two types of habitats.

[821] Please see footnote 1.

[822] Please see footnote 11.

[823] De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L. & van Beukering, P. (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem services*, *1*(1), 50-61.

[824] Please see footnote 18.

[825] Haines-Young, R., Potschin, M., (2010). The links between biodiversity, ecosystem services and human well-being D. Raffaelli, C. Frid (Eds.), *Ecosystems Ecology: a New Synthesis*, Cambridge University Press, Cambridge (2010), pp. 110-139.

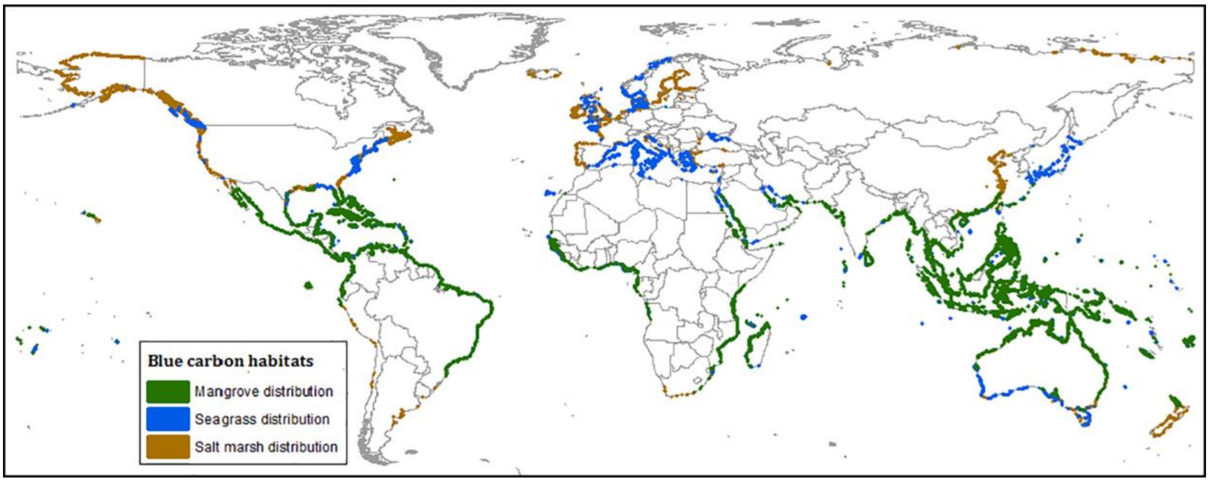
The figures presented here are also potentially affected by geographical bias in the numbers of studies and reports found for the different regions of the world. Most valuation studies focus on Asia, Europe and North America with a paucity of reports focusing on Africa or Oceania[826.]

Lastly, our present study is only looking at changes in the area of remaining coastal wetlands, and not at the state of those that remain. However, it is clear that many remaining wetlands continue to face severe pressures and that their state of health continue to be deteriorated, thus impacting the services rendered by coastal wetlands ecosystems.

7.3.5 Description of the baseline (method and results)

Coastal wetlands include mangroves, salt marshes, seagrass, coral reefs, beaches, estuaries, and coastal water bodies that lie between 0 and −6 meters depth[827]. Mangroves and salt marshes are the two most prominent types of ecosystems with mangroves mainly distributed along tropical muddy coasts, with an estimated total area around 137 682 km^2, while salt marshes dominate the muddy coasts from subtropical, temperate to sub-polar and arctic zones, with a total area of 54 662 km^2 (according to the values reported by Bertram et al. (2021)[828]). This study will thus consider these two biomes, for a total area of **192 344 km^2**, for the monetisation of the nursery services.

Figure 5.52. Global distribution of coastal ecosystems



Source figure: Himmes-Cornell et al. (2018)[829]

The world's coastal wetlands have been diminishing since the 18th century, notably because many of these coastal areas have been reclaimed for other use (e.g., aquaculture) before their significance was recognized. Coastal wetlands are threatened from both human activity and

[826] Davidson, N. C. (2014). How much wetland has the world lost? Long-term and recent trends in global wetland area. *Marine and Freshwater Research*, *65*(10), 934-941.

[827] Ramsar Convention Secretariat 2010. Available at: https://www.ramsar.org/sites/default/files/documents/library/strp_africa2010_3.pdf

[828] Bertram, C., Quaas, M., Reusch, T. B., Vafeidis, A. T., Wolff, C., & Rickels, W. (2021). The blue carbon wealth of nations. *Nature Climate Change*, *11*(8), 704-709.

applications. Cambridge University Press, New York, N.Y., USA.

[829] Himes-Cornell, Amber; Pendleton, Linwood; Atiyah, Perla (2018). *Valuing ecosystem services from blue forests: A systematic review of the valuation of salt marshes, sea grass beds and mangrove forests. Ecosystem Services, 30(), 36–48.*

natural hazards, such as climate change, sea level rise, local subsidence, decreased sediment supply, and acidification[830].

Although the area of coastal wetlands is rather small compared to e.g. other terrestrial ecosystems, their productivity is comparable to many of the most productive ones. According to Li et al. (2018), about two-thirds of marine animals, such as fish, shrimps, crabs etc., must spend some time at coastal wetlands during their life history, as these areas represent nursery grounds for them. In addition, it is proven that over 90% of marine fisheries are sourced from coastal zones, either through harvesting of wild organisms or mariculture[831]. As a result, the degradation of coastal wetlands affects severely the provision of the supply of services provided by these ecosystems, including the provision of nursery habitats.

The baseline for the monetary value of the nursery population and habitat maintenance service is extracted from the study by de Groot et al. (2012) who established that the nursery services from coastal wetlands (tidal marsh, mangroves and saltwater wetlands) were worth 11 510 (2021)€/ha/y[832] - hence 221 billion (2021)€/y when multiplied by the surface area covered currently by coastal wetlands.

This value was obtained by sourcing the value of this ecosystem service from a number of existing database and from other relevant studies with data on ecosystem services values. Groot et al. then proceeded to the standardization of the values since the values were reported in the literature in different metrics and currencies, in different time periods and price levels. The values they used have been estimated using a range of economic approaches. Hence, they have decided to standardise the values to common spatial, temporal and currency units with the International dollars per hectare per year (Int$/ha/year), which is converted here in €/ha/y (in 2021 value).

Building on this baseline, the two different scenarios (BAU and SUE) can be elaborated.

7.3.6 Description of the" business as usual" (BAU) scenario (method and results)

The BAU scenario for nursery services considers that the level of pressures exerted on coastal wetlands originating from anthropogenic activities and from the impacts of climate change follows the current trends. As a result, from these pressures, mangroves and salt marshes continue being degraded and their distribution worldwide diminishes.

The BAU scenario assumes that the area covered by coastal wetlands globally, considering only mangroves and salt marshes, is 192 344 km^2.

In order to estimate the area covered by these biomes in 2050, the present study uses annual discount rates reported by Hoegh-Guldberg et al. (2019). The average rate of mangrove loss is estimated at -0.11%. y^{-1} [833] and the average rate of salt marshes loss at -1.5%. y^{-1} [834].

[830] Li, X., Bellerby, R., Craft, C., & Widney, S. E. (2018). Coastal wetland loss, consequences, and challenges for restoration. *Anthropocene Coasts*, *1*(1), 1-15.

[831] Hinrichsen, D., and Olsen, S. 1998. Coastal waters of the world: trends, threats, and strategies. *Island Press*, Washington, D.C., USA. 298 pp.

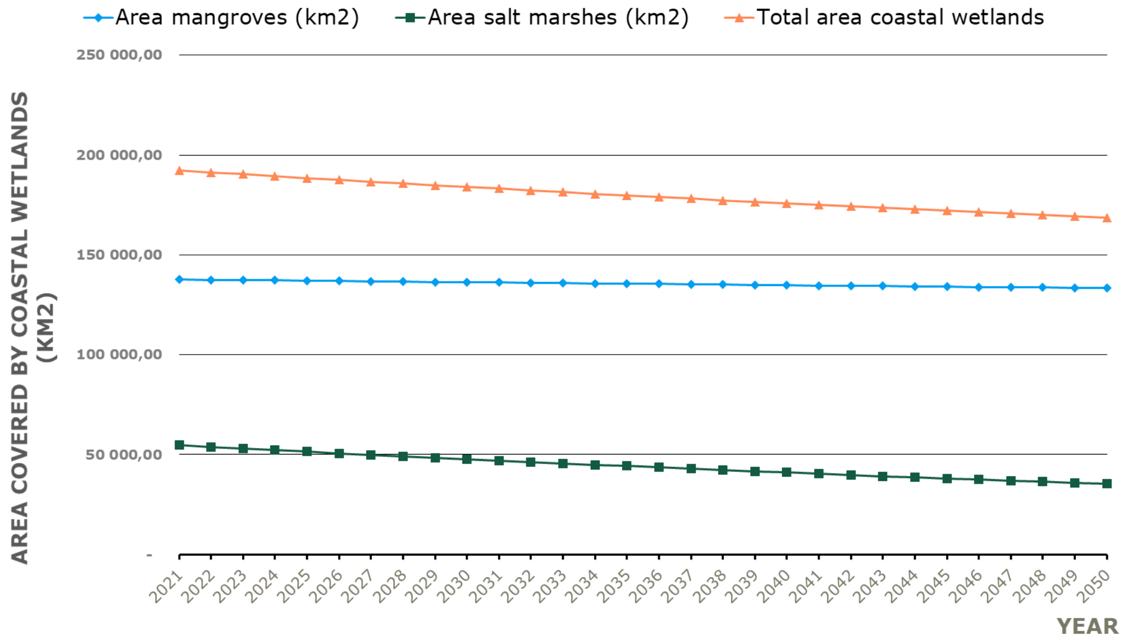
[832] The original value reported by de Groot et al. (2012) is 10,648 US$/ha/year globally (in 2007 value) and was converted into EUR2021 value.

[833] Bunting, P., R. Lucas, A. Rosenqvist, L.-M. Rebelo, L. Hilarides, N. Thomas, A. Hardy, et al. (2018). "The Global Mangrove Watch—A New 2010 Baseline of Mangrove Extent." Remote Sensing 10. 1669. 10.3390/rs10101669.

[834] Pendleton, L., D.C. Donato, B.C. Murray, S. Crooks, W.A. Jenkins, S. Sifleet, C. Craft, et al. (2012). "Estimating Global 'Blue Carbon' Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems." PLOS ONE 7 (9): e43542.

From these estimates we could draw the future trends in the loss of coastal wetlands between 2021 and 2050 (see figure below).

Figure 5.53. Estimated loss of coastal wetlands between 2021 and 2050



The BAU scenario then assumes that the supply of services is proportional to the ecosystem size. Consequently, the loss of economic benefits derived from coastal wetlands provision of nursery services is assumed to be proportional to the loss of surface covered globally by mangroves and salt marshes.

By multiplying the area covered by coastal wetlands in 2050 under the BAU scenario by the value of de Groot et al. (2012) it is found that the monetary value of the nursery service in 2050 would be 194 billion (2021)€/y.

The authors of the present study acknowledge the fact that the methodology used present important limitations, hence the findings presented here should be considered with caution.

7.3.7 Description of the "scaled up efforts" scenario (method and results)

The approach used to define the SUE scenarios assumes that the surface covered by coastal wetlands globally (and their state) would at least be maintained up to 2050 to current levels, thanks to improved understanding, management, and restoration[835]. Examples of the implementation of restoration projects are the development of Integrated Coastal Zone Management (ICZM). These systems are defined as resource management system following an integrative, holistic approach and an interactive planning process in addressing the complex management issues in the coastal area[836]. Restoration and conservation efforts have proven to

[835] Lee, S.Y., S. Hamilton, E.B. Barbier, J. Primavera, and R.R. Lewis. (2019). "Better Restoration Policies Are Needed to Conserve Mangrove Ecosystems." *Nature Ecology & Evolution* 3 (6): 870.

[836] Thia-Eng, C. (1993). Essential elements of integrated coastal zone management. *Ocean and Coastal Management* 21:81-108

be efficient as it is for instance documented that the rates of mangrove loss have declined from 2.1 percent/year in the 1980s to 0.11 percent/year in the past decade[837].

The "scaled-up effort" scenario goes along with the objective of conserving and using wisely wetlands as an important pathway to meeting many of the 17 goals and 169 targets of the Sustainable Development Goals[838]. The Convention on Wetlands (also known as Ramsar) is a custodian of SDG 6 Target 6.6 which states that efforts should be put to achieve the "protection and the restoration of water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes"[839].

In its 4th strategic plan for 2016-2024 the Convention on Wetlands[840] indicates as its first priority area of focus for the next nine years the "preventing, stopping and reversing of the loss and degradation of wetlands". This could be achieved by addressing the drivers of wetland loss and degradation and effectively conserving managing the protected wetland areas (e.g. the Ramsar Site network). In addition, the Convention on Biological Diversity's Global Biodiversity Outlook 410[841] indicates that the area of human-made wetlands tends to be increasing, even though it notes that the quality of these may be lower than that of the ones destroyed.

The SUE scenario, in a similar way as the BAU scenario, assumes that the supply of services is proportional to the ecosystem size. It is thus assumed here that the maintenance of coastal wetlands distribution and state globally could maintain the monetary value of the nursery and habitat service to a constant level, namely **221 billion (2021)€/y.**

7.4 Waste Remediation Services

7.4.1 Description of Ecosystem Service / Benefit and Impact

The marine realm is where a significant amount of waste and pollutants from anthropogenic activities eventually settles. These pollutants include organic pollutants, e.g. pesticides or polycyclic aromatic hydrocarbons (PAHs), inorganic pollutants, e.g. heavy metals (HM), and nutrients. Nutrients, such as nitrate and phosphate, are of particular concern today. They land into the seas mainly as a result of land-based human activities such as agriculture and they can lead to eutrophication of coastal ecosystems[842]. Eutrophication is the process by which an ecosystem experiences an increase in the rate of organic matter supply[843]. This process can affect the physiology and growth of marine organisms, impact pelagic and benthic community structures and can have cascading effects on ecosystem functioning and services.

[837] Hoegh-Guldberg. O., et al. (2019). "The Ocean as a Solution to Climate Change: Five Opportunities for Action." Report. Washington, DC: World Resources Institute. Available online at http://www.oceanpanel.org/climate

[838] Global Wetland Outlook: Special Edition 2021. Available at: https://static1.squarespace.com/static/5b256c78e17ba335ea89fe1f/t/61b8a904f3ceb458e9b5ca44/1639491853578/Ramsar+GWO_Special+Edition+2021%E2%80%93ENGLISH_WEB.pdf

[839] Sustainable Development Goals. Available at: https://sdgs.un.org/goals/goal6

[840] Fourth Strategic Plan of the Convention on Wetlands for 2016-2024. Available at: https://www.ramsar.org/sites/default/files/documents/library/4th_strategic_plan_2016_2024_e.pdf

[841] Report "Progress towards the Aichi Biodiversity Targets: An Assessment of Biodiversity Trends, Policy Scenarios and Key Actions". Available at https://www.cbd.int/gbo4advance

[842] Jessen, C., Bednarz, V. N., Rix, L., Teichberg, M., & Wild, C. (2015). Marine eutrophication. In *Environmental indicators* (pp. 177-203). Springer, Dordrecht.

[843] Idem

Marine living organisms act by storing, burying and transforming many of these wastes through assimilation and chemical decomposition, either directly or indirectly. These processes include[844]:

- The cycling or detoxification through which wastes are changed into harmless or less toxic compounds. An example of this process is bioturbation through which mega and macro-fauna organisms carry out reworking and re-mixing of sediments on the deep-sea floor. This serves to bury and recycle wastes through assimilation and chemical re-composition and helps to detoxify and purify waters.
- The sequestration or storage of waste in the environment in such a way that they are no longer biologically available and thus no longer exhibit toxicity. However, it should be noted that stored sequestration may be reversible if conditions are altered.
- The exportation and transport of waste through for instance atmospheric, benthic and lateral export.

These processes, often called waste bioremediation or waste treatment, are of critical importance to the health of the marine environment and ultimately for human health and as such these processes can be regarded as regulating ecosystem services.

The System of Environmental-Economic Accounting— Ecosystem Accounting white paper describes this ecosystem service (ES) as the "*ecosystem contributions to the restoration and maintenance of the chemical condition of surface water and groundwater bodies through the breakdown or removal of nutrients and other pollutants by ecosystem components that mitigate the harmful effects of the pollutants on human use or health*."[845] It may be recorded as a final or intermediate ecosystem service. This ES has been labelled in different ways by other ecosystems classifications such as the service of "Water purification and waste treatment" by the Millennium Ecosystem Assessment (MA)[846], as the "Water quality regulation" by the UK's National Ecosystem Assessment classification (NEA)[847], and more recently as "Mediation of waste, toxics and other nuisances" by the Common International Classification of Ecosystem Services (CI- CES)[848].

The present study uses the term "waste remediation" to describe the "retention and breakdown of organic pollutants, including excess nutrients and inorganic pollutants" ecosystem service.

7.4.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Human economic activities and in particular agricultural activities produce a large variety of waste that are introduced in the marine environment either by accident or voluntarily. Incorrectly managed discharges of wastewater can have serious implications marine biological diversity and ecological integrity and can ultimately lead to the alteration of the capacity of

[844] Watson, S. C., Paterson, D. M., Queirós, A. M., Rees, A. P., Stephens, N., Widdicombe, S., & Beaumont, N. J. (2016). A conceptual framework for assessing the ecosystem service of waste remediation: in the marine environment. *Ecosystem services*, *20*, 69-81.

[845] United Nations et al. (2021). System of Environmental-Economic Accounting— Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing. Available at: https://seea.un.org/ecosystem-accounting

[846] Millennium Ecosystem Assessment. Available at: https://www.millenniumassessment.org/en/index.html

[847] UK National Ecosystem Assessment. Available at: http://uknea.unep-wcmc.org/About/NEAReportStructure/tabid/62/Default.aspx

[848] Common International Classification of Ecosystem Services. Available at: https://cices.eu/

marine ecosystems to deliver the service of retention and breakdown of organic and inorganic pollutants.

One of the most important impacts on the provisioning of the waste remediation service is the enhanced input of nutrients – more specifically of nitrate (N) and phosphate (P) – mostly originating from municipal wastes and agricultural sources into rivers and eventually in the ocean. This enhanced input, called eutrophication, can affect the functioning of marine ecosystems through "the exacerbation and rapid growth of eutrophic deoxygenated zones"[849]. This is a source of pressure on marine fauna and flora, and it is also eventually a major threat to human health and well-being through water quality degradation.

7.4.3 Description of methodology for monetisation incl. indicators used and data sources

The most commonly applied approach that has been found in the literature for valuing the waste remediation service is to estimate the cost of replacing the service with man-made infrastructure (the "replacement cost" method) or to estimate the cost that would have been supported to rehabilitate a certain system function to maintain the supply of service (the "avoided cost" method). In other words, it is valued indirectly by estimating the cost of an alternative approach i.e. the cost of using some other resource to achieve the same end as the one in question. For example, the value of water quality improvement by a wetland might be estimated using the cost of equivalent water treatment methods.

It has also been found that valuation studies often make use of the benefit transfer (also called "value transfer") method in order to be able to transfer ecosystem service values calculated in previous studies done in a similar ecosystem to the system they are studying. Researchers have frequently used the benefit transfer method in studies that seek to value ecosystem services at a global scale, including the waste remediation service[850].

For the present study, the monetary valuation of the ecosystem service of interest will be operationalised on the basis of coastal wetlands providing for waste remediation services. Indeed, while this service occurs in all marine environments – from estuaries to the continental shelf, to deep sea habitats – the focus of this study will be on coastal wetlands as there is extensive evidence that specific habitats found in brackish and coastal water habitats (e.g. salt marshes, sea grasses and mangroves) provide an important waste remediation function[851].

The methodology used here will be looking at:

- A baseline as described by global studies on the distribution of coastal wetlands ecosystems and the value of the waste remediation service they provide. This value will be based on the avoided cost that humans get from having ecosystems providing these services, thus not having to replace the service with man-made infrastructure such as wastewater treatment plants. This global value is extracted from studies where the valuation is based on avoided cost and benefit transfer economic approaches.
- A business-as-usual (BAU) scenario that assumes the continued degradation of coastal wetlands and the consequent loss in value associated to the service they provide, at the time horizon of 2050.
- A scaled-up effort (SUE) scenario that considers that the frequency and distribution of coastal wetlands in 2050 is maintained through increased efforts in conservation and through

[849] Please see footnote 3.

[850] Himes-Cornell, A., Grose, S. O., & Pendleton, L. (2018). Mangrove ecosystem service values and methodological approaches to valuation: where do we stand?. *Frontiers in Marine Science*, 376.

[851] Ribeiro, H., Mucha, A. P., Almeida, C. M. R., & Bordalo, A. A. (2014). Potential of phytoremediation for the removal of petroleum hydrocarbons in contaminated salt marsh sediments. *Journal of environmental management*, *137*, 10-15.

the reduction of pollutants inputs in marine environment from inland anthropogenic activities.

7.4.4 Assessment of reliability and robustness of methodology and data sources

The methodology used is based on values extracted from secondary literature, and in particular from the global assessment of ecosystem services values by de Groot et al. (2012)[852] and the report from Hoegh-Guldberg et al. (2019)[853] on coastal and marine ecosystems where they detail long-term and recent trends in the rate of loss of global wetland areas. These meta-analysis and literature review studies are based on case studies; hence a first limitation lies in the fact that the results they display are average numbers and approximations.

In addition, to be able to provide an estimation of the monetary value of the retention and breakdown of organic, inorganic pollutants and excess nutrients service by marine and coastal ecosystems, researchers have been relying extensively on the benefit transfer method. However, it has been shown that often authors do not consider adequately the source and context of the benefit transfer values. Himmes-Cornell et al. (2018) explain how values are not inherently transferrable since they are "very context specific and can change greatly from one community or context to another depending on how the ecosystem is used and the unique ecological, economic, and social context"[854]. This issue is exacerbated when the benefit transfer method is applied on the basis of global value estimates, such as the ones found in de Groot et al. (2012). Indeed, global studies rely on published case studies to extrapolate values calculated for local ecosystem services to biomes at the global scale. Even though this approach provides the opportunity to bring the attention of decision-makers to the importance of ecosystem services, it leads at the same time to the obliteration of differences at the local and regional scales. The benefits provided by an ecosystem service in a given area is not necessarily the same at a different location. As a result, applying a value to an ecosystem service calculated for another region will likely overinflate the calculated value[855].

This limitation is highlighted by Himmes-Cornell et al. (2018) who compare the global value of the waste treatment service provided by coastal wetlands estimated by Costanza et al. (1997) and by de Groot et al. (2012) with the average value they calculated from the literature review conducted. They show that the value reported by de Groot et al. (2012) – which will be used asmthe baseline value of the present study – is significantly higher than the value they calculate from the literature review. The reason for this being the inclusion of ecosystem services values from a 1978 study.

Lastly, a strong limitation to the present study lies in the fact that the two scenarios that are used to compare the long-term economic impacts of improved efforts with a business-as-usual situation assume that the supply of services is proportional to the ecosystem size. This assumption has been extensively discussed in the literature and it is shown that the supply of ecosystem services per unit area is rarely homogeneous[856]. In addition, this assumption doesn't consider the *state* of the ecosystem considered but only its surface area. Hence, results presented here should be taken with caution since they are used to illustrate and substantiate

[852] De Groot, R., Brander, L., Van Der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L. and Hussain, S., (2012). Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem services*, *1*(1), pp.50-61.

[853] Hoegh-Guldberg. O., et al. (2019). "The Ocean as a Solution to Climate Change: Five Opportunities for Action." Report. Washington, DC: *World Resources Institute*. Available online at http://www.oceanpanel.org/climate

[854] Please see footnote 9.

[855] Emerton, L. (2014). Assessing, Demonstrating and Capturing the Economic Value of Marine & Coastal Ecosystem Services in the Bay of Bengal Large Marine Ecosystem. Phuket: Bay of Bengal Large Marine Ecosystem Project.

[856] Please see footnote 9.

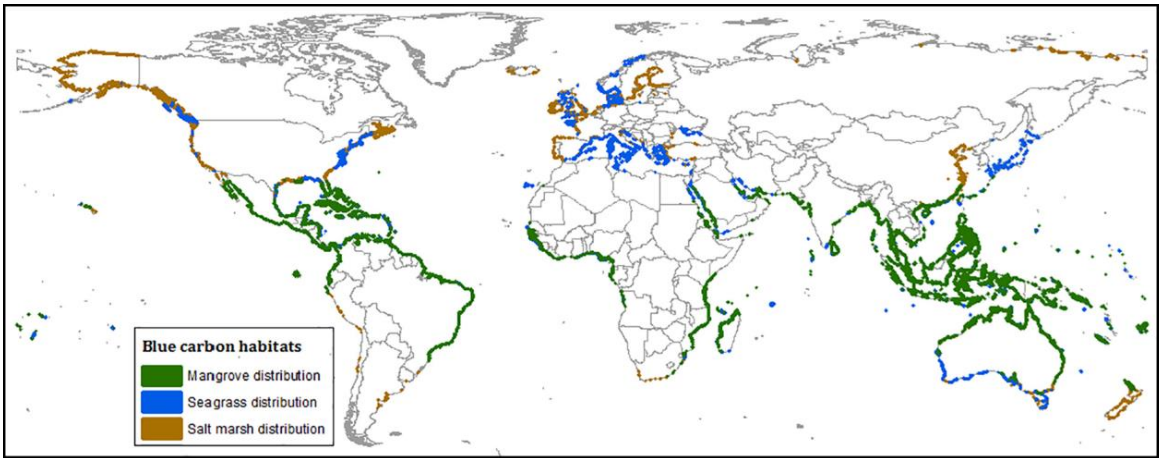
the potential impacts of the two scenarios on the economic benefits that are derived from the waste remediation service.

7.4.5 Description of the baseline (method and results)

The baseline for calculating the value of the retention and breakdown of organic pollutants service will be estimated on the basis of the distribution of coastal wetlands ecosystems (more specifically mangroves and salt marshes biomes) and the value of the waste bioremediation service they provide.

Coastal wetlands include mangroves, salt marshes, seagrass, coral reefs, beaches, estuaries, and coastal water bodies that lie between 0 and −6 meters depth[857]. Mangroves and salt marshes are the two most prominent types of ecosystems with mangroves mainly distributed along tropical muddy coasts, with an estimated total area around 137 682 km^2, while salt marshes dominate the muddy coasts from subtropical, temperate to sub-polar and arctic zones, with a total area of 54 662 km^2 (according to the values reported by Bertram et al. (2021)[858]). This study will thus consider these two biomes, for a total area of 192 344 km^2, for the monetisation of the nursery services.

Figure 5.54 Global distribution of coastal wetlands ecosystems.



Source: Himmes-Cornell et al. (2018,b)[859]

The world's coastal wetlands have been diminishing since the 18th century, notably because many of these coastal areas have been reclaimed for other use (e.g., aquaculture) before their significance was recognized. Coastal wetlands are threatened from both human activity and natural hazards, such as climate change, sea level rise, local subsidence, decreased sediment supply, and acidification[860].

[857] Ramsar Convention Secretariat 2010. Available at: https://www.ramsar.org/sites/default/files/documents/library/strp_africa2010_3.pdf

[858] Bertram, C., Quaas, M., Reusch, T. B., Vafeidis, A. T., Wolff, C., & Rickels, W. (2021). The blue carbon wealth of nations. *Nature Climate Change*, *11*(8), 704-709.

[859] Himes-Cornell, Amber; Pendleton, Linwood; Atiyah, Perla (2018). *Valuing ecosystem services from blue forests: A systematic review of the valuation of salt marshes, seagrass beds and mangrove forests. Ecosystem Services, 30(), 36–48.*

[860] Li, X., Bellerby, R., Craft, C., & Widney, S. E. (2018). Coastal wetland loss, consequences, and challenges for restoration. *Anthropocene Coasts*, *1*(1), 1-15.

Although the area of coastal wetlands is rather small compared to e.g. other terrestrial ecosystems, their productivity is comparable to many of the most productive ones. According to Li et al. (2018), about two-thirds of marine animals, such as fish, shrimps, crabs etc., must spend some time at coastal wetlands during their life history, as these areas represent nursery grounds for them. In addition, it is proven that over 90% of marine fisheries are sourced from coastal zones, either through harvesting of wild organisms or mariculture[861].

As a result, the degradation of coastal wetlands affects severely the provision of the supply of services provided by these ecosystems, including the provision of waste remediation services.

The baseline monetary value of this ecosystem service is extracted from the study by de Groot et al. (2012). In this global study de Groot's team estimated the value of several ecosystem services per biomes by using values from multiple studies to calculate an average, unit value (per unit area) and then multiplied that average by the estimated global area of a set of biomes based on global land use maps. They found that the value of the waste remediation ecosystem service provided by coastal wetlands is 175,250 (2021) €/ha/y **– hence 3,371 billion (2021) €/y** [862]

It is however important to note that other studies such as the literature review by Himmes-Cornell et al. (2018) have demonstrated that the total ecosystem service values obtained by de Groot et al. (2021) were considerably different than other average values that have been published for case studies. This is particularly the case for some ecosystem service values provided by coastal habitats and more specifically for the waste remediation service provided my mangroves. They find that the average value of this service is 2827 (2007) US$/ha/year, to be compared with the value 162,125 (2007) US$/ha/year reported

In addition, they show that the two main economic methods used to value this ecosystem services provided by mangroves are the benefit transfer method and the replacement cost method, and that there is a significant difference in the monetary value estimated for the waste remediation service depending on which one of these two methods is applied. According to their findings, the use of the benefit transfer tends to overestimate the value of the waste remediation service provided by mangroves and when only considering case studies that apply the replacement cost method the average value estimated is 72 (2007) US$/ha/year.

For the purpose of this study, the value of de Groot et al. will be used since it allows to capture the value of coastal wetlands (and not only of mangroves as for Himmes-Cornell et al.(2018)). This will serve to better capture the global value of the waste remediation service provided by coastal ecosystems.

7.4.6 Description of the" business as usual" (BAU) scenario (method and results)

Coastal wetlands are facing increasing pressures from anthropogenic activities that generate numerous types of pollutants, such as in-land activities e.g. industrial activities, agriculture, coastal development, marine activities e.g. pollution by ships, oil and gas exploration, or pollution from atmospheric deposition. In addition, marine and coastal ecosystems continue to be degraded by several pressures that originate from climate change impacts, such as ocean acidification, ocean warming and sea-level rise. These pollutions can degrade the state of marine waters and ultimately can cause serious damage to ecosystems functioning.

[861] Hinrichsen, D., and Olsen, S. 1998. Coastal waters of the world: trends, threats, and strategies. *Island Press*, Washington, D.C., USA. 298 pp.

[862] The initial value reported by de Groot et al. (2021) is 162,125 (2007)US$/ha/year and has been converted into 2021 value.

Changes to coastal ecosystems, such as mangroves, tidal flats, estuaries or generally coastal vegetation can affect the ability of these ecosystems to purify inland water flows to the ocean from organic and inorganic pollutants. In other words, the continued degradations foreseen in the likely event of a "business-as-usual" scenario in 2050, in which the intensity of pressures on coastal ecosystems is not reduced, is expected to severely impact the provision of services by these ecosystems.

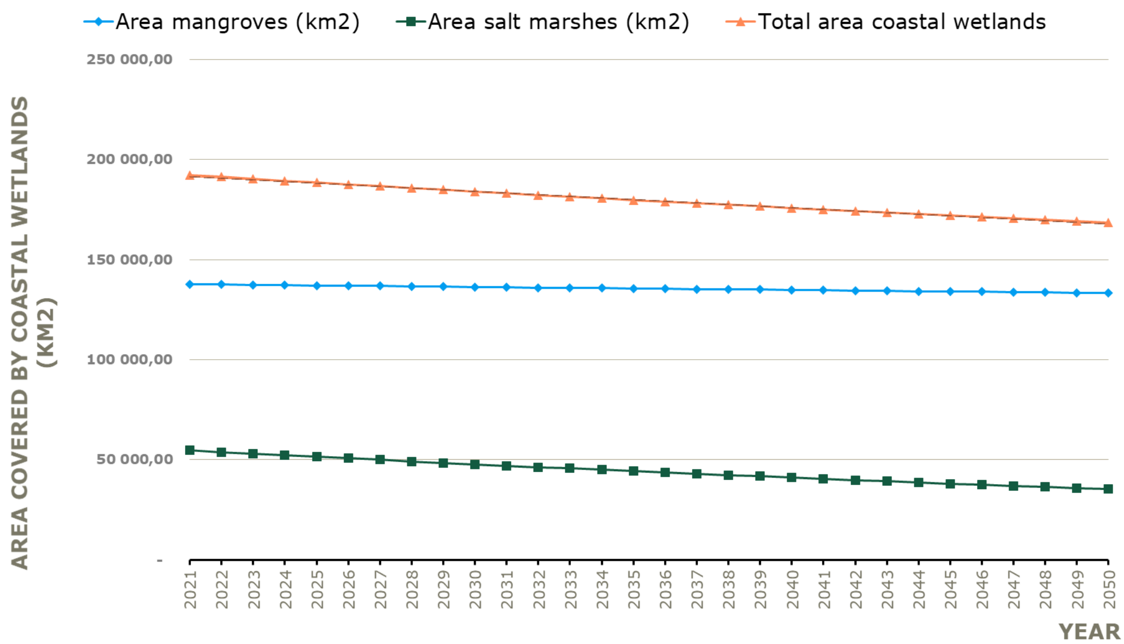
The BAU scenario in the present study thus considers that the level of pressures exerted on coastal wetlands originating from anthropogenic activities and from the impacts of climate change follows the current trends. Resulting from these pressures, mangroves and salt marshes continue being degraded and their distribution worldwide diminishes.

The BAU scenario assumes that the area currently covered by coastal wetlands globally, considering only mangroves and salt marshes, is 192 344 km^2.

In order to estimate the area covered by these biomes in 2050, the present study uses annual discount rates reported by Hoegh-Guldberg et al. (2019). The average rate of mangrove loss is estimated at -0.11%. y^{-1} [863] and the average rate of salt marshes loss at -1.5%. y^{-1} [864].

From these estimates we could draw the future trends in the loss of coastal wetlands between 2021 and 2050 (see figure below). The area covered by coastal wetlands in 2050 under the BAU scenario is 168 621 km^2.

Figure 5.55 Estimated loss of coastal wetlands between 2021 and 2050



The BAU scenario then assumes that the supply of services is proportional to the ecosystem size. Consequently, the loss of economic benefits derived from coastal wetlands provision of

[863] Bunting, P., R. Lucas, A. Rosenqvist, L.-M. Rebelo, L. Hilarides, N. Thomas, A. Hardy, et al. (2018). "The Global Mangrove Watch—A New 2010 Baseline of Mangrove Extent." Remote Sensing 10. 1669. 10.3390/rs10101669.

[864] Pendleton, L., D.C. Donato, B.C. Murray, S. Crooks, W.A. Jenkins, S. Sifleet, C. Craft, et al. (2012). "Estimating Global 'Blue Carbon' Emissions from Conversion and Degradation of Vegetated Coastal Ecosystems." PLOS ONE 7 (9): e43542.

waste remediation services is assumed to be proportional to the loss of surface covered globally by mangroves and salt marshes.

By multiplying the area covered by coastal wetlands in 2050 under the BAU scenario by the value of de Groot et al. (2012) it is found that the monetary value of the waste remediation service in 2050 would be **2,955 billion (2021) €/y.**

The authors of the present study acknowledge the fact that the methodology used present important limitations, hence the findings presented here should be considered with caution.

7.4.7 Description of the “scaled up efforts" scenario (method and results)

The approach used to define the SUE scenarios assumes that the surface covered by coastal wetlands globally (and their state) would at least be maintained up to 2050 to current levels, thanks to improved understanding, management, and restoration[865]. Examples of the implementation of restoration projects are the development of Integrated Coastal Zone Management (ICZM). These systems are defined as resource management system following an integrative, holistic approach and an interactive planning process in addressing the complex management issues in the coastal area[866]. Restoration and conservation efforts have proven to be efficient as it is for instance documented that the rates of mangrove loss have declined from 2.1 percent/year in the 1980s to 0.11 percent/year in the past decade[867]. Several case studies have contributed to highlight the potential – both environmental and economic – of such approaches to marine and coastal ecosystems conservation, an example being the paper “Embedding ecosystem services in coastal planning leads to better outcomes for people and nature” by Arkema et al. (2015) that focuses on informed management of social and ecological systems to sustain delivery of ecosystem services to people[868].

The SUE scenario, in a similar way as the BAU scenario, assumes that the supply of services is proportional to the ecosystem size. It is thus assumed here that the maintenance of coastal wetlands distribution and state globally could maintain the monetary value of the nursery and habitat service to a constant level: **3,371 billion (2021) €/y.**

It should be noted that in the SUE scenario developed in the present study, the costs of the efforts for conserving the coastal wetlands and the investment, operation and maintenance costs associated to the treatment of wastewater have not been considered. However, some studies have been able to conduct such valuation exercise such as the report from the United Nations Environment Programme, the *Economic valuation of wastewater – the cost of action and the cost of no action*[869]. The result of the comparison conducted in the report demonstrate that even when considering the costs of action associated to treatment of wastewater, it is profitable to act against pollution from untreated wastewater in the long run.

[865] Lee, S.Y., S. Hamilton, E.B. Barbier, J. Primavera, and R.R. Lewis. (2019). “Better Restoration Policies Are Needed to Conserve Mangrove Ecosystems.” *Nature Ecology & Evolution* 3 (6): 870.

[866] Thia-Eng, C. (1993). Essential elements of integrated coastal zone management. *Ocean and Coastal Management* 21:81-108

[867] Please see footnote 12.

[868] Arkema, K. K., Verutes, G. M., Wood, S. A., Clarke-Samuels, C., Rosado, S., Canto, M., ... & Guerry, A. D. (2015). Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. *Proceedings of the National Academy of Sciences*, *112*(24), 7390-7395.

[869] Hernández-Sancho, F., Lamizana-Diallo, B., Mateo-Sagasta, J., & Qadir, M. (2015). *Economic valuation of wastewater: the cost of action and the cost of no action*. United Nations Environment Programme (UNEP).

7.4.8 Comparison of results from the two scenarios

The difference between the BAU value and the SUE value in 2050 is the cost of inaction. It is estimated that the cost of inaction in 2050 would be an estimated **416 billion (2021) €/y** if we consider the total area covered by mangroves and salt marshes globally[870].

7.5 Biological Control Services

7.5.1 Description of Ecosystem Service / Benefit and Impact

Biological control services contribute to the maintenance of population dynamics and resilience through food web dynamics, disease and pest control[871].

The SEEA-EA framework distinguishes two different biological control services. Pest control services are defined as 'ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of pests on biomass production processes or other economic and human activity', and disease control services as 'ecosystem contributions to the reduction in the incidence of species that may prevent or reduce the effects of species on human health'. Examples of how these services are delivered by different marine ecosystem components are presented below:

- Out of approximately 5,000 marine algal species, around 300 are known to form blooms as a result of changes in water temperature, seasonal / temporal stratification or nutrient inputs among other factors. Harmful algal blooms (HABs) are natural atypical proliferations of micro and macro algae which can have significant effects on human, animal and ecosystem health, including through the production of algal toxins[872,873] that lead to reduced water quality with consequences for bathing water quality and the food chain, reducing both recreation and leisure as well as food provisioning services[874]. There are a number of marine invertebrates, such as sponges or bivalves, that obtain food by filtering out plankton or nutrients suspended in water, and can therefore help to control the concentration of opportunistic species such as HAB[875]. Similarly, seagrass and macroalgae can also control HABs through algicidal and growth-inhabiting bacteria that associate with them[876];
- Jellyfish aggregations are a natural feature of healthy pelagic ecosystems, although high density of these organisms have been observed in many coastal areas around the globe, likely promoted by climate change effects, eutrophication and overfishing of jellyfish

[870] Based on own calculations, the surface area of mangroves and salt marshes globally is estimated to be 16 862 129 ha in 2050.

[871] Broszeit, S., Beaumont, N.J., Hooper, T.L., Somerfield, P.J., Austen, M.C., 2019. Developing conceptual models that link multiple ecosystem services to ecological research to aid management and policy, the UK marine example. Marine Pollution Bulletin 141. https://doi.org/10.1016/j.marpolbul.2019.02.051

[872] Turner, A.D., Lewis, A.M., Bradley, K., Maskrey, B.H., 2021. Marine invertebrate interactions with Harmful Algal Blooms – Implications for One Health. Journal of Invertebrate Pathology 186. https://doi.org/10.1016/j.jip.2021.107555

[873] Townhill, B.L., Tinker, J., Jones, M., Pitois, S., Creach, V., Simpson, S.D., Dye, S., Bear, E., Pinnegar, J.K., 2018. Harmful algal blooms and climate change: exploring future distribution changes. ICES Journal of Marine Science 75 (6). doi:10.1093/icesjms/fsy113

[874] See footnote 871

[875] Smaal, A.C., Ferreira, J.G., Grant, J., Petersen, J.K., Strand, O. (Eds), 2019. Goods and services of marine bivalves. Springer Open. https://doi.org/10.1007/978-3-319-96776-9

[876] Inaba, N., Trainer, V.L., Onishi, Y., Ishii, K.I., Wyllie-Echeverria, S., Imai, I., 2017. Algicidal and growth-inhibiting bacteria associated with seagrass and macroalgae beds in Puget Sound, WA, USA. Harmful Algae 62. http://dx.doi.org/10.1016/j.hal.2016.04.004

predators and competitors among other factors[877]. Massive aggregations can have impacts on tourism and leisure, fisheries and aquaculture, as well as on coastal industrial installations. Predation on jellyfish by fish or marine turtles can reduce the abundance of such species helping to keep ecosystems in balance[878,879];

- Macroalgae and seagrass can develop large deposits on beaches and in the surf zone of beaches, also referred to as wracks, fulfilling a number of ecological functions, including coastal protection from erosion, acting as a refuge for intertidal invertebrates or becoming a source of food and nutrients for marine ecosystems[880,881]. However, when these deposits accumulate in excessively large quantities, they can also have deleterious effects on underlying sediment processes, impacting shallow-water marine benthic communities[882]; hindering fishing activities through accumulation in nets[883,884], or preventing access to beaches by humans or by marine fauna, such as marine turtles for nesting[885]. Ecological balance therefore plays a key role to minimise their persistence;
- Microbial contamination can be introduced in marine and coastal ecosystems through sewage discharges, which can be incidental (e.g. insufficient capacity in urban infrastructure following an intense rainy event that causes overflows) or systematic (e.g. lack of appropriate wastewater treatment, from land sources or from ships). It transfers rapidly within food chains and/or through a number of transport vectors, including microplastic[886]. Seagrasses can have antibacterial and antifungal properties[887] that help to remove microbiological contamination from the water column, reducing exposure to bacterial pathogens, benefitting humans, fish or invertebrates among others[888]. The marine microbial community also provides critical detoxification services, including through the filtering of

[877] Bosch-Belmar, M., Milisenda, G., Basso, L., Doyle, T.K., Leone, A., Piraino, S., 2020. Jellyfish impacts on marine aquaculture and fisheries. Reviews in fisheries science and aquaculture 29 (2). https://doi.org/10.1080/23308249.2020.1806201

[878] See footnote 871

[879] Hays, G.C., Doyle, T.K., Houghton, J.D.R., 2018. A Paradigm Shift in the Trophic Importance of Jellyfish? Trends in Ecology & Evolution 33 (11). https://doi.org/10.1016/j.tree.2018.09.001

[880] Guerrero-Meseguer, L., Veiga, P., Rubal, M., 2020. Spatio-temporal variability of anthropogenic and natural wrack accumulations along the driftline: Marine litter overcomes wrack in the northern sandy beaches of Portugal. Journal of Marine Science Engineering 8 (12). https://doi.org/10.3390/jmse8120966

[881] Rodil, I.F., Lastra, M., López, J., Mucha, A.P., Fernandes, J.P., Fernandes, S.V., Olabarria, C., 2019. Sandy beaches as biogeochemical hotspots: the metabolic role of macroalgal wrack on low-productive shores. Ecosystems 22. Available at: https://link.springer.com

[882] Faria, J., Prestes, A.C.L., Moreu, I., Cacabelos, E., Martins, G.M., 2022. Dramatic changes in the structure of shallow-water marine benthic communities following the invasion by *Rugulopteryx okamurae* (*Dictyotales, Ochrophyta*) in Azores (NE Atlantic). Marine Pollution Bulleting 175. https://doi.org/10.1016/j.marpolbul.2022.113358

[883] Ruitton, S., Blanfuné, A., Boudouresque, C.F., Guilemain, D., Michotey, V., Roblet, S., Thibault, D., Thibault, T., Verlaque, M., 2021. Rapid Spread of the Invasive Brown Alga Rugulopteryx okamurae in a National Park in Provence (France, Mediterranean Sea). *Water 13*(16). https://doi.org/10.3390/w13162306

[884] Sempere-Valverde, J., García-Gómez, J.C., Ostalé-Valribieras, E., Martínez, M., Olaya-Ponzone, L., González, A.R., Sánchez-Moyano, E., Megina, C., Parada, J.A., Espinosa, F., 2019. expansion of the exotic brown algae *Rugulopteryx okamurae* (E.Y. Dawson) I.K. Hwang, W.J. Lee & H.S. Kim in the strait of Gibraltar. 1st Mediterranean Symposium on the Non-Indigenous Species (Antalya, Turkey, 17-18 January 2019). Available at: http://www.rac-spa.org

[885] Maurer, A.S., Stapleton, P., Layman, C.A., Burford Reiskind, M.O., 2021. The Atlantic *Sargassum* invasion impedes beach access for nesting sea turtles. Climate Change Ecology 2. https://doi.org/10.1016/j.ecochg.2021.100034

[886] Bowley, J., Baker-Austin, C., Porter, A., Hartnell, R., Lewis, C., 2021. Oceanic hitchhikers – Assessing pathogen risks from marine microplastic. Trends in Microbiology 29 (2). https://doi.org/10.1016/j.tim.2020.06.011

[887] United Nations Environment Programme, 2020. Out of the blue: The value of seagrasses to the environment and to people. UNEP, Nairobi. Available at: https://sapientia.ualg.pt

[888] Lamb, J.B., Van de Water, J.A.J.M., Bourne, D.G., Altier, C., Hein, M.Y., Fiorenza, E.A., Abu, N., Jompa, J., Harvell, C.D., 2017. Seagrass ecosystems reduce exposure to bacterial pathogens of humans, fishes, and invertebrates. Science 355. Available at: https://people.clas.ufl.edu

water, reducing effects of eutrophication and degrading toxic hydrocarbons[889], but this is separately covered under the Section on Water Purification Services - Retention and breakdown of organic pollutants including excess nutrients and inorganic pollutants (still pending).

7.5.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

The high occurrence of problematic pest organisms and pathogens can cause declines in native biodiversity, affecting a number of economic activities, and also have a direct impact on human wellbeing. The proliferation and spread of pests and pathogens can be facilitated by vessel movements, aquaculture and fishing practices, as well as incidental / systematic pollution events. This can be further exacerbated by climate change, habitat change and pollution, including in relation to non-indigenous species[890].

7.5.3 Description of methodology for monetisation incl. indicators used and data sources

Given the variety of biological control mechanisms, ecosystem components involved and wide range of resources that can be impacted[891], two examples available in literature have been used to exemplify the monetary value associated with biological control services:

- Economic impact of health costs associated with HAB:
- Baseline conditions are described based on global studies of HAB frequency and distribution[892] and using estimates derived by Kouakou and Poder (2019)[893];
- The Business as Usual (BAU) scenario is based on current HAB frequency and distribution, and associated health costs being maintained by 2050; and
- The Scaled-up Efforts (SUE) scenario is based on increased governance efforts aimed at reducing the health incidence of HAB being realised by 2050.
- Economic impact on fisheries and aquaculture associated with jellyfish blooms:
- Baseline conditions are described based on global studies of the impact of jellyfish blooms on fisheries and aquaculture activities[894];
- Given that no global estimates on the impact of jellyfish blooms have been found, no BAU / SUE scenarios have been established, but notes are made on the relationship between climate change trends and jellyfish blooms, and governance measures that may help to maximise benefits associated with the control of jellyfish blooms.

[889] Díaz, S., Tilman, D., Fargione, J., 2005. Biodiversity Regulation of Ecosystem Services. Chapter 11 in Ecosystems and Human Well-being: Current State and Trends, Volume 1 (Hassan, R., Scholes, R., Ash, N., Eds). Available at: https://www.millenniumassessment.org

[890] Atalah, J., Hopkins, G.A., Fletcher, L.M., Castinel, A., Forrest, B.M., 2015. Concepts for biocontrol in marine environments: is there a way forward? Management of Biological Invasions 6. 10.3391/mbi.2015.6.1.01

[891] Anderson, D.M., Fensin, E., Gobler, C.J., Hoeglund, A.E., Hubbard, K.A., Kulis, D.M., Landsberg, J.H., Lefebvre, K.A., Provoost, P., Richlen, M.L., Smith, J.L., Solow, A.R., Trainer, V.L., 2021. Marine harmful algal blooms (HABs) in the United States: History, current status and future trends. Harmful Algae 102. https://doi.org/10.1016/j.hal.2021.101975

[892] Hallegraeff, G., Anderson, D.M., Belin, C., Dechraoui Bottein, M.Y., Bresnan, E., Chinain, M., Enevoldsen, H., Iwataki, M., Karlson, B., McKenzie, C.H., Sunesen, I., Pitcher, G.C., Provoost, P., Richardson, A., Schweibold, L., Tester, P.A., Trainer, V.L., Yñiguez, A.T., Zingone, A., 2021. Perceived global increase in algal blooms is attributable to intensified monitoring and emerging bloom impacts. Communications Earth & Environment 2 (117). Available at: https://www.nature.com

[893] Kouakou, C.R.C. and Poder, T.G., 2019. Economic impact of harmful algal blooms on human health. A systematic review. Journal of Water & Health 17 (4). https://doi.org/10.2166/wh.2019.064

[894] See footnote 875

7.5.4 Assessment of reliability and robustness of methodology and data sources

The assessment presented in this section is based on information provided by secondary sources, which apply the "avoided damage" valuation approach, i.e. use the cost of damages prevented by a given ecosystem to estimate the value of the resulting benefits, in this case biological control services that reduce HAB and jellyfish bloom incidence. However, it should be noted that only two examples are used to exemplify the value of these services, and that the source of primary data used as a basis may have a number of geographical and contextual bias. It should also be noted that there are a significant number of benefits to health and different economic sectors related to the biological control role that these and a number of other marine organisms play.

7.5.5 Description of the baseline (method and results)

Hallegraeff *et al.* 2021[895] explored different databases on the geographic range of harmful algal species, finding that the largest number of records available is in Europe, followed by North Asia, the Mediterranean and North America, which can be related to monitoring and reporting efforts. Records available show that harmful algae lead to a range of events, namely the release of high phytoplankton counts and seafood toxins, and of the latter, Diarrhetic Shellfish Toxins (DST) is found to be the most frequently toxin recorded in Europe and the Mediterranean, whilst Paralytic Shellfish Toxins (PST) prevails in North and South America, the Caribbean, as well as North and South-East Asia, as shown in the Figure overleaf.

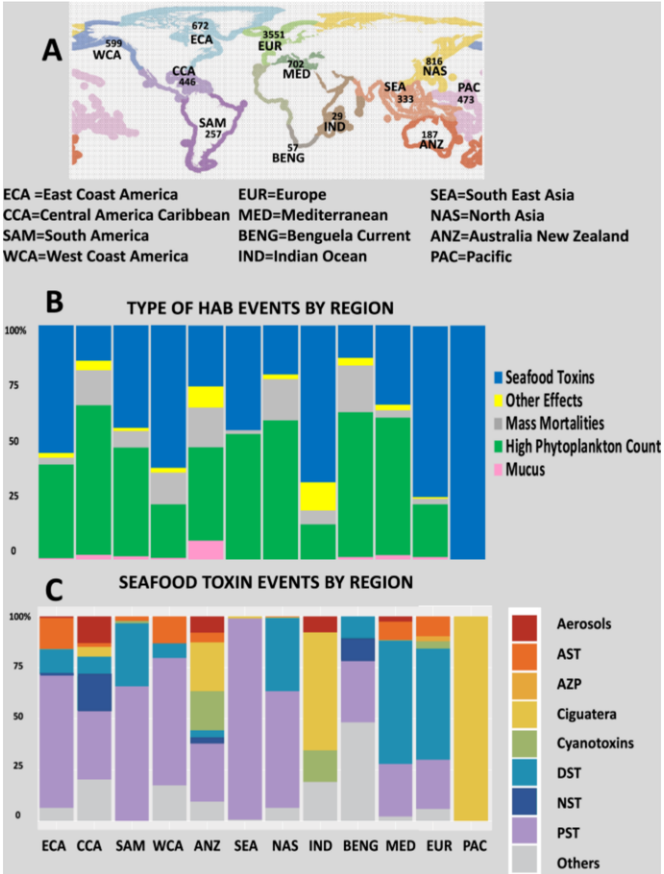
Kouakou and Poder (2019)[896] estimated that the economic impact of HAB on human health could have a global burden of €25.7 million[897] every year, based on the assumption of 1,000 human infections per year (and that of these only 1% result in death, 24% result in a moderate case of illness and 75% result in mild cases of illness).

[895] See footnote 883

[896] See footnote 893

[897] Conversion from 2016 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846

Figure 5.56 Relative abundance in different geographic regions of types of harmful algal phenomena and types of seafood toxin syndromes.



Source: Hallegraeff et al. 2021.

7.5.6 Description of the" business as usual" (BAU) scenario (method and results)

While observational datasets in some regions indicate temporal trends of increasing HABs, other regions show HABs to be decreasing. However, these findings are limited by geographic variations in sampling efforts and limitations of existing long-term observations[892]. Overall, there is growing observational evidence and mechanistic understanding that climate change will alter the frequency, severity, timing and spatial patterns of some HAB species but not others[898].

Accordingly, it has been assumed that under a BAU scenario, the number of human infections per year would be maintained and so would the annual average cost estimated for the baseline scenario (€25.7 million) in 2050.

7.5.7 Description of the "scaled up efforts" scenario (method and results)

Under a SUE scenario, governance and policy mechanisms would be envisaged to introduce measures known to favour the reduction of HAB events, or at least the extent to which these could lead to human infections. These include:

- Significantly reducing the input of substances leading to eutrophication;

[898] GlobalHAB. 2021. Guidelines for the Study of Climate Change Effects on HABs. Paris, UNESCO-IOC/SCOR. M. Wells *et al.* (eds.) (IOC Manuals and Guides no 88). Available at: https://oceanexpert.org

- Protection and enhancement of biodiversity to maintain a healthy balance in marine and coastal ecosystems, as Resistance to invasions and diseases tends to increase, together with productivity or nutrient retention, with increasing species numbers[899];
- Promoting the uptake of natural filtration systems, particularly within the vicinity of vulnerable areas, including through constructed wetlands, restored bivalve reefs, which are widely used to remove human pathogenic microorganisms from terrestrial effluent[900];
- Promoting the introduction of health warning systems in higher risk areas by involving not only the public health authorities, but also community planners, utility managers and designers, supporting and expanding, at the same time, a global HAB monitoring network[901].

7.5.8 Description of the baseline

The global impact of jellyfish blooms on fisheries and aquaculture has been studied by Bosch-Belmar *et al.* 2020[877], who found that:

- The most common taxa reported to interfere with fisheries include *Aurelia spp.*, *Chrysaoora spp.*, and *Nemopilema nomurai*, with 60% of reports notified in the North Pacific region (where the highest marine capture production is concentrated), followed by the Mediterranean Sea (19%) and in relation trawling (58%) and set net (33%) fishing methods. Main impacts include the damage of catch and the damage or clogging of nets, but also indirect effects through food webs and reduction in fish catches due to food competition or fish eggs and larvae predation. For instance, in Japan, economic losses associated with *N. nomurai* was estimated at c. €230 million[902] between 2005 and 2006. Economic losses due to a reduction in fish catches attributed to jellyfish blooms in the northern Adriatic trawling fleet has been estimated at €8.2 million[903] per year[904];
- The most common taxa reported to interfere with aquaculture include *Pelagia noctiluca* and *Aurelia spp,* with 60% of reports notified in the North Atlantic region, followed by the South Pacific (17%) and Mediterranean Sea (14%) particularly affecting salmon farms. Main impacts include fish mortality, gill and skin damage and growth reduction and structural damages to a lesser extent. As an example, Irish and Scottish aquaculture have suffered up to €1.1 million[905] in losses due to mass salmon mortalities caused by *P. noctiluca* invasions[906].
- Jellyfish may also be regarded as a target species for aquaculture (including for direct / indirect food provisioning services) and for marine genetic resources (e.g. they contain bioactive molecules of interest to a number of industries). A more realistic picture of the impacts of jellyfish on fishery and aquaculture could be obtained taking these aspects in consideration[907].

[899] See footnote 889

[900] See footnote 875

[901] See footnote 887

[902] Conversion from 2004 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846

[903] Conversion from 2013 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846

[904] See footnote 877

[905] Conversion from 2016 US$ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov, and 2021 yearly average US$/EUR exchange rate of 0.846

[906] See footnote 877

[907] See footnote 876

7.5.9 BAU and SUE scenarios

Future scenarios of climate change and ocean warming foresee the increasing frequency of jellyfish blooms as a potential driver of negative impacts on fishery and aquaculture, which may also be a symptom of marine ecosystems in distress. Jellyfish may also establish different links between the two sectors.

More responsible fishery activities (i.e., reducing overfishing, responsible use of sustainable resources) may gradually keep jellyfish blooms in check (by increased fish predation and competition for zooplankton food), so reducing jellyfish-related pressures and risks for aquaculture.

7.6 Pollination Services

7.6.1 Description of Ecosystem Service / Benefit and Impact

The SEEA-EA framework defines pollination services as 'the ecosystem contributions by wild pollinators to the fertilization of crops that maintains or increases the abundance and/or diversity of other species that economic units use or enjoy'. They can be recorded as final or intermediate services, although for marine ecosystems they have been referred to as ecological functions that generate final ecosystem services[908], i.e., intermediate services.

There is extensive literature[909,910,911,912] on the role that pollinators have in the provisioning of food, raw products and further ecosystem services, with global values based on pollinator-dependent crops estimated using different methods.

Although most of these studies focus on pollinators across different terrestrial ecosystem types (e.g. mainly crop pollination), there are a number of marine ecosystems that can also rely on biotic pollination, particularly in the absence of wind or water flows (i.e. abiotic pollination independent of ecosystem condition). This includes seagrasses, which form extensive meadows in shallow waters, and are considered amongst the world's most productive ecosystems, providing a number of ecosystem services, including carbon sequestration, soil stabilisation, water purification, and habitat maintenance for a number of coastal and marine organisms[913].

Although seagrasses are clonal plants, flowering and associated sexual reproduction increases genetic diversity, particularly important for re-colonization after major disturbances and maintaining the gene-flow and connectivity among different populations[914,].

908 United Nations, 2021. System of Environmental-Economic Accounting—Ecosystem Accounting: Final Draft (Vol. 3, Issue March). Available at: https://unstats.un.org

909 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), 2019. Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. Available at: https://ipbes.net

910 Bartholomee, O., Lavorel, S., 2019. Disentangling the diversity of definitions for the pollination ecosystem service and associated estimation methods. Ecological Indicators, 107 https://doi.org/10.1016/j.ecolind.2019.105576

911 Guimaraes Porto, R., Fernandes de Almeida, R., Cruz-Neto, O., Tabarelli, M., Felipe Viana, B., Peres, C.A., Lopes, A.V., 2020. Pollination ecosystem services. A comprehensive review of economic values, research funding and policy actions. Food security 12. https://doi.org/10.1007/s12571-020-01043-w

912 Wojcik, V., 2020. Ecosystem Services: Pollinators and Pollination. Chapter in Terrestrial Ecosystems and Biodiversity, Wang, Y. (Ed) https://doi.org/10.1201/9780429445651

913 Van Tussenbroek, B.I., Villamil, N., Marquez-Guzman, J., Wong, R., Monroy-Velazquez, V., Solis-Weiss, V., 2016. Experimental evidence of pollination in marine flowers by invertebrate fauna. Nature Communications 1, 12980. https://doi.org/10.1038/ncomms12980

914 See footnote 913

Marine biotic pollination and seed dispersal has been linked to marine invertebrates[915] but also to marine mammals and marine turtles[916,917]. Many migratory seabirds are also known to greatly contribute to long-distance seed dispersal, benefitting a number of coastal but also terrestrial ecosystems[918,919]. In addition, terrestrial biotic pollination and seed dispersal (through insects, mammals and birds among others) play an important role in coastal ecosystems, including mangroves[920], salt marshes and vegetation in sandbanks, mudflats and sandflats[921]. The actual contribution of biotic pollination versus abiotic pollination is likely to depend on a number of environmental settings[922]. Interactions in some ecosystem types, such as salt marsh are not well known[921923]. No attempts to estimate the value of this ecosystem service in marine and coastal environments have been found.

7.6.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Abiotic pollination and larval dispersal are vulnerable to changes in water temperature and/or current speeds[924], which can be affected by climate change effects.

The condition and abundance of key pollinators influences the extent to which these can perform their function, and accordingly the long-term protection and maintenance of coastal and marine ecosystems should include appropriate conservation of these species[925].

7.6.3 Description of methodology for monetisation incl. indicators used and data sources

Whilst the primary focus of ecosystem accounting is on the measurement of final ecosystem services, and it has not been possible to estimate the current value of marine and coastal pollination services due to a lack of data, this short section has described the importance of pollination in marine and coastal ecosystems, underlying ecosystem characteristics and processes as well as dependencies between different ecosystem types, which are important to acknowledge[926].

915 See footnote 913

916 See footnote

917 Tol, S.J., Jarvis, J.C., York, P.H., Grech, A., Congdon, B.C., Coles, R.G., 2017. Long distance biotic dispersal of tropical seagrass seeds by marine mega-herbivores. Scientific Reports 7. DOI: 10.4225/28/57ABBA449E639.

918 Kleyheeg, E., Fiedler, W., Saf, K., Waldenstrom, J., Wikelski, M., Liduine van Toor, M., 2019. A comprehensive model for the quantitative estimation of seed dispersal by migratory mallards. Frontiers in Ecology and Evolution 26. https://doi.org/10.3389/fevo.2019.00040

919 Lovas-Kiss, A., Sánchez, M.I., Coughlan, N.E., Alves, J.A., Green, A.J., 2018. Shorebirds as important vectors for plant dispersal in Europe. Ecography 42 (5). https://doi.org/10.1111/ecog.04065

920 Chakraborti, U., Mitra, B., Bhadra, K., 2019. Diversity and ecological role of insect flower visitors in the pollination of mangroves from the Indian Sundarbans. Current Science. DOI: 10.18520/cs/v117/i6/1060-1070

921 Fantinato, E., Buffa, G., 2019. Animal-mediated interactions for pollination in salt marsh communities. Plant Sociology 56 (2). DOI: 10.7338/pls2019562/02

922 See footnote 913

923 See footnote 921

924 Álvarez-Noriega, M., Burgess, S.C., Buers, J.E., Pringle, J.M., Wares, J.P., Marshall, D.J., 2020. Global biogeography of marine dispersal potential. Nature Ecology and Evolution 4. https://doi.org/10.1038/s41559-020-1238-y

925 See footnote

926 See footnote 908

8. Cultural ecosystem services

8.1 Cultural Services – Recreation-related Services

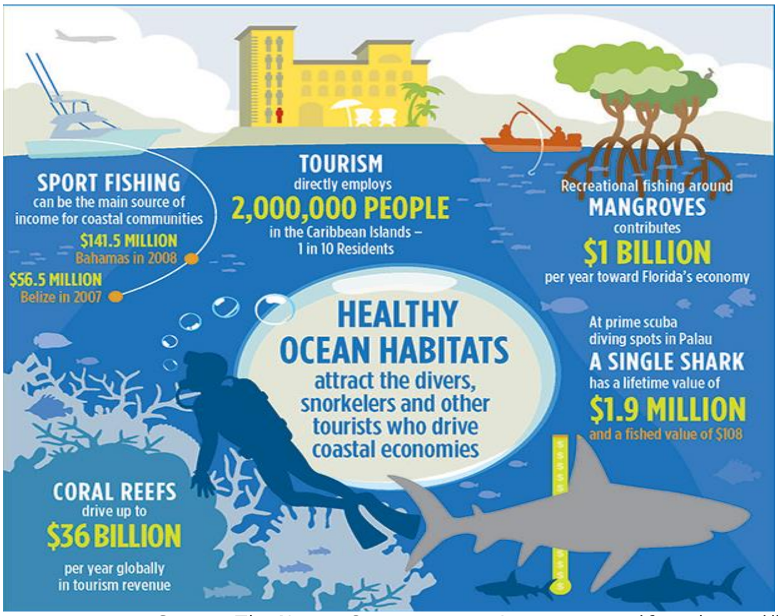
8.1.1 Description of Ecosystem Service / Benefit and Impact

The SEEA-EA framework[927] defines recreation-related services as 'the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use and enjoy the environment through direct, in-situ, physical and experiential interactions with the environment. This includes services to both locals and non-locals (i.e. visitors, including tourists)'.

This definition reflects that tourism can be analysed both as a cultural service, but also as an economic industry whose main function is converting natural supplies into goods and services[928].

There are a number of activities associated with recreation-related services provided by marine and coastal ecosystems, such as water-based sports, recreational fishing or wildlife fishing among others, some examples and their economic contribution illustrated in the Figure below.

Figure 5.57 Economic contribution of coastal tourism to the economy.



Source: The Nature Conservancy; picture accessed from https://blogs.worldbank.org

[927] United Nations, 2021. System of Environmental-Economic Accounting—Ecosystem Accounting: Final Draft (Vol. 3, Issue March).

[928] Pueyo-Ros, J., 2018. The role of tourism in the ecosystem services framework. Land 7 (3). Available at: https://www.researchgate.net

8.1.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Climate change, pollution and tourism are perceived to be the biggest threats to marine ecosystems[929].

Besides plastic pollution, coastal tourism is observed to be a direct contributor to aesthetic pollution, degradation of water quality, damage to marine habitats, as well as changes in animal behaviour.[930] For instance, Maya Bay, one of Thailand's most famous beach attractions for two decades, had to be shut down for more than three years, as overcrowding from tourism had caused damage to the beach and marine ecosystem. It was assessed that more than 80% of the coral around the bay had been destroyed by pollution from litter, boats and sunscreen. The local government decided to close the Bay to tourists indefinitely as of 2018 until the ecosystem "fully recovers to a normal situation". However, as coral grows only about 0.5cm per year, this was predicted to be a very lengthy process.[931] As of January 2022, the bay re-opened, but under very strict conditions and with only minimal tourism allowed.[932]

Another area that is gravely affected by pollution is the Black Sea. Besides direct pollution from the coast, the Danube River, representing 58% of the total effluents to the Sea, collects water from 120 rivers. Each of these rivers brings between 6 and 50 pieces of litter into the sea every hour. Furthermore, there is an increased danger of pollution with inorganic nutrients, heavy metals, oil residues, pesticides, insecticides, or industrial and household waste.[933] Research performed in 2021 on the Turkish coast found around 2500 pieces of waste per 500 square meters, with more than 125 face masks, across more than 1320km of Turkish territory, all washed ashore from the Black Sea.[934][935] This is a major contributor to the economic losses in Turkey (~€84 million) as it affects the tourism, shipping and fishing economies[936]. The situation is not different in Romania. However, over the past decade, Romania has invested heavily in improving its beaches and cleaning up the Black Sea, leading to increases in tourism of more than 45% in 10 years, before the start of the pandemic. This was prompted by a 2009 government policy titled "Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea".

[929] https://om.ciheam.org/om/pdf/a57/04001977.pdf

[930] https://elibrary.gbrmpa.gov.au/jspui/handle/11017/3474

[931] https://www.weforum.org/agenda/2018/10/thailand-is-closing-its-iconic-bay-from-the-beach-after-a-temporary-pause-in-visitors-wasnt-enough-to-repair-destruction-by-tourists

[932] https://edition.cnn.com/travel/article/thailand-maya-bay-reopening/index.html

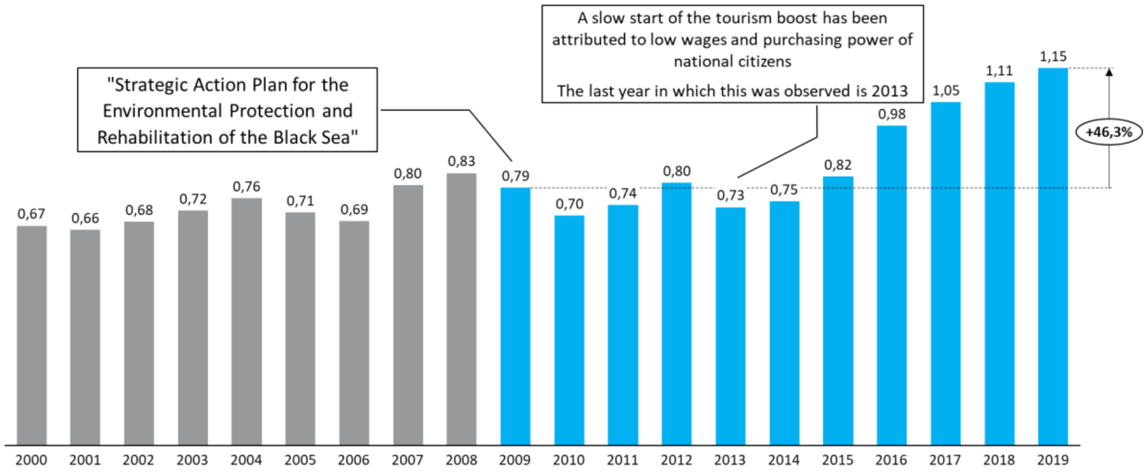
[933] https://www.spiritbsb.online/sources-of-pollution-and-pollutants-from-the-coastal-area-of-%E2%80%8B%E2%80%8Bthe-black-sea-in-romania/

[934] https://www.dailysabah.com/turkey/plastic-pollution-threatens-turkeys-black-sea-coastline/news

[935] https://tudav.org/wp-content/uploads/2020/10/MarineLitterintheBlackSea_tudav.pdf

[936] https://wwfeu.awsassets.panda.org/downloads/05062019_wwf_turkey_guidebook.pdf

Figure 5.58 Number of tourists on Romanian beaches (in million).



Source: National Statistics Institute

It can thus be seen that there is a circular relationship between tourism and ecosystem health or pollution. Ecosystems in good health attract tourists, which, in turn, harm the ecosystems and cause pollution. As this happens, tourists no longer visit those destinations. Consequently, ocean governance needs to target the ecosystem and tourism simultaneously and be location-specific, as some geographies may benefit from increased ("green") tourism while some may require a reduction of it altogether.

8.1.3 Description of methodology for monetisation incl. indicators used and data sources

The focus of valuating recreation-related services should be made in relation to the contribution of ecosystem services to the economic value of the recreational use of the environment. However, the consumption expenditure of tourists, tourism revenues or the employment impact of tourism[937] can also be used as a proxy. The monetisation of recreation-related services uses Europe as a case study, selected due to data availability. Results are then extrapolated to the rest of the world to produce an indicative picture of global developments. Most data pertaining to Europe's coastal tourism is extracted from Eurostat, while more specific breakdowns of tourism spending and gross value added (GVA) are based on the EU Blue Economy Report of 2021[938] and the (UN)WTO. The effect of ocean governance in this sector will be assessed as the economic gain or loss from an increase or decrease in tourism due to governance policies, respectively.

Moreover, a model is developed with focus on plastic pollution as a quantifiable negative effect of tourism. In order to assess the cost of tourism in terms of pollution, we employ Deloitte's report "The price tag of plastic pollution"[939] and forecast the development of this cost given the predicted evolution of coastal tourism. The associated indicator for the monetisation of plastic pollution consists of two factors:

- the cost of removing the plastic from the ocean, and

[937] Hasler, B., Ahtiainen, H., Hasselström, L., Heiskanen, A.S., Soutukorva, A., Martinsen, L, 2016. Marine ecosystem services in Nordic marine waters and the Baltic Sea – possibilities for valuation. Available at: https://norden.diva-portal.org

[938] https://ec.europa.eu/oceans-and-fisheries/system/files/2021-05/the-eu-blue-economy-report-2021_en.pdf

[939] https://www2.deloitte.com/content/dam/Deloitte/my/Documents/risk/my-risk-sdg14-the-price-tag-of-plastic-pollution.pdf

- the loss in economic value caused by the pollution.

In order to monetise the economic impacts (benefits and costs) of pollution on the coastal the tourism sector, the input-output (I-O) model is employed. The basis of this model is the linkage and inter-connection of economic sectors relevant to tourism. I-O tables compile industrial activity across sectors in a matrix of monetary transactions[940]. These tables are published at the national level by the local government or are aggregated at the European level.

The driving factor of the model is the concept that currency spent in one sector will be later re-distributed to other sectors, re-entering the economy and creating more value-add as a multiplier to the initial spending.

The I-O table used for this model represents the EU27 economy in 2019 and is extracted from Eurostat. This table covers a wide spectrum of economies providing a reliable estimate for the worldwide spectrum, in absence of a global (I-O) matrix.

Furthermore, a qualitative discussion is included, in which we discuss necessary considerations for the implementation of ocean governance within the context of coastal tourism.

8.1.4 Assessment of reliability and robustness of methodology and data sources

Robustness in the context of the analysis refers to the degree of reliability of the end results based on the variance in inputs, as well as the inclusion of sufficient indicators.

Robustness issues in the analysis predominantly stem from the infeasibility of quantifying many of the aspects pertinent to coastal tourism, given the scope of the research. This includes challenges in the quantification of some indicators linking tourism, associated impacts and economic implications. Similarly, the monetary impact of some impacts cannot be assessed. For instance, while it would be possible to estimate the effect of coastal tourism on inflation, it is infeasible to ascertain the impact of this change on the overall economy.

The Table below identifies some impacts of tourism on the local economy of the destination, used to select the link between (plastic) pollution and coastal tourism as an indicator for further analysis.

Table 5.11 List of impacts of coastal tourism

Environmental impacts	Economic impacts	Socio-cultural impacts
Pollution	Degradation of infrastructure	Inflation
Infrastructure	Touristification of residential areas	Economic dependence on tourism
Visual	Marginalisation of residents	Infrastructure cost
Congestion	Hostility	Accessibility
Damage	Criminality	Destination image
Overcrowding	Modification of recreational area	
	Loss of cultural identity	

Source: Overtourism: impact and possible policy responses, European Parliament, 2018. See: https://www.europarl.europa.eu/RegData/etudes/STUD/2018/629184/IPOL_STU(2018)629184_EN.pdf

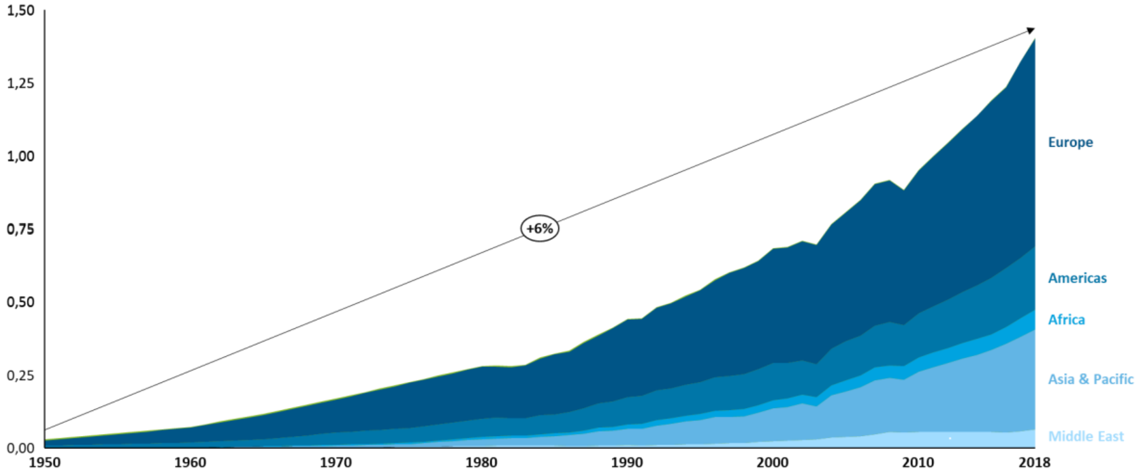
The data sources for the quantitative analysis were carefully reviewed and selected. Most data, as well as the I-O matrix, were retrieved from Eurostat. Any additional assumptions or inputs, whenever relevant, were based on reports and datasets published by reliable sources, such as the European Commission or recent Deloitte reports.

[940] https://www.researchgate.net/publication/261175197_Input-Output_Models

Description of the baseline

Tourism is a major part of the global economy. It has been increasing by more than 6% per year and has multiplied more than 55 times since the 1950s. Europe is the leading region, having multiplied more than 42 times since the 1950s and representing 50% of tourist arrivals in 2018.

Figure.5.59 Number of international tourist arrivals by region per year (in billions). Source: UNWTO



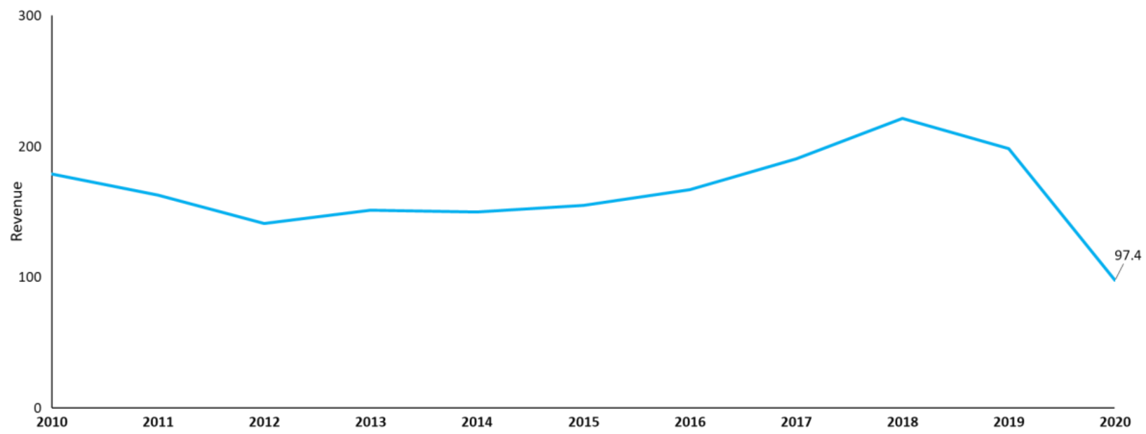
It is estimated that 80% of global tourism occurs in coastal areas. Within Europe, coastal tourism already is the largest sector, employing more than 2.1 million people and being responsible for 40% of GVA and 60% of employment in the Blue Economy[941] (see Figure.5.60). While coastal municipalities make up only 15% of the land area of the EU, 47% of all nights of tourist paid accommodation occur there[942].

Figure.5.60 Assessed economic impact of coastal tourism in the EU (Revenue billion EUR)[943]. Source: Eurostat, Blue Economy report 2021

941 The Blue Economy is the "sustainable use of ocean resources for economic growth, improved livelihoods, and jobs while preserving the health of ocean ecosystem" (World Bank 2017, https://www.worldbank.org/en/news/infographic/2017/06/06/blue-economy); https://ec.europa.eu/oceans-and-fisheries/system/files/2021-05/the-eu-blue-economy-report-2021_en.pdf

942 https://www.espon.eu/what-are-main-impacts-coastal-tourism

943 Blue Economy report 2021 –https://op.europa.eu/en/publication-detail/-/publication/0b0c5bfd-c737-11eb-a925-01aa75ed71a1 - The figures computed for 2019 and 2021 assumes constant prices, thus excluding inflation.

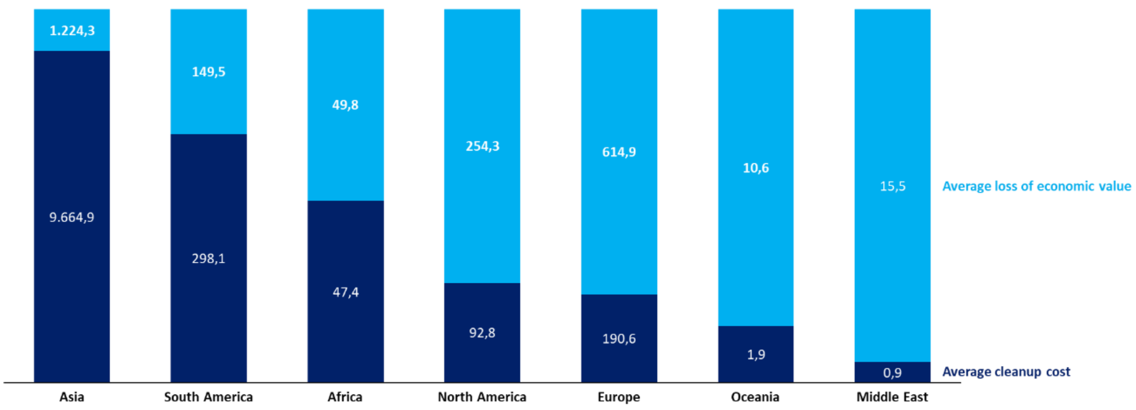


Impact of plastic pollution on Tourism

Tourism is a known contributor to pollution and ecosystem degradation. During peak tourist seasons, there is an increase of 40% of plastic discarded, contributing to over 8 million tonnes of plastic ending up in the oceans each year. [944] Most of the plastic that ends up in the ocean flows from inland through rivers. Although the plastic in the oceans comes from inland, it impacts the recreation related services in the ocean and this should be accounted within the assessment.

The estimated the cost of river plastic pollution by region can be seen in the following Figure. For each region indicated in the figure, a distribution of plastic clean-up costs, as well as potential loss of economic value on a number of sectors, including coastal tourism, due[945] to the plastic, is displayed as a percentage. Notably, the cost varies significantly by region, but so does the distribution of the total cost across the two components. It can be seen for the Middle East, Oceania and Europe and North America, the average clean-up costs mitigate a significant marginal loss of economic value.

Figure.5.61 Overview of the cost components in 2018 by region, (in million USD).



[944] https://www.wwf.org.uk/updates/tourists-cause-almost-40-spike-plastic-entering-mediterranean-sea-each-summer

[945] the loss in economic value is modelled by analysing the fisheries and aquaculture revenue of a country and allocating a loss percentage in the range of 0.3 to 5% (Takehama 1990, Ten Brink et al 2009). Similar to potential loss of economic value for tourism, an uncertainty range is considered instead of a fixed value to ensure the exploratory nature of the model and account for regional and national differences.

Source: Deloitte 2021, "The price tag of plastic pollution: An economic assessment of river plastic"

At the same time, plastic pollution and ecosystem degradation have been shown to have negative impacts on tourism. A study performed by the WWF estimated that plastic pollution in the Mediterranean causes the tourism sector to lose up to 268 million EUR per year[946]. Similarly, the Australian government has directly linked the ecosystem health of the Great Barrier Reef to a decrease in tourism, stating that "The Reef's health is critically important to the stability and value of the Reef tourism industry. Declines in Reef health […] have significantly impacted tourism visitation."[947] The statement was mentioned in relation to the observation post cyclone Debbie that damaged a part of the Reef in 2017. Tourist numbers decreased by more than 32% in the two following years.[948] In 2016, before the cyclone, the Reef contributed $6,4 billion to the total value added of the country and provided 64.000 jobs, 90% of which in the tourism industry[949].

Impact of Ocean Governance on pollution

Evidence how Ocean Governance impacts pollution and, therefore, indirectly impacts tourism, is demonstrated via an example in France. In 2013, the Étang de Berre and Bolmon belonged to the IUCN Red List of Ecosystems. The waters were filled with industrial waste and debris, with some parts of the water being red due to the chemical spills from nearby factories. However, due to local governance, the area has been improved and thus removed from the Red List. By 2021, the Belmond Pond Loop has become a popular hiking trail for tourists.[950]

Barbados is one of the few global "million-dollar reefs", meaning that it generates more than one million USD per square km. Nearly 40% of all national employment and economic activity revolves around tourism and the vast majority of it occurs along the coast. This causes environmental pressures, such as overfishing, coastal overdevelopment, pollution, and climate threats, and research indicates that tourists may not return to the island if the ecosystems are damaged.[951] Through the data collected, it is observed that tourists are willing to pay environmental levy upon visiting, in order to preserve the local ecosystem. The willingness to pay of the tourists as a function of the levy amount is shown in the figure below. As the levy amount increases, the willingness of the tourists to pay reduces, which can be expected. However, this provides valuable insight into the possibility of distribution of costs fairly to protect the local ecosystem

[946] https://www.wwf.fr/sites/default/files/doc-2019-06/20190607_Rapport_Stoppons_le_torrent_de_plastique_WWF-min.pdf

[947] Great Barrier Reef Marine Park Authority, 2021

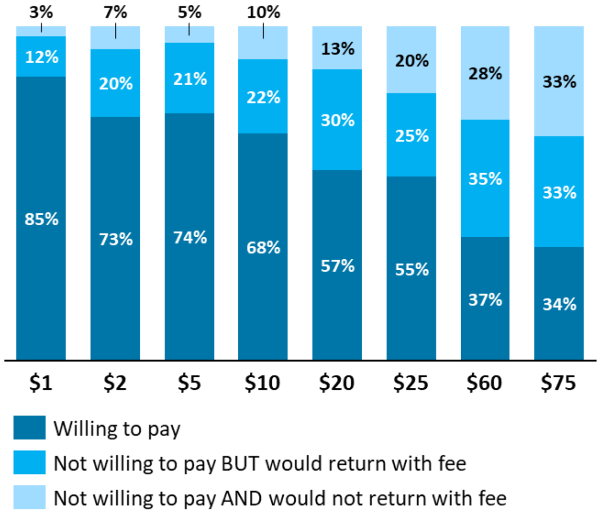
[948] https://www.gbrmpa.gov.au/our-work/Managing-multiple-uses/tourism-on-the-great-barrier-reef/numbers

[949] https://www2.deloitte.com/au/en/pages/economics/articles/great-barrier-reef.html

[950] https://www.alltrails.com/trail/france/bouches-du-rhone/tour-de-l-etang-de-bolmon/photos

[951] https://www.wri.org/insights/maintaining-million-dollar-reefs-and-beaches-barbados-and-beyond

Figure.5.62 Tourists in Barbados willing to pay an environmental fee based on fee amount, in %. Total number of respondents: 2.907



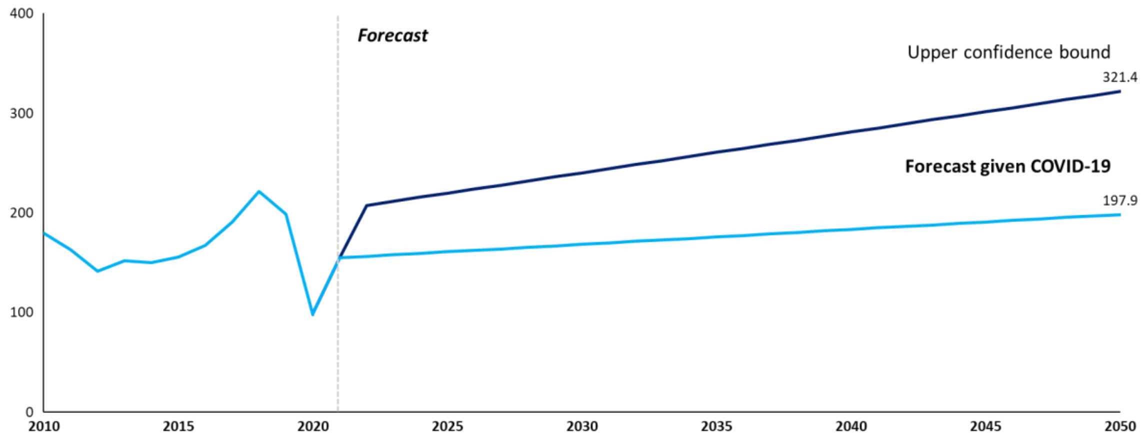
Source: World Resources Institute, based on Schumann et al. (2017)

8.1.5 Description of the "business as usual" scenario (method and results)

In Europe, coastal tourism is expected to grow by more than 3.5% and to become the largest value-adding segment of the ocean economy by 2030[952].

The "business as usual" scenario follows the current trends and potential developments of the industry when projected for 2050. The Figure below shows historical data about the economic value of coastal tourism in the EU, as well as potential forecasts. In particular, the forecast line represents a slow recovery of the economy, despite the persistent existence of the COVID-19 virus. The upper confidence bound is a forecast fully excluding 2020 and 2021, and assuming full and immediate recovery from the virus in 2022. This interval includes the most probable developments in the industry, such as the potential re-opening of the global economy only after some years, or, alternatively, the immediate re-opening followed by a new lockdown.

Figure 5.63 (Predicted) economic impact of the coastal tourism industry in the EU (€ billion)

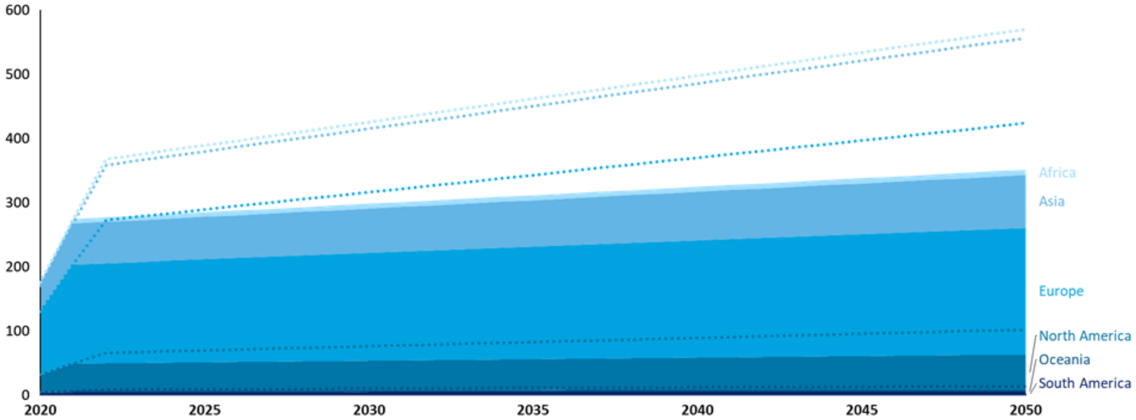


[952] https://blogs.worldbank.org/voices/Sustainable-Tourism-Can-Drive-the-Blue-Economy

Source: Eurostat, EU Blue Economy Report 2021, and Deloitte analysis[953]

Using the data from Europe, the following Figure extrapolates the results to other continents, by proportionally estimating the number of tourists in these regions and adjusting their estimated economic impact by the average local prices[954].

Figure 5.64 Predicted economic impact of the coastal tourism industry per region (€ billion).



. Source: World Bank, and Deloitte analysis
Note: the dotted lines represent the upper confidence interval per continent, with the colours matching those of the forecast

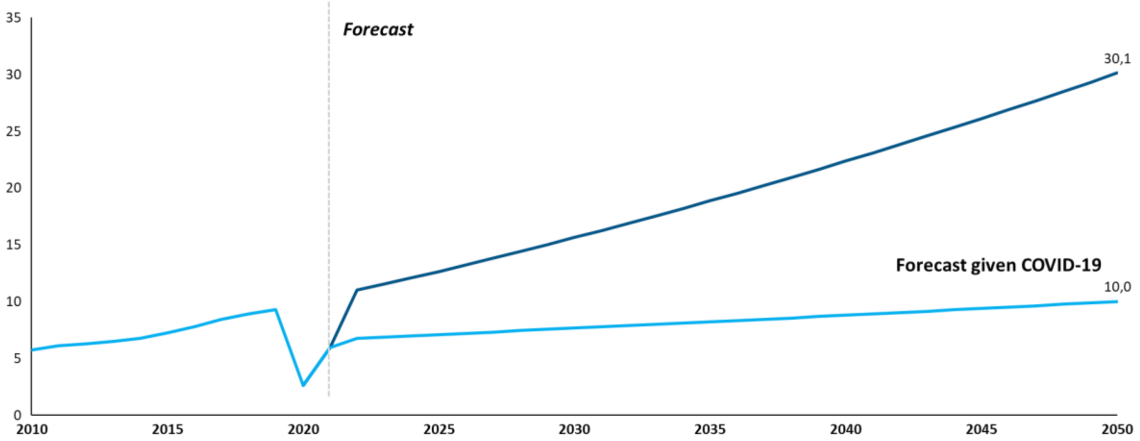
As can be expected, these increases in tourism (number of tourists) are associated with higher costs, including the costs to manage plastic pollution (both for clean-up and the loss of economic value).

The costs of managing pollution increase exponentially with increase in tourism, making it increasingly difficult to allocate sufficient resources. The Figure below estimates the cost of removing plastic litter caused by Europe from the oceans under the two scenarios presented above.

[953] Coastal tourism as defrined in the Blue Economy report 2021; Coastal tourism covers beach-based tourism and recreational activities, e.g. swimming, sunbathing, and other activ-ities for which the proximity of the sea is an advantage, such as coastal walks and wildlife watching; while Maritime tourism covers water-based activities and nautical sports, such as sailing, scuba diving and cruising (see 4.7.7). In the Blue Economy report, coastal tourism also covers maritime tourism and is broken down into three main sub-sectors: (1) Accommodation, (2) Transport and (3) Other expenditures

[954] The model used is available upon request

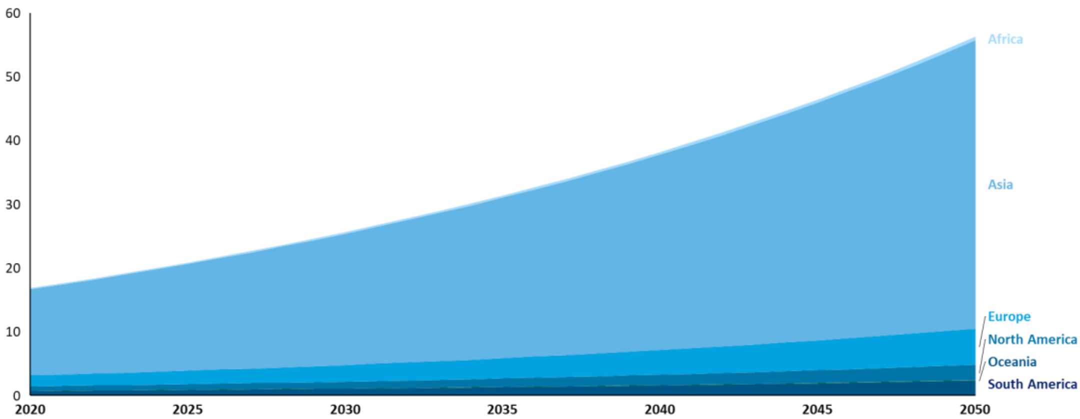
Figure 5.65 (Predicted) cost of managing plastic pollution in Europe, given expected tourism (€ billion)



Source: Eurostat, Deloitte 2021 "The price tag of plastic pollution: An economic assessment of river plastic" and Deloitte analysis

Similarly, the Figure below shows the estimated forecast for other regions based on the extrapolation of the results from Europe,[955]

Figure 5.66 Predicted cost of reducing plastic pollution by region (€ billion).



Source: World Bank, Deloitte 2021 "The price tag of plastic pollution: An economic assessment of river plastic" and Deloitte analysis

8.1.6 Specific considerations for calculating the "scaled up efforts" scenario

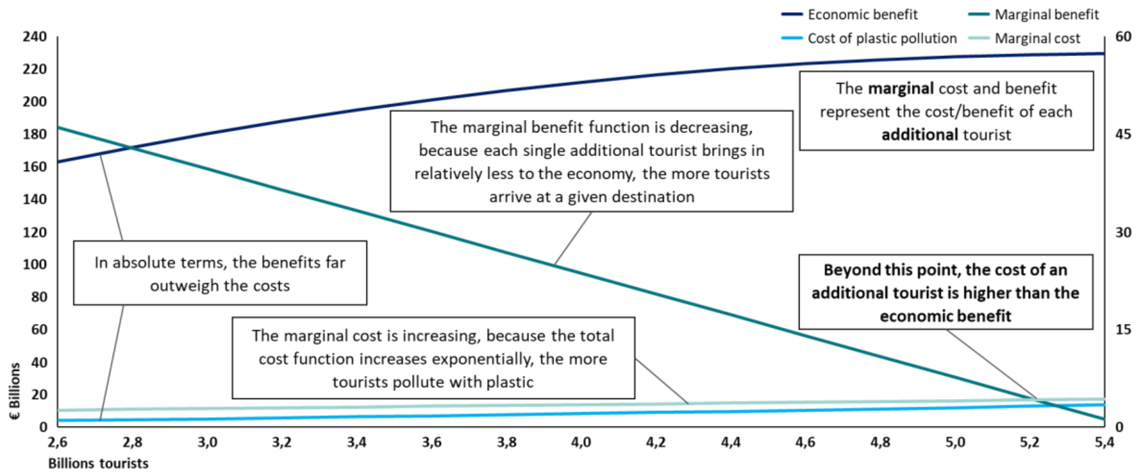
The scaled-up efforts scenario aims to balance the costs and benefits of ocean governance and to identify an optimal mix of policies. This approach focuses on the economic concept of marginal costs and benefits. While the usual functions express the total value of costs and benefits for a certain number of tourists, the marginal functions express the change in these figures caused by a single additional tourist at each level. The following Figure explains this further, where the total benefits far outweigh the costs, regardless of the number of tourists.[956] However, looking at the marginal figures, we see that the benefit per additional tourist is rapidly decreasing, while the cost is steadily increasing. At some point, at slightly above 5.2 billion

[955] The extrapolation was chosen as a method to estimate the cost due to data availability issues across other regions than Europe.

[956] Strictly speaking, at much higher numbers, the costs will eventually outweigh the benefits due to their exponential factor, but that number is too far out of the range of consideration.

tourists per year, the cost of an additional tourist will be higher than the economic gain. Assessing the economic benefits of tourism and comparing them to the identified costs, it is observed that, in case of Europe, there is a point beyond which an additional tourist night costs more than the economic value it brings.

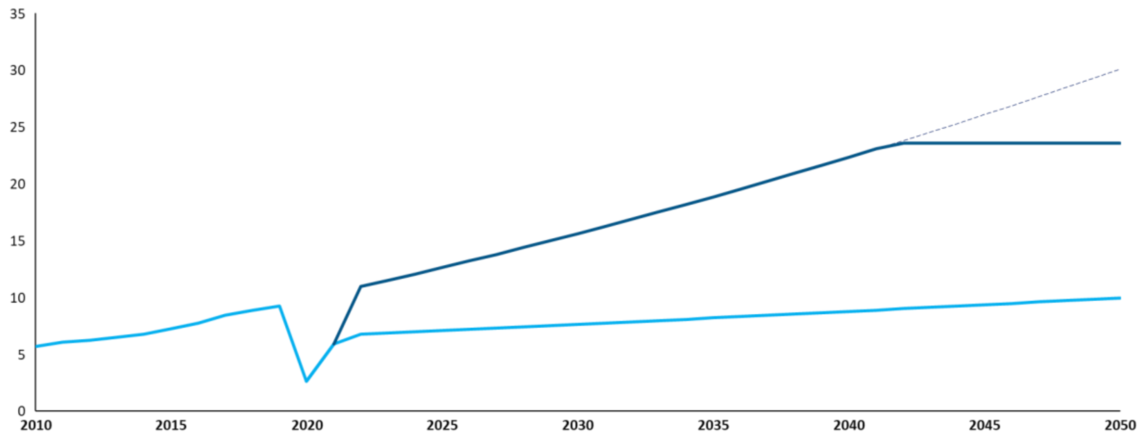
Figure 5.67 Estimated cost and benefit functions for the EU coastal tourism industry, EUR on the vertical axes, number of tourists on the horizontal axis



This observation implies that there is a maximum economic profit from coastal tourism in Europe, which is associated to an optimal number of tourist nights.

This effect is shown in the next Figure. However, it should be noted that this number does not account for the distribution of tourism. As tourists tend to cluster around "hotspot coastal destinations", it is likely that the optimal number of tourists is much lower, due to other adverse effects such as strains on the infrastructure or damage to the destination ecosystems due to overcrowding.

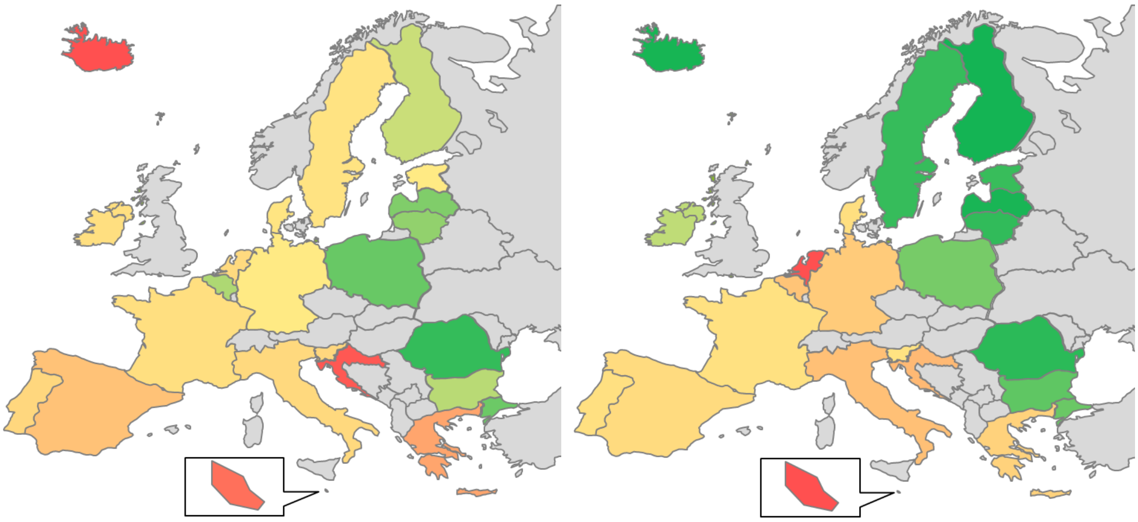
Figure 5.68 Predicted cost of removing plastic pollution in Europe, given expected tourism (€ billion)



Source: Eurostat, Deloitte 2021 "The price tag of plastic pollution: An economic assessment of river plastic" and Deloitte analysis

To explore the impact of hotspot destination, it is important to account for the distribution of tourists within destinations. The following Figure shows the tourism density and intensity in EU coastal regions.[957] Ocean governance could particularly target over-tourism in areas in which there is already a perceived overcrowding issue, such as Malta or Croatia. Furthermore, in the case of other regions, the optimal number of tourists may be much lower, and it may also yield lower profits. In Asia, for instance, the cost of plastic is much higher, whilst the economic value of tourism is much lower than in Europe.

Figure 5.69 (left)Tourism intensity (number of tourists per year, per population), 2019; (right) Tourism density (number of tourists per year, per square km), 2019. Note: grey areas either lack (specific) data or do not have coastal tourism



Source: Eurostat, and Deloitte analysis

8.1.7 Comparison of results from the two scenarios

Comparing the business as usual and the scaled up efforts scenarios, it is observed that there are advantages for the tourism sector to implementing SUE in ocean governance. On the one hand, improving the management of plastic pollution can bring great economic value, while on the other, limiting tourism in some areas can alleviate some of the pressures on the oceans caused by the sector. Limiting tourism can also cause a better distribution, as people will find alternative destinations and contribute to previously under-used destinations.

We have seen some small, localised activities already taking place across global economies, but more effort is needed to ensure sustainable development of the industry. Ocean Governance and responsible tourism, such as environmental taxes, can help alleviate some of the issues associated with the tourism sector and mitigate the costs associated with its growth.

8.2 Non-recreational Cultural Services

8.2.1 Description of Ecosystem Service / Benefit and Impact

Cultural ecosystem services are the non-material benefits obtained from ecosystems that contribute to human wellbeing. They are often under-represented due to difficulties in

[957] Tourism density is defined as yearly number of tourists per square km; tourism intensity is defined as yearly number of tourists per population.

identifying and valuing their associated intangible attributes[958], even though they can sometimes matter more to society than material benefits[959]. The SEEA-EA framework distinguishes four different cultural ecosystem services. Of these, recreation-related services, with a focus on tourism, are considered separately, whereas the other three are considered together in this section, defined as:

- Visual amenity services, the ecosystem contributions to local living conditions, in particular through the biophysical characteristics and qualities of ecosystems that provide sensory benefits, especially visual. This service can combine with other ecosystem services, including recreation-related services or noise attenuation services to underpin amenity. Accordingly, their value and that of recreation-related services may be considered in combination;
- Spiritual, artistic and symbolic services, the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that are recognised by people for their cultural, historical, aesthetic, sacred or religious significance. These services may underpin people's cultural identity and may inspire people to express themselves through various artistic media; and
- Education, scientific and research services, the ecosystem contributions, in particular through the biophysical characteristics and qualities of ecosystems, that enable people to use the environment through intellectual interactions with the environment.

In addition, 'ecosystem and species appreciation' are identified as a flow to non-use values, which "concerns the wellbeing that people derive from the existence and preservation of the environment for current and future generations, irrespective of any direct or indirect use". All marine and coastal ecosystem types can provide for these non-recreational cultural services in different ways and to different extents, some examples include:

- Coastal and marine wetlands, which include estuaries, mangroves, seagrass beds or coral reefs among others, and that besides providing for a number of provisioning and regulating services, they offer cultural services through their natural features associated with[960]:
  - Spiritual importance, such as sacred sites used for ceremonial activities[961];
  - Inspirational activities, such as seagrasses used as inspiration for creative activities[962];
  - Aesthetic values, such as coral reefs attracting recreational divers; or
  - Educational resources, with a number of wetland areas used for educational activities.
- Sea-ice ecosystems, predominant in polar regions, which provide a number of cultural services in addition to provisioning and regulating services, including through indigenous

[958] Martin, C.L., Momtaz, S., Gaston, T., Moltschaniwskyj, N.A., 2016. A systematic quantitative review of coastal and marine cultural ecosystem services: current status and future research. Marine Policy 74. https://doi.org/10.1016/j.marpol.2016.09.004

[959] Cao, H., Wang, M., Su, S., Kang, M., 2022. Explicit quantification of coastal cultural ecosystem services: A novel approach based on the content and sentimental analysis of social media. Ecological Indicators 137. https://doi.org/10.1016/j.ecolind.2022.108756

[960] Ramsar Convention on Wetlands, 2018. Global Wetland Outlook: State of the world's wetlands and services to people. Available at: https://papers.ssrn.com

[961] Hattam, C., Broszeita, S., Langmead, O., Praptiwide, R.A., 1 Lim, V.C., Creencia, L.A., Hauh, T.D., Maharjad, C., Wulandarid, P., Setia, T.M., Sugardjito, J., Javier, J., Jose, E., Gajardo, L.J., Then, A.Y.H., Amri, A.Y., Johari, S., Justine, E.V., Austen, M., 2021. A matrix approach to tropical marine ecosystem service assessments in South east Asia. Ecosystem Services 51. https://doi.org/10.1016/j.ecoser.2021.101346

[962] See footnote 961

and local knowledge systems, cultural identity and spirituality, as well as extensive research opportunities[963]; or

- In general, most marine habitats with strong physical and visual characteristics, particularly within coastal areas, provide visual amenity services, such as seascapes that comprise alternating sandy beaches and rocky headland reefs with clear waters[964] and are associated with human wellbeing benefits.

8.2.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Coastal areas accommodate a significant proportion of the world's population and play an essential role in improving human physical and mental health and enhancing social cohesion among communities. Intensifying human activities within coastal areas (e.g. urbanisation, coastal erosion) as well as sea level rise can impact coastal and marine ecosystems and the extent to which they can provide cultural services, threatening societal sustainability. Species diversity and composition are also considered to drive the aesthetic and inspirational value of coastal ecosystems[965], and accordingly changes to these can impact the overall value assigned to visual amenity and other cultural services.

8.2.3 Description of methodology for monetisation incl. indicators used and data sources

Attempts to evaluate non-recreational cultural services from marine and coastal environments are limited[966, 967, 968], mainly due to the lack of suitable methodologies and indicators to assess them simultaneously or difficulty to avoid double-counting given their strong relationship with other cultural and non-cultural ecosystem services[969]. Recommendations to consider these within the context of specific locations have also been made given the variety of cultural contexts they can be found in[970,971] and may explain the challenges of considering their value at a global scale.

[963] Steiner, N.S., Bowman, J., Campbell, K., Chierici, M., Eronen-Rasimus, E., Falardeau, M., Flores, H., Fransson, A., Herr, H., Insley, S.J., Kauko, H.M., Lannuzel, D., Loseto, L., Lynnes, A., Majewski, A., Meiners, K.M., Miller, L.A., Michel, L.N., Moreau, S., Nacke, M., Nomura, D., Tedesco, L., Van Franeker, J.A., Van Leeuwe, M.A., Wongpan, P., 2021. Climate change impacts on sea-ice ecosystems and associated ecosystem services. Science of the Anthropocene 9 (1). https://doi.org/10.1525/elementa.2021.00007

[964] MacDiarmid, A.B., Law, C.S., Pinkerton, M., Zeldis, J., 2013. New Zealand marine ecosystem services. In Dymond JR ed. Ecosystem services in New Zealand – conditions and trends. Manaaki Whenua Press, Lincoln, New Zealand. Available at: https://www.landcareresearch.co.nz

[965] Tribot, A.S., Deter, J., Claverie, T., Guillhaymon, F., Villéger, S., Mouquet, N., 2019. Species diversity and composition drive the aesthetic value of coral reef fish assemblages. Biology Letters 15(11). https://doi.org/10.1098/rsbl.2019.0703

[966] Mehvar, S., Filatova, T., Dastgheib, A., Van Steveninck, E.D.R., Ranasinghe, R., 2018. Quantifying economic value of coastal ecosystem services. A review. Journal of Marine Science 6(1). https://doi.org/10.3390/jmse6010005

[967] Martin, C.L., S. Momtaz, T. Gaston, and N.A. Moltschaniwskyj. 2016. A systematic quantitative review of coastal and marine cultural ecosystem services: Current status and future research. Marine Policy 74: 25–3

[968] Rodrigues, G.J., A. Conides, S. Rivero Rodriguez, S. Raicevich, P. Pita, K. Kleisner, C. Pita, P. Lopes, et al. 2017. Marine and coastal cultural ecosystem services: Knowledge gaps and research priorities. One Ecosystem 2: e12290.

[969] Ahtiainen, H., Liski, E., Pouta, E. et al., 2019. Cultural ecosystem services provided by the Baltic Sea marine environment. Ambio 48. https://doi.org/10.1007/s13280-019-01239-1

[970] Geange, S., Townsend, M., Clark, D., Ellis, J.I., Lohrer, A.M., 2019. Communicating the value of marine conservation using an ecosystem service matrix approach. Ecosystem Services 35. https://doi.org/10.1016/j.ecoser.2018.12.004

[971] Ryfield, F., Cabana, D., Brannigan, J., Crowe, T., 2019. Conceptualising 'sense of place' in cultural ecosystem services. A framework for interdisciplinary research. Ecosystem Services, 36. https://doi.org/10.1016/j.ecoser.2019.100907

In order to assess the economic value of these services, the study conducted by De Groot *et al.*, 2012[972] has been used, as it provides the average Total Economic Value (TEV) for a number of non-recreational cultural services provided by different biomes, namely:

- Coral reefs, providing for aesthetic information and cognitive development; and
- Coastal systems, providing for spiritual experience and cognitive development.

Coastal systems include estuaries, continental shelf area and sea grass, but exclude wetlands. The coastal zone is the most urbanised region in the world, hosting 15 of the 20 megacities (with populations > 10 million people). However, given that there are no reliable global scale assessments of historical trends in shoreline changes for rocky and muddy substrates, with a number of regions owning very little information and data on their ecosystems[973], this section has focused on non-recreational cultural services provided by coral reefs through aesthetic information and cognitive development only.

Two different scenarios are used to calculate the cost of inaction (estimated as the difference between them):

- comparing the long-term effects of "business as usual" (BAU scenario), in which coral reefs degrade over time at similar rates to those historically recorded; and
- a "scale up" of ocean governance efforts (SUE scenario), in which it is assumed that the extent of non-degraded coral reefs is maintained to current levels through halting ongoing degradation and restoration initiatives.

8.2.4 Assessment of reliability and robustness of methodology and data sources

The assessment is based on information provided by secondary sources, i.e. Groot *et al.* 2012, who calculate the global value of these cultural services through the extrapolation of estimates made for individual case studies, and accordingly, there are a number of assumptions and limitations associated with this extrapolation approach, including geographical / contextual bias. Accordingly, estimates should only be considered as indicative, as these are likely to underestimate the overall value associated with non-recreational cultural services provided by coral reefs, with other biomes also likely to provide a range of non-recreational cultural services.

The approach used to define the BAU scenarios is limited to assuming that historical decadal degradation rates reported by Eddy *et al.* (2021)[974] continue up to the year 2050, with monetary values decreasing proportionally.

The approach used to define the SUE scenario is limited to assuming that the extent of coral reefs (and their value) would at least be maintained up to 2050 to current levels.

[972] De Groot, R., Brander, L., Van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L.C., Brink, P.T., Beukering, P.V., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services 1.

[973] UN, 2021. Second World Ocean Assessment. Available at: https://www.un.org

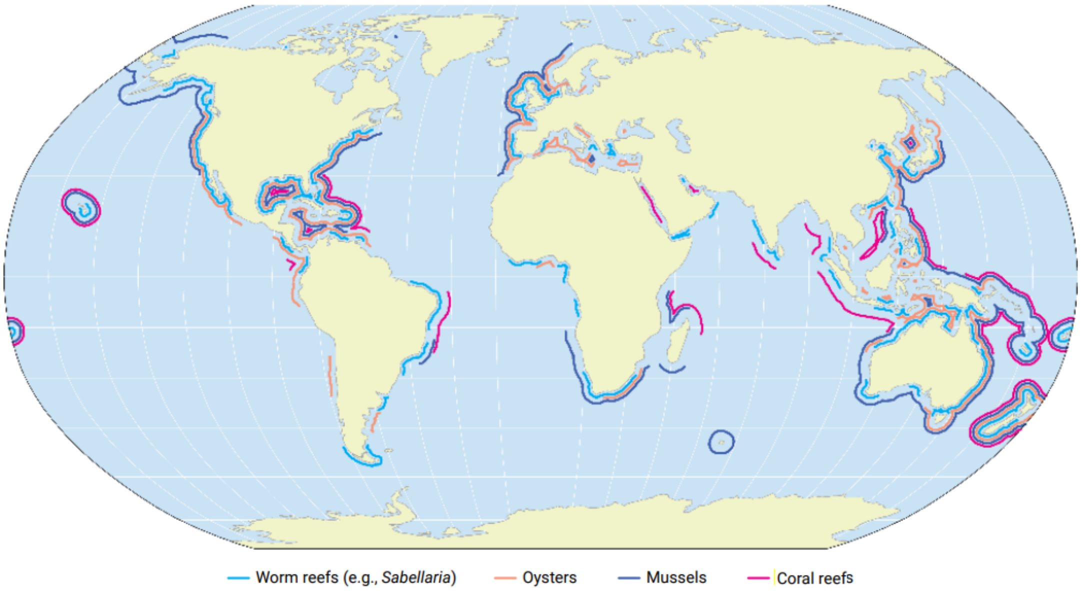
[974] Eddy, T.D., Lam, V.W.Y., Reygondeau, G., Cisneros-Montemayor, A.M., Greer, K., Palomares, M.L.D., Bruno, J.F., Ota, Y., Cheung, W.W.L., 2021. Global decline in capacity of coral reefs to provide ecosystem services. One Earth 4 (9). https://doi.org/10.1016/j.oneear.2021.08.016

8.2.5 Description of the baseline (method and results)

It is estimated that coral reefs cover approximately 0.5% of the oceans, which is equivalent to approximately $1.5x10^8$ ha[975], of which 30% is already reported to be severely damaged[976] ($4.5x10^7$ ha).

Cold-water corals are known to occur along continental margins, mid-ocean ridges and seamounts worldwide. Corals are also characteristic habitats in tropical and subtropical coastlines. The global distribution of coral and other biogenic reefs is illustrated in Figure 5.70.

Figure 5.70 Global distribution of coastal biogenic reefs.



Source: UN, 2021

The baseline for the monetary value of non-recreational cultural services associated with aesthetic information and cognitive development from coral reefs is extracted from the study by De Groot *et al.* (2012) who established that these services were worth 12,312 €/ha/year and 1,238 €/ha/year globally[977] respectively. Based on the estimated extent of non-degraded coral reefs worldwide, these cultural services would currently have a total monetary value of €1.42 billion:

- Aesthetic information = €1.29 billion (91%)
- Cognitive development = €0.13 billion (9%)

8.2.6 Description of the" business as usual" (BAU) scenario (method and results)

In recent years, coral reefs have undergone mass bleaching on an annual basis and have been exposed to a number of pressures associated with human activities, such us overfishing and

975 Leão, Z.M.A.N., Kikuchi, R.K.P. & Oliveira, M.D.M. 2008. Coral bleaching in Bahia reefs and its relation with sea surface temperature anomalies. Biota Neotrop. 8 (3). Available at: https://www.scielo.br

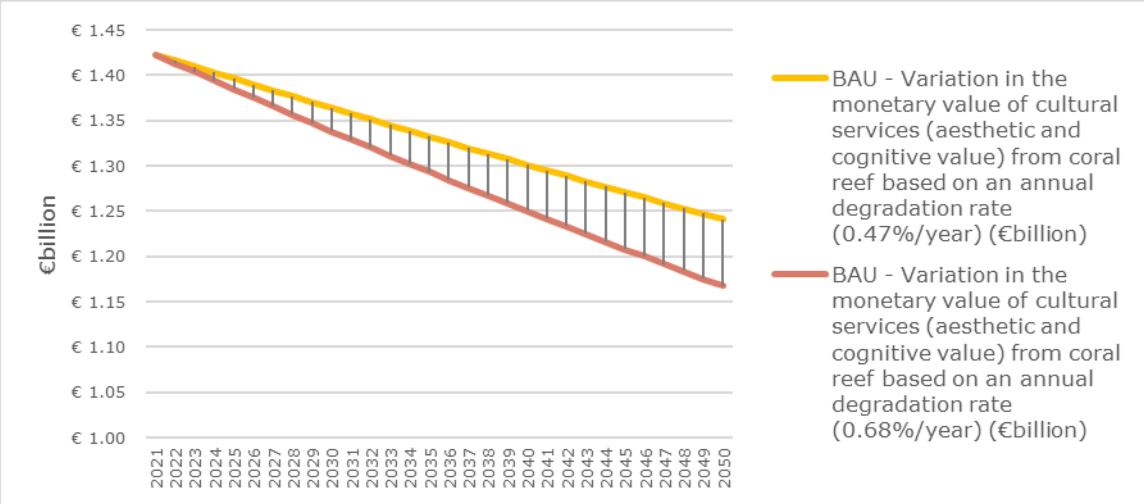
976 See footnote 973

977 Conversion from 2007 int. $ using US$ deflator sourced from the US Internal Revenue Service Website: https://www.irs.gov , and 2021 yearly average US$/EUR exchange rate of 0.846

marine pollution. Historically, the average decadal rate of loss in coral coverage has been estimated to range from 4.7% to 6.8%, noting that most regions have limited sampling effort[978].

Based on the current extent of coral reef cover and assuming that historical degradation rates continue into the future, the annual monetary value of cultural services from coral reefs associated with aesthetic and cognitive values could be reduced to a range between €1.17 and €1.24 billion in 2050.

Figure 5.71 Predicted evolution of the monetary value of cultural services from coral reefs associated with aesthetic information and cognitive development) under two different business as usual scenarios assuming 0.47% and 0.68% annual degradation rates.



8.2.7 Description of the "scaled up efforts" (SUE) scenario (method and results)

The SUE scenario assumes that the extent of coral reefs (and their cultural monetary value in relation to aesthetics information and cognitive development) would at least be maintained up to 2050 at current levels. This could be achieved through increased implementation of appropriate management / governance strategies at different scales, which could include:

- Addressing the root causes of environmental degradation, including greenhouse gas mitigation or fossil fuel divestment[979];
- Effective implementation of marine ecosystem-based management, including the extension of marine protected areas, fisheries management, ensuring compliance with water quality regulations, etc[980]; or
- Active interventions to build the biological resilience of coral reefs, particularly from projected escalation of global warming and ocean acidification, most of which may only be applicable at local / regional scales[981]:
- Introduction of structures to provided habitat, stabilise substrate and enhance recruitment;

[978] See footnote 974

[979] Morrison, T.H., Adger, N., Barnett, J., Brown, K., Possingham, H., Hughes, T., 2020. Advancing coral reef governance into the Anthropocene. One Earth 2 (1). https://doi.org/10.1016/j.oneear.2019.12.014

[980] See footnote 979

[981] Anthony, K.R.N., Helmstedt, K.J., Bay, L.K., Fidelman, P., Hussey, K.E., Lundgren, P., Mead, D., mCIEOD, i.m., Mumby, P.J., Newlands, M., Schaffelke, B., Wilson, K.A., Hardisty, P.E., 2020. Interventions to help coral reefs under global change—A complex decision challenge. Plos One 15(8) https://doi.org/10.1371/journal.pone.0236399

- Translocation of larval slicks and in situ relocation of corals;
- Control of algae and other species that inhibit coral growth and reproduction;
- Coral treatment using probiotics, feeding, medicine, etc; or
- Selective breeding or use of gene-engineering to increase thermal tolerance of natural coral populations;

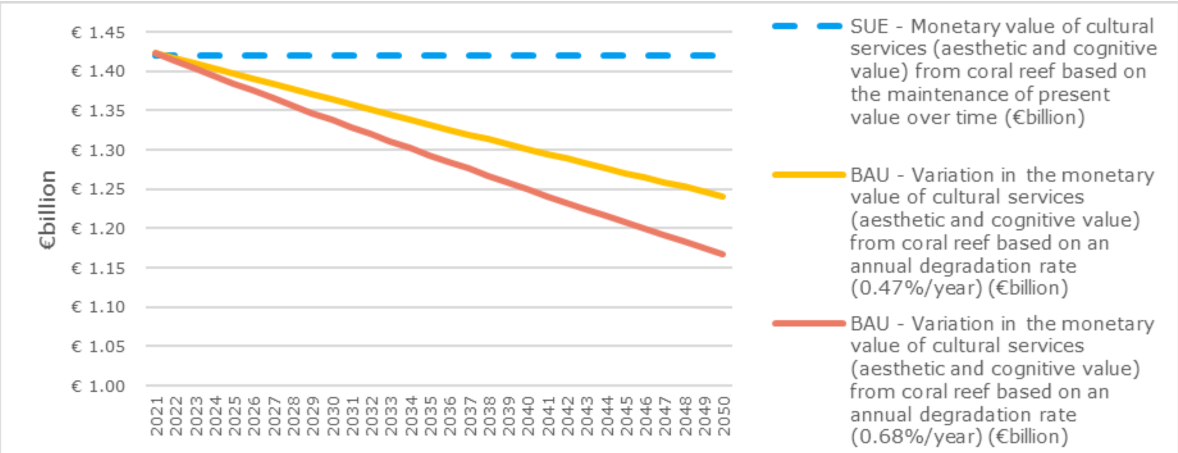
Morrison *et al.* 2020[982] identify that promoting combined interventions can risk forming a governance trap, i.e. a misdiagnosis of the problem and its origin, combined with a miscalculation of stakeholders responsible for its solution, lead to constraints in addressing the problem. The authors call for effective ocean governance that is 979:

- Based on an analysis of intervention options according to their intensity and scale of cause and effect;
- Informed by the anticipated way in which different interventions may work in combination or applied in a sequence; and
- Informed by an assessment of the broader scientific and political implications of a particular intervention or combination of interventions.

8.2.8 Comparison of results from the two scenarios

The difference between the BAU and SUE value in 2050 is considered as a proxy for the cost of inaction. It is estimated that the cost of inaction in 2050 could range between €0.18 and €0.25 billion.

Figure 5.72: Predicted evolution of the monetary value of cultural services from coral reefs (associated with aesthetic information and cognitive development) under two different business as usual scenarios assuming 0.47% and 0.68% annual degradation rates, in comparison with a scaled up efforts scenario that maintains present monetary values up to 2050.



Source: Own calculation

8.2.9 Comparison of results from the two scenarios

The difference between the BAU value and the SUE value in 2050 is the cost of inaction. It is estimated that the cost of inaction in 2050 would be an estimated **27 billion (2021) €/y** if we consider the total area covered by mangroves and salt marshes globally[983].

[982] See footnote 979

[983] Based on own calculations, the surface area of mangroves and salt marshes globally is estimated to be 16 862 129 ha in 2050.

9. Abiotic flows

9.1 Mineral Extraction

9.1.1 Description of Ecosystem Service / Benefit and Impact

The SEEA-EA framework defines abiotic flows as "contributions to benefits from the environment that are not underpinned by or reliant on ecological characteristics and processes". They arise from the abstraction/extraction of resources, including geological resources.

Within a marine and coastal context, the marine minerals extraction industry has historically targeted marine aggregates[984], placer deposits[985], sulphur or salt among others; and extraction activities have generally been confined to nearshore areas (within depths of 50 m). However, the industry is evolving into deeper areas (< 200 m)[986,987], with a particular focus[988] on the deep seabed mining (DSM) of:

- polymetallic nodules[989], which are nodules of varying sizes (from micro-nodules to about 20 cm) that occur at the unconsolidated sediment-water interface composed mainly of manganese, iron, silicates and hydroxides. They include trace metal contents such as nickel, copper, cobalt, manganese and Rare Earth Elements (REE) of great commercial interest;
- polymetallic sulphides[990], which are metalliferous muds that occur in high-temperature hydrothermal vents and high sulphide accumulation sites, are associated with mid-ocean ridges and volcanic arcs. These can contain large amounts of copper, zinc, lead, iron, silver and gold; and
- cobalt-rich ferromanganese crusts[991], which occur at depths between 400 and 5,000 m in areas of significant volcanic activity. They can have a higher cobalt percentage (up to 2 %), platinum (0.0001 %) and REE besides nickel and manganese,

These depths are covered within around 50% of the earth's surface and represent 95% of the global biosphere in terms of inhabitable volume[992]. Of all minerals associated with these deposits, there are four that stand out in importance:

Table 5.12 Mineral resources and their applications.

Resource	Uses
Cobalt	Primarily used in the production of superalloys resistant to high temperatures (such as aircraft gas turbo engines). Also used in rechargeable batteries-notably lithium-ion batteries used in hybrid electric vehicles. These batteries contain high proportions of cobalt as 60% of the cathode in lithium-ion batteries is composed of lithium cobalt oxide.

[984] granular materials extracted from the seabed and used in construction, including sand and gravel

[985] minerals that have been concentrated by physical processes, such as waves, wind and currents. These include diamonds, cassiterite (tin), ilmenite (titanium), rutile (titanium), zircon (zirconium), chromite (chromium), monazite (thorium), magnetite (iron) and gold

[986] https://www.iucn.org/resources/issues-briefs/deep-sea-mining

[987] United Nations, 2021. The second World Ocean Assessment. Available at: https://www.un.org

[988] International Seabed Authority. Minerals: Exploration Areas. Available at: https://www.isa.org.jm

[989] International Seabed Authority. Minerals: Polymetallic Nodules. Available at: https://www.isa.org.jm

[990] International Seabed Authority. Minerals: Polymetallic Sulphides. Available at: https://www.isa.org.jm

[991] International Seabed Authority. Minerals: Cobalt-rich Ferromanganese Crusts. Available at: https://www.isa.org.jm

[992] https://www.frontiersin.org/articles/10.3389/fmars.2017.00418/full

Resource	Uses
Copper	Primarily used for electricity production and distribution, but also for transport sector components.
Lithium	Mainly used in rechargeable batteries for a wide range of products, such as mobile phones and electric vehicles. Aluminium-lithium alloys are also used in aircraft or bicycle frames, while lithium oxide is used in special glasses and glass-ceramics.
Nickel	Primarily used to make stainless steel and other alloys resistant to high temperatures and corrosive environments. Also used in batteries, including rechargeable batteries and hybrid vehicles.

Source: Miller et al. 2018[993] and Royal Society of Chemistry website[994]

Furthermore, there is interest in methane extracted from gas hydrates associated with marine sediment on continental slopes and rises. Gas hydrates are ice-like solid crystalline structures containing methane, ethane, propane or butane, though methane hydrate is the most common naturally occurring one. These hydrates can have a potentially high yield, with 1 m^3 of methane hydrate yielding around 164 m^3 methane gas. Extraction is, however, technologically complex and costly.

9.1.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Marine mineral extraction supports a number of industries, including the ever-growing technology sector. This abiotic flow is independent of ecosystem state changes, abundance or condition, however, extraction activities can have detrimental effects on marine and coastal ecosystems, and are generally only permitted in areas designated for it under certain conditions, regulated by coastal states when activities take place within national jurisdiction, and by the International Seabed Authority (ISA) when proposed in areas beyond national jurisdiction, so far only covering exploration licences for deep-sea minerals, with a regulatory regime for exploitation activities currently under development[995].

In terms of activities involved, as an example, DSM comprises the release of a collector vehicle from the main ship, which travels to the seabed, collecting nodules that are pumped back to the ship through a pipe. On the ship, the nodules are separated from unwanted sediments, the latter being pumped back into the sea. Notably, as the collector vehicle moves across the seabed floor, it creates a sediment cloud (or plume), which is carried away and distributed by ocean currents. A second plume is caused by the return of unwanted sediments into the ocean. These plumes cause great concerns to researchers, as their effects on the marine ecosystem are not yet fully known[996].

Researchers estimate that sediments accumulate at a rate of 1 millimetre every millennium, meaning that areas targeted for DSM are effectively lost. This causes concerns that the activity

[993] Miller et al (2018) An overview of seabed mining including the current state of development, environmental impacts, and knowledge gaps. See: https://www.frontiersin.org

[994] See: https://www.rsc.org

[995] Lodge, M., n.d. The International Seabed Authority and Deep Sea Mining. Available at: https://www.un.org

[996] Hein, J.R., Koschinsky, A. & Kuhn, T., 2020. Deep-ocean polymetallic nodules as a resource for critical materials. Nat Rev Earth Environ 1, 158–169. https://doi.org/10.1038/s43017-020-0027-0

may impact the local biological community in irreversible ways, but the damage may extend further into the ocean as the plumes travel[997].

Firstly, sediment plumes can upset phytoplankton blooms at the sea surface and introduce toxic metals into the food chains. As the mining waste travels, it can also damage seamounts and coral reefs, putting entire fisheries at risk. Pacific islands, in particular, rely on these fisheries for food security and livelihood. Furthermore, there is also a danger of light pollution disrupting deep-sea species and noise pollution affecting the swimming and schooling behaviour of tuna, as well as causing dolphins and whales to strand[998].

Regarding hydrate extraction, environmental risks accidental leakage of methane during the dissociation process - methane is a greenhouse gas 28 times more potent than CO2. Additionally, mining activities could increase water temperatures, which may melt and destabilise the hydrates, further increasing the risks.

9.1.3 Description of methodology for monetisation incl. indicators used and data sources

Monetisation for this benefit is operationalised on the basis of marine minerals as an abiotic flow with a contribution to the economy. In order to assess the economic impact of marine mineral extraction, we examine:

- the value-added of the marine aggregate extraction sector to the economy at present, as DSM is currently undertaken on an exploratory basis and there is limited data on other mineral types or on gas hydrates. This is based on data sourced from:
- The British Geological Survey (BGS) world mineral statistics 2015 – 2019, which contains mineral production (tonnes) data per country worldwide; and
- European Aggregates Associated (UEPG), which collates the best available aggregates production data across Europe[999]. Marine aggregates are distinguished from non-marine, corresponding to approx. 2% of aggregate production in 2019. Trend figures[1000] also include some countries outside the EU.

The potential revenue from DSM in the future we assess by:

- Assessing the demand for minerals found on the seabed based on 2021 forecasts published by the International Energy Agency, which assessed the quantities needed to sustain green energy transition and energy storage capabilities; and
- Comparing these to forecast availability and capacity for land-based mining, which is based on historical data from World Mining Data. Further information, such as current land-based reserves, is retrieved from the 2021 Mineral Commodity Summaries report of the USGS[1001]. Data on recycling possibilities for these materials are taken from a UNEP report. Prices for the estimate of the economic impact are extracted, whenever possible, from the World Bank Commodity Price Dataset.

Following the initial analysis of baseline conditions and of the forecasts, a qualitative analysis will discuss the benefits and disadvantages of engaging in deep-sea mining.

[997] https://news.mit.edu/2019/understanding-impact-deep-sea-mining-1206

[998] https://news.mongabay.com/2020/06/deep-sea-mining-an-environmental-solution-or-impending-catastrophe/

[999] Available at: https://uepg.eu

[1000] Idem

[1001] https://pubs.usgs.gov/periodicals/mcs2021/mcs2021.pdf

9.1.4 Assessment of reliability and robustness of methodology and data sources

Data used has been sourced from reputable sources. In relation to DSM, while it is difficult to assess the exact costs and benefits of an emerging industry, the presented forecasts are based on reliable estimates.

9.1.5 Description of the baseline

Marine Aggregates

Marine aggregates are currently the most mined material from the marine environment, with established industries in Europe, China and Korea among others. It is estimated that between 50 and 150 million m^3 of marine aggregates are extracted per year, corresponding to an overall revenue of between €0.9 and €2.8 billion. Current development trends indicate that sand demand will increase at an accelerated rate. Within the OSPAR region, the extraction of marine sand and gravel has increased approximately 30% over the last decade[1002].

Salt Production

The British Geological Survey, in its overview of world mineral production, identifies the production of about 35 million tons of salt from seawater out of reported total world production of 265 million tons but it does not identify the source of salt for many countries[1003]. The second world ocean assessment. notes that salt production from seawater has remained relatively stable, with the notable exception of a 34% increase in India.

Hydrate Deposits

Continental shelf margins contain 95% of all global methane hydrate deposits, while research estimates around 1.5x 10^{16} m^3 of gas hydrates at sea level.

Deep seabed mining (DSM)

The economics of DSM is intimately linked to the state of mining technology and the increased demand for metals in cutting-edge technology applications.

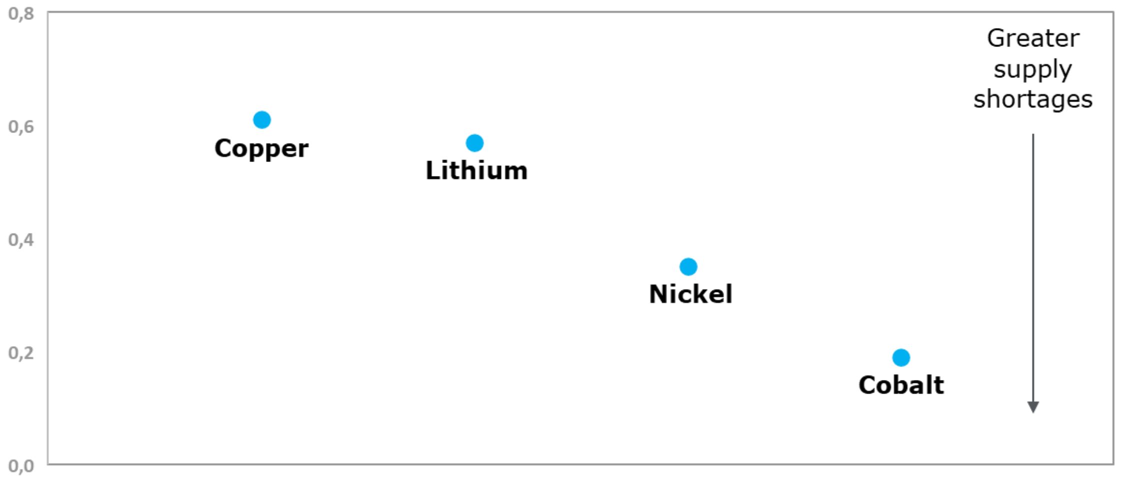
At present, minerals targeted by DSM exploration activities are extracted through land-based mining operations, which can lead to the destruction of habitats, erosion, and soil and water contamination. There are also concerns that land-based mining may not be able to supply enough minerals to sustain the rising demand for batteries, especially in politically unstable countries. For instance, currently, much of the global land-based mining occurs in the Democratic Republic of Congo, which produces 60% of the global supply of cobalt.[1004] In 2021, an IMF publication showed the expected supply to demand ratios for minerals necessary for renewable energy, showing that there will be shortages of important materials by 2050.

[1002] OSPAR EIHA, 2021

[1003] Brown, T.J., Idoine, N.E., Wrighton, C.E., Raycraft, E.R., Hobbs, S.F., Shaw, R.A., Everett, P., Deady, E.A., Kresse, A C, 2019. World Mineral production 2015 – 2019. Available at: World mineral statistics | MineralsUK (bgs.ac.uk)

[1004] https://news.mit.edu/2019/understanding-impact-deep-sea-mining-1206

Table 5.13 Expected supply to demand ratio by 2050 for four materials.



Source: IMF[1005]

Besides mining, most metals are inherently recyclable in the sense that their function and quality can be used multiple times in more than one product or service. Recycling is defined here as 'destructive recycling' considering that metal in a product at the end of life is re-melted and refined for secondary uses. An assessment of the recycling potential of selected minerals can be found in the table below.

Table 5.14 Recycling potential of selected materials

Mineral	End-of-life recycling rates	Recycled content rates
Cobalt	68%	32%
Copper	43%-53%	20%-37%
Lithium	<1%	<1%
Nickel	57%-63%	29%-41%

Notes: End-of-life (EOL) recycling rates: the functional recycling of EOL metal, as pure metal (e.g., copper) or alloy (e.g., brass). Recycled content (RC): the fraction of (scrap) metal entering the recycling process out of the total original production (approximated as total extraction of metal ore minus losses through tailings and slags).
Source: UNEPS[1006]

Preliminary research indicates that DSM could help addressing the predicted demand gap, and there have been four primary locations identified to have potential for densities high enough for commercial extraction: (1) the Clarion Clipperton Zone (CCZ), (2) the Peru basin, (3) the Penrhyn basin in the Cook Islands, and (4) the Indian Ocean[1007]. Some densely covered nodule fields have been estimated to contain more than 10kg/m^2. The CCZ alone is estimated to contain six times more cobalt and three times more nickel than all known land-based stores, as well as significant deposits of manganese and copper[1008].

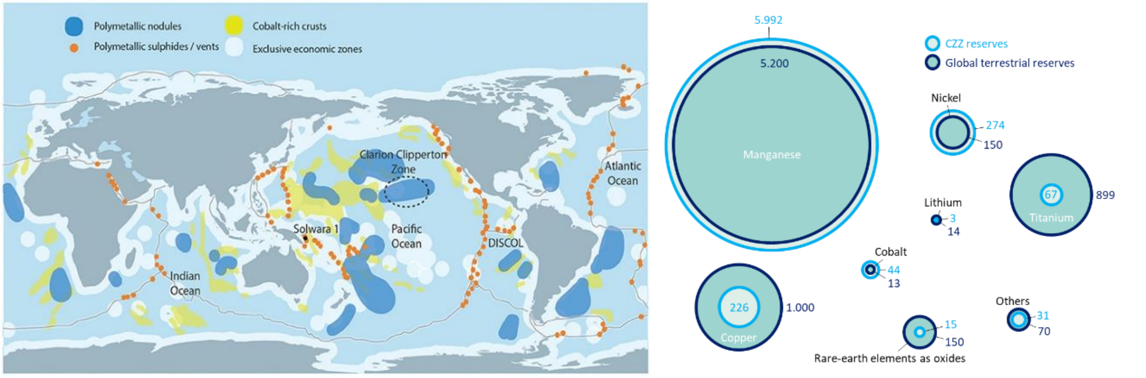
[1005] See: https://blogs.imf.org

[1006] See: https://wedocs.unep.org

[1007] See: https://www.sprep.org/attachments/VirLib/Regional/deep-sea-mining-cba-PICs-2016.pdf

[1008] See: https://news.mit.edu/2019/understanding-impact-deep-sea-mining-1206

Figure 5.73 Ocean deposits distribution (left) and mineral reserves in the Clarion-Clipperton Zone (CCZ) compared to land-based reserves, in million tonnes (right).



Source: Miller et al. (2018), Hein et al (2013)[1009]

As of 2020, however, DSM has not commenced as a commercial activity, but several stakeholders have obtained contracts to explore the seabed. This was done under consideration of allowing marine animals "plenty of habitat" in the abyssal plain[1010].

9.1.6 Description of the "business as usual" (BAU) scenario

The BAU scenario is only considered in relation to DSM and analyses current trends and estimates for the future production and demand of deep-sea minerals, with a focus on cobalt, copper, lithium and nickel. It should be noted that given the 15-year exploration contracts initiated by the ISA, it is unlikely that deep-sea mining will commence and sufficiently mature before 2040. Therefore, this scenario will assume that this means of production will be unavailable in the near future.

Using historical trends from World Mining Data, the development of mining capacity until 2050 has been forecasted. However, it should be noted the trend of the yearly yield from mining is likely to develop at a slower rate than depicted, due to slowing investments and financing for metals and mining. This is due to growing investor focus on environmental, social, and governance considerations, or ESG[1011].

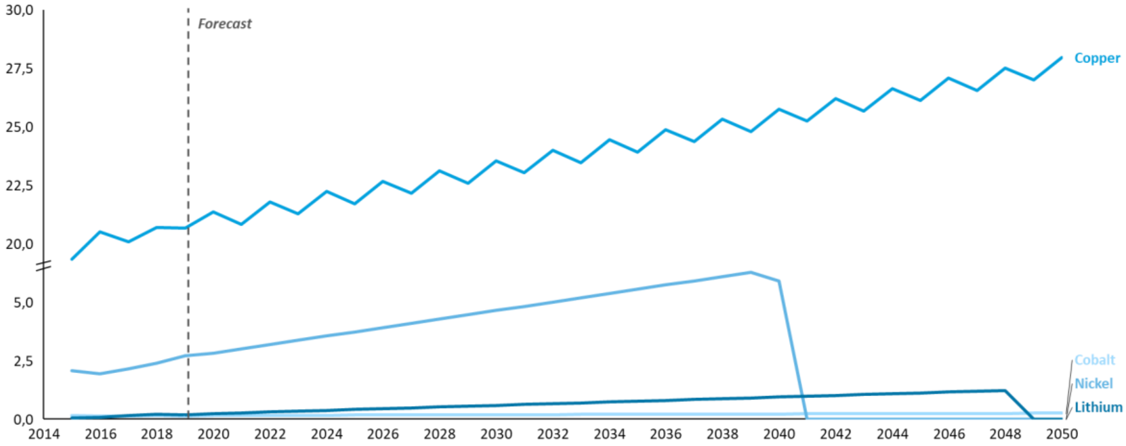
Given this forecast and the volume of known land reserves, it is predicted that some may be depleted before 2050. This timeline may be prolonged through the discovery of new reserves, but it is not possible to predict such events. Given the volume of known land reserves as of 2020, and the forecast, the figure below shows the expected development of land mining yields.

[1009] https://media.nature.com

[1010] https://news.mongabay.com/2020/06/deep-sea-mining-an-environmental-solution-or-impending-catastrophe/

[1011] https://blogs.imf.org

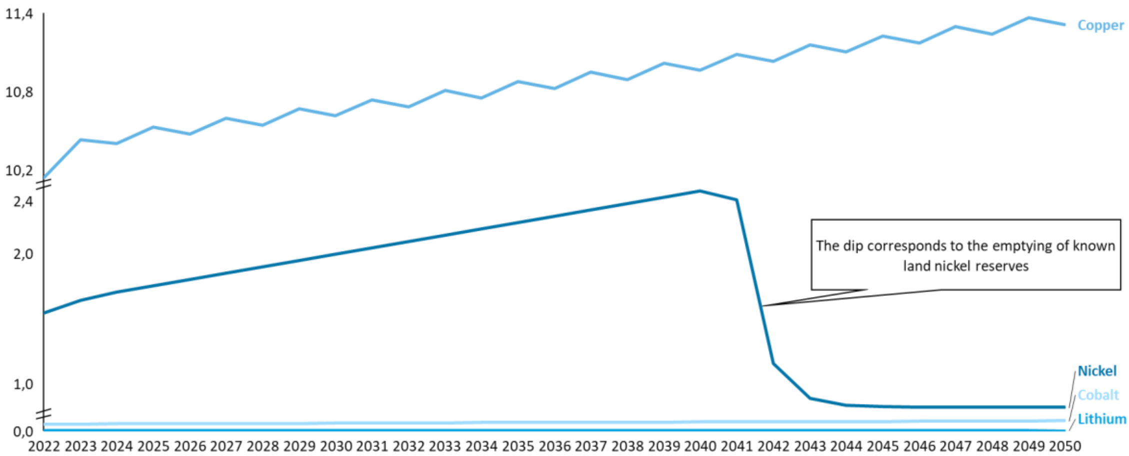
Figure 5.74 (Predicted) extraction of minerals from land reserves (in million metric tonnes).



Source: World Mining Data[1012]; USGS 2021[1013]; and analysis of the study team

Besides mining activities, these metals can be recycled from discarded commercial products. Taking into account the estimated volume in circulation, the recycling potential and the expected new procurement of each material, the usable metals stemming from recycling are forecasted in the figure below.

Figure 5.75 Forecast recycling potential of selected minerals (in million metric tonnes).



Source: World Mining Data, USGS 2021, UNEP and Deloitte analysis

While there is little information to be found about the yearly evolution of the demand for these minerals, several institutions have published estimates for 2040 and 2050 respectively. The most recent of these estimates were reported by the International Energy Agency (IEA) in 2021[1014] and were quoted by the IMF later that year. The IEA report addresses the rising demand for renewable energy and energy storage needs, for instance, due to the increasing popularity of electric cars, as well as potential transitions to different materials for production.

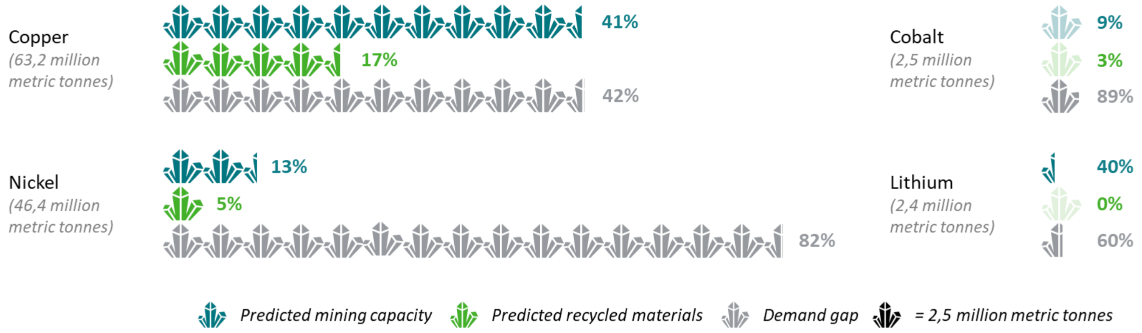
[1012] https://www.world-mining-data.info

[1013] https://pubs.usgs.gov

[1014] https://iea.blob.core.windows.net/assets/24d5dfbb-a77a-4647-abcc-667867207f74/TheRoleofCriticalMineralsinCleanEnergyTransitions.pdf

Using these figures and the forecasts presented above, Figure 5.76 presents the estimated state of the industry in 2040, while the figure below shows the forecast of the loss in economic value by 2040 due to the lack of supply of these materials. Due to lacking land-based supply, the global economy stands to lose up to $1.350 billion, most of which is due to nickel, a metal with estimated high demand, low available reserves, and a high relative price.

Figure 5.76 Forecast of available minerals relative to expected demand (in million metric tonnes).



Sources: World Mining Data; USGS, 2021; UNEP; International Energy Agency; and Deloitte analysis

Figure 5.77: Estimated loss in economic value due to demand gap by 2040 (in billion USD).

Sources: World Bank Commodity Price Data (The Pink Sheet), ISE[1015], Metalary[1016], and Deloitte analysis.

A previous report published by the World Bank in 2017[1017] also aimed to forecast demands by 2050. Although the figures they predicted were more conservative, the land-based supply was identified to deplete before this.

9.1.7 Description of the "scaled up efforts" scenario (method and results)

The table below elaborates on identified advantages and disadvantages of DSM.

Table 5.15 Advantages and disadvantages of DSM.

Advantages	Disadvantages
Small terrestrial footprint	Likely higher costs of transportation due to the centralised nature of deep sea resources
High initial investments: "the global deep sea mining equipment & technologies market garnered $811.9 million in 2020, and is estimated to reach $72.81 billion by 2030,"	There will likely be a period of "trial and error" in order to optimise the process
	Long term destruction of deep sea ecosystems
	Exact long-term impacts on the ocean are mostly unknown
	Potential of eradicating marine species that have not even been discovered yet

[1015] See: https://en.institut-seltene-erden.de

[1016] See: https://www.metalary.com

[1017] https://documents1.worldbank.org/curated/en/207371500386458722/pdf/117581-WP-P159838-PUBLIC-ClimateSmartMiningJuly.pdf

Advantages	Disadvantages
"the total estimated cost of a single deep-sea mining venture works out to $ 11.90 billion"	

Sources: https://www.globenewswire.com; Sharma, R. (2011). Deep-sea mining: Economic, technical, technological, and environmental considerations for sustainable development. Marine Technology Society Journal, 45(5), 28-41. https://www.resolve.ngo; https://www.iucn.org;

DSM could be an activity to ensure the availability of important metals and minerals, but the sector must be governed well in order to mitigate and prevent potential severe adverse effects. International ocean governance can take a proactive role in implementing policies for sustainable DSM, as damage caused may be irreversible, but preventable.

9.1.8 Ocean governance of mineral and oil extraction

As described in previous sub-sections, DSM is an infant industry. Pilots which are run at this moment, are highly regulated. Projects are regulated by coastal states when activities take place within national jurisdiction, and by the International Seabed Authority (ISA) when proposed in areas beyond national jurisdiction. A parallel can be drawn between mineral and oil extraction. Presently, offshore oil legislation involves assessing and monitoring petroleum and mining operations, awarding contracts, and determining tax and royalties. Environmentally, it offers legislation for environmental protection and sanitation and provides regulations for liability.[1018] Overarching concerns are obligations to protect and preserve the marine environment and to prevent, reduce and control pollution related to offshore energy activities. These regulations have the objective to help the ecosystem sustain itself. Therefore, regulations provide macro-economic benefits in the long term. Extending the offshore energy production to deep-sea mining, a decision has to be made in which direction to head. The two possible options to pursue are:

- an anticipative response; or
- a wait-and-see policy.

The second direction was taken by the oil industry. Only after the Torrey Canyon disaster in 1967, where 94 to 164 million litres of crude oil was spilt and hundreds of kilometres of beaches were polluted, drastic changes were made in maritime law and the response to pollution. It catalysed also the work on liability and compensation in response after the event.[1019] These regulations were imposed while nearly 100 years earlier, pioneers were able to patent the first off-shore drilling rig.[1020]

Early off-shore oil rigs were not regulated, but lessons can be learnt from history. To prevent extraordinary costs, an anticipative response is suggested, including maritime spatial planning in zones where to extract minerals and where to protect the ecosystem. Ocean governance possibly offers the following advantages:

- Clarity for both countries and companies. Benefits to local governments and companies are clear when anticipative ocean governance is introduced. Possibly it reduces friction between countries. Companies extracting minerals from the seabed know what the field is where they can play in, and governments can motivate in which areas permits are granted for extracting minerals

[1018] https://tethys.pnnl.gov/sites/default/files/publications/giannopolous-2020.pdf

[1019] https://www.imo.org/en/OurWork/Legal/Pages/LiabilityAndCompensation.aspx

[1020] https://www.academia.edu/25960555

- Ecosystems will be assisted to sustain themselves. Ocean governance ensures the sustainability of ecosystems, stimulating collaboration between countries by globally optimizing the profits from the ocean, instead of locally.
- Ocean governance on DSM will decrease land-based mining, as described in previous subsections. Indirectly, ocean governance reduces the disadvantages of land-based mineral extraction.

9.1.9 Comparison of results from the two scenarios

The discussion and the industry are still in their early stages. It is not reasonable to compare results, given that research is still being conducted.

9.2 Abstraction of Water

9.2.1 Description of Ecosystem Service/ Benefit and Impact

Abstraction consists in taking water, for example via a pipe from the ocean, using it for an industrial, commercial or residential process, and then returning it to the ocean. In many cases the extracted coastal water is used as a cooling mechanism for coastal power stations, but other uses include the operation of fish farms and fish processing factories, manufacture of food, wood, chemical products, and agriculture.

Water can also be abstracted from the oceans to produce potable water. Desalination is the process of removing salts and other minerals from otherwise undrinkable water to produce freshwater for human consumption or other uses. Desalination has indeed become an efficient alternative resource to mitigate water shortage in many countries throughout the world[1021], and it is now seen as one of the most viable solutions to meet the increasing demand for fresh water[1022]. Currently there are 15,906 operational desalination plants with an estimated total capacity of 95.37 million m^3/day, but the desalination capacity is expected to exceed 200 million m^3/day in 2030[1023] to keep pace with the growing demand for seawater desalination, which is expected to increase three-fold by 2050[1024].

9.2.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

The abstraction of seawater can cause significant adverse environmental impacts depending on the use of the water extracted, the technology, and the energy requirements of the abstraction process.

Desalination of the abstracted water leads to brine discharges which can damage the environment. Brine consists in the mix of minerals extracted from the ocean and has a much higher salt concentration compared to the original seawater. Brine is normally disposed of in the ocean, but this can lead to environmental problems. Due to their high salinity and density, they can negatively impact on benthic sea life, for example in the case of the Posidonia

[1021] Bernat et al. (2010). The economics of desalination for various uses. Chapter 18 in *Re-thinking water and food security*.

[1022] Hunt et al. (2021). Deep seawater cooling and desalination: Combining seawater air conditioning and desalination. Sustainable Cities and Society 74, 103257.

[1023] Ihsanullah et al. (2021). Desalination and environment : A critical analysis of impacts, mitigation strategies, and greener desalination technologies. Science of the Total Environment, 780, Article 146585.

[1024] Gao et al. (2017). An economic assessment of the global potential for seawater desalination to 2050. Water, 9 (10).

Oceanica, and also cause oxygen depletion when sodium bisulphite is used as chlorine control[1025]. The temperature of the discharged brine is also important and can potentially lead to temperature variations altering the fragile equilibrium of marine ecosystems.

Desalination can also pose a threat to marine life, as fish, larvae and other organisms can be injured or killed when trapped or sucked into open water surface intake pipes.

Most forms of desalination are energy intensive. The non-negligible energy consumption in the desalination process contributes to environmental pollution and global warming, depending on the type of technology and fuel used. This is clearly an issue for conventional desalination plants which rely on fossil fuels. If fossil fuels are used as the primary energy source, then both greenhouse gases (GHG) such as CO_2 and acid rain gases such as NO_x and SO_x are emitted in the atmosphere[1026].

For these reasons, it is also important to consider and put in place alternative strategies which are more environmentally friendly. Water conservation, water use efficiency, storm water capture and reuse, and recycling water, can become effective strategies to reduce pollution and limit the environmental damages of desalination while supplying similar amounts of freshwater where needed.

9.2.3 Description of methodology for monetisation incl. indicators used and data sources

Due to lack of data, it has not been possible to estimate quantitatively the current value of abstraction of water abiotic flows at the global level. More specifically, no studies looking at the monetary value of environmental impacts of water abstraction on marine ecosystems have been found.

However, we reviewed relevant literature showcasing some case studies as well as collected statistics which can help to understand the magnitude of the economic and employment benefits of the desalination and, more in general, abstraction of water sector.

Most of the economic benefits of abstracting water to produce freshwater for human consumption are due to its role in mitigating the detrimental economic impacts of water scarcity[1027]. Using a Computable Generable Equilibrium (CGE) model for Israel, Palatnik (2019) assessed the economic value of seawater desalination arising by limiting water shortages that affect the country's economy and cause an economic loss. According to the results, the value of desalinated water corresponds to about $4 per m^3, which is higher than its direct costs.

Since to higher water shortages correspond higher losses of GDP[1028], the following chart shows that the value of desalinated water is higher when desalinated capacity is low. As desalinated capacity increases, water shortage and corresponding GDP loss decline, diminishing the value of additional desalination capacity.

The author concludes that seawater desalination can bring substantial economic value due to its role in diminishing natural freshwater shortages.

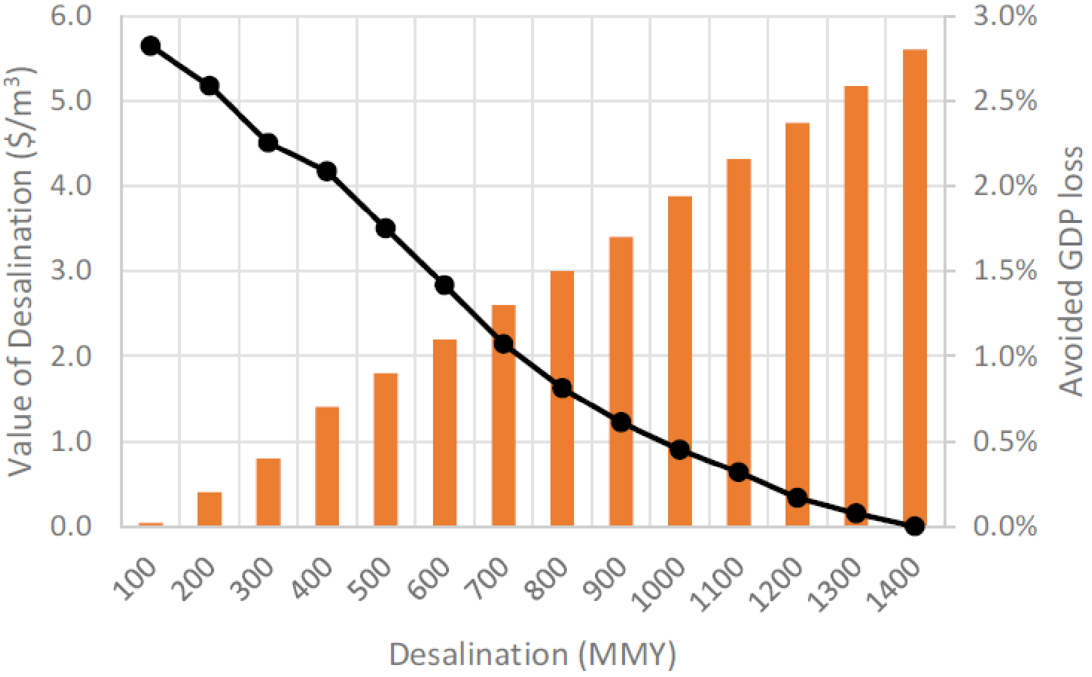
[1025] Bernat et al. (2010). The economics of desalination for various uses. Chapter 18 in *Re-thinking water and food security*.

[1026] Sustainable Water Integrated Management – Support Mechanism (SWM-SM) (2012). Economic considerations for supplying water through desalination in South Mediterranean countries.

[1027] Dolan et al. (2021). Evaluating the economic impact of water scarcity in a changing world. Nature Communications 12, article 1915.

[1028] Gross Domestic Product (GDP).

Figure 5.78 The value of seawater desalination in terms of avoided GDP loss



Source: Palatnik (2019)[1029].

Another study looked into the employment and economic benefits of seawater desalination for the local value chain. In a case study for Texas, Ziolkowska et al. (2013)[1030] investigated the socio-economic impacts related to the construction of a desalination plant in the region and in interlinked sectors. According to their estimates, 2,050 jobs could be created in the San Antonio region and 316 additional jobs could arise in other regions within Texas, with an expected GVA (Gross Value Added) impact of US$262.8 million over 10 years from the construction of the plant.

While the desalination sector is still relatively small in many economies, including in the European Union (EU), it significantly impacts associated societal and economic sectors and jobs (e.g in agriculture of tourism)[1031], particularly in water-scarce regions and small islands. These could further expand in the future as desalination development will become more economically feasible for countries undergoing continued development by 2050, including in the South-East Asia and South America[1032].

[1029] Palatnik (2019). The economic value of seawater desalination – The case of Israel: Proceedings of 2015 and 2016 ACMES conferences. In: Economy – Wide modelling of water at regional and global scales. Glyn Wittwer editor, Springer.

[1030] Ziolkowska et al. (2013). Perspectives and challenges for water desalination – A socio-economic multi-regional analysis and a case study for Texas.

[1031] JRC (2021). Smart specialisation in the context of Blue Economy – Analysis of desalination sector.

[1032] Gao et al. (2017). An economic assessment of the global potential for seawater desalination to 2050. Water 9, 763.

While the desalination plants could have a positive economic impact several studies highlight that they can also entail many negative impacts on marine ecosystems. The paper by Soliman et al. (2021)[1033] describe some of them, including:

- Brine discharge is a potential threat to marine life and water quality, as it contains dangerously high concentration of salts and other minerals. In addition, because of its high density and salinity, brine waste can accumulate in and around disposal areas smothering bottom dwelling species and significantly altering coastal ecosystems.
- Most desalination plants are very energy-intensive. Desalination could lead to an increased fossil fuel dependence, increased greenhouse gas emissions, and could exacerbate climate change.
- Desalination surface water – but also open ocean water - intakes are a threat to marine life. Mature fish, larvae, and other marine life can be significantly injured or killed when they become trapped or sucked into open water surface intake pipes.

However no economic or monetary assessments are conducted in these studies.

9.3 Renewable Energy Generation

9.3.1 Description of Ecosystem Service / Benefit and Impact

The marine environment offers an enormous opportunity to generate significant amounts of energy generated by offshore energy infrastructures. Many thousands of structures have been installed in the oceans providing energy from both fossil fuels and renewable sources, and the last decade saw the installation of as many infrastructures as in the 50 years before[1034].

Offshore renewable energy has in particularly grown rapidly as it offers a vital solution for the energy transition to a decarbonised energy sector and economy, and can mitigate the effects of climate change[1035]. Ocean renewable energy represents an opportunity for many countries to satisfy their increasing energy demand and reduce their dependency on imported fossil fuels while using alternative and clean sources of energy. Being installed offshore, these technologies could be used not only to provide electricity to land-based activities, but also to other offshore installations, e.g. fish farms and aquaculture, coastal protection systems, etc.

Marine renewable energy refers to any type of technology in the marine space that is used to generate renewable energy, an example being offshore wind energy. This technology takes advantage of the force of the wind that is produced on the high seas, where it reaches a higher and more constant speed than on land due to absence of barriers, and is currently at the most advanced stage of development compared to all other offshore energy technologies. Currently most of existing offshore wind farms are of the "fixed foundation" type, located in shallow waters (up to 50 or 60 meters deep), but when fixed foundations become uneconomical (for depth over 60 meters) floating wind turbines anchored to the ocean floor become the only available option. This type of turbine is more recent and is starting to be deployed to take advantage of the higher wind potential of deeper offshore areas.

[1033] Soliman, M. N., Guen, F. Z., Ahmed, S. A., Saleem, H., Khalil, M. J., & Zaidi, S. J. (2021). Energy consumption and environmental impact assessment of desalination plants and brine disposal strategies. *Process Safety and Environmental Protection*, *147*, 589-608.

[1034] Gourvenec et al. (2022). Global assessment of historical, current and forecast ocean energy infrastructure: Implications for marine space planning, sustainable design and end-of-engineered-life management. Renewable and Sustainable Energy Reviews 154, 111794.

[1035] Zullah et al. (2016). Easing climate change with recent wave energy technologies. Fundam Renewable Energy Appl. ,6:217.

In the scientific literature, marine renewable energy is distinct from the so-called *ocean renewable energy*, which refers specifically to drawing power from the ocean to generate energy from tidal currents, tidal range, waves, temperature gradients, and salinity gradients[1036].

Currently the following types of ocean renewable energy exist or are under development[1037]:

- Tidal barrage, generating energy from the difference in height between high and low tides;
- Tidal in-stream, using hydrokinetic underwater turbines to generate electricity from fast flowing currents;
- Wave, producing energy from surface motion of ocean waves or from pressure fluctuations below the surface;
- Ocean thermal, making use of temperature differences between upper surface layer and deeper layers of the sea;
- Salinity gradient, using the difference in salt concentration between fresh and seawater.

Ocean renewable energy therefore rely on the movements of natural resources like currents or on the gravitational forces of the Sun, Moon and Earth, making them not only a clean but also a more predictable source of energy.

Importantly, these technologies can also be combined with other marine renewables, for example with wind turbines to boost capacity and energy generation[1038]. They can also be used to provide energy in areas without on-grid infrastructure like remote islands.

Besides supplying energy, ocean and marine renewables offer a means to achieve some of the Sustainable Development Goals (SDGs), especially SDGs 7, 13 and 14: "access to affordable and clean energy, combatting climate change and its impact and sustainable use of oceans, seas and marine resource"[1039].

9.3.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

Abiotic flows are independent from ecosystem state changes, but potential conflicts may arise over the usage of marine space and resources, which could be instead devoted to other maritime activities such as shipping, fishing and deference. In this sense, certain geographical areas with good environmental conditions for the development of offshore renewable energy could be already dedicated to other maritime activities, therefore limiting the effective generation potential that the ocean offers to produce renewable energy. This existing conflict requires careful marine spatial planning, coordination work and implementation of dedicated policies among key players such as the government, the shipping and other maritime industries[1040].

Besides conflicts with other uses of the marine environment, it is important to acknowledge that renewable energy generation can also have unintended and detrimental effects on marine life and the environment. Underwater turbines might disrupt fisheries and coral reefs, while ocean renewable energies located near the shore can influence migration patterns of aquatic

1036 OES. International Energy Agency (2020). Ocean energy systems.

1037 Quirapas and Taeihagh (2021). Oceanc renewable energy development in Southeast Asia: Opportunities, risks and unintended consequences. Renewable and Sustainable Energy Reviews 137, 110403.

1038 Sustainable Energy Association of Singapore (SEAS) (2018). A position paper by the sustainable energy association of Singapore marine renewables working group.

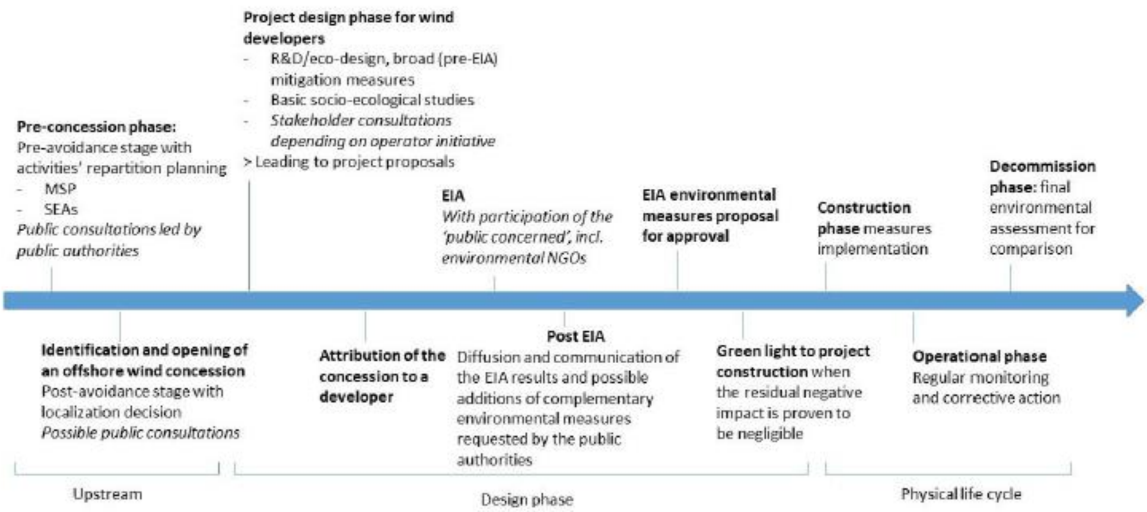
1039 UN General Assembly. Resolution adopted by General Assembly. Paris: UN, 2015.

1040 Quirapas and Taeihagh (2021). Oceanc renewable energy development in Southeast Asia: Opportunities, risks and unintended consequences. Renewable and Sustainable Energy Reviews 137, 110403.

animals and cause unnatural silt build-ups impeding the flow of sediments[1041]. Changes in waves and currents affect fish species that depend on currents to transport larvae, with a potential alteration in spawning and feeding grounds for these species[1042]. Tidal plants located at the mouth of estuaries can alter the flow of saltwater into and out of estuaries, impacting the hydrology and salinity of these nursery environments for many marine organisms[1043]. Finally, ocean thermal mainly affects the nearby marine environment through heating the water (with detrimental effects especially on corals), release of toxic chemicals, and entrainment of small organisms in intake pipes. Offshore renewables will be crucial in achieving the climate transition targets, but to be truly sustainable their development should be fully compatible with marine biodiversity recovery and ocean resilience[1044]. While some effects have already been studied, there is still uncertainty on some of the environmental impacts arising over the lifecycle of renewable energy technologies in the ocean, especially for technologies such as tidal and waves which still are in their infancy phase.

Among the available technologies, offshore wind farms are by far the renewable energy infrastructure with the most data available regarding their environmental impacts. Pressures arise over the entire project development cycle (depicted in the figure below), with the major environmental concerns being increased noise levels, risk of collisions for migratory birds, changes to benthic and pelagic habitats impacting fisheries, alteration to food webs, pollution from increased vessel traffic and release of contaminants from seabed sediments[1045]. Once operational, vibrations from the windmills can also disturb marine mammals. To limit the influence on the sea fauna, it is therefore key to plan and locate the offshore wind farms far from birds' and marine mammals' migration corridors.

Figure 5.79 Offshore wind energy project development cycle



Source: WWF (2021).

1041 UNESCAP (2012). Fact sheet: ocean energy.

1042 Shaw (1982). Wave energy: a design challenge. New York: Halsted Press.

1043 Pelc and Fujita (2002). Renewable energy from the ocean. Marine Policy 26, 471-479.

1044 WWF (2021). Nature protection and offshore renewable energy in the European Union.

1045 Bailey et al. (2014). Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. Aquatic Biosystems 10, 8.

9.3.3 Description of methodology for monetisation incl. indicators used and data sources

The economic benefits of ocean and marine renewable energy can be operationalised by assessing the employment benefits that renewable energy generation can deliver.

The analysis has been performed according to the following steps:

- Source information on the current employment generated per unit of installed marine and ocean renewable energy in terms of e.g. jobs per MW[1046];
- Estimate the technical deployment potential of marine and ocean renewable energy at the global level up to the year 2050, e.g. in TW[1047] of installed capacity;
- Calculate the current annual employment generated by marine and ocean renewable energy at the global level, e.g. in terms of jobs created following the expansion in installed renewable capacity over a year;
- Define a set of assumptions to project the deployment of marine and ocean renewable energy in the business as usual (BAU) and scaled up effort (SUE) scenarios;
- Calculate the future annual employment benefit generated by marine and ocean renewable energy at the global level in the BAU and SUE scenarios.

This methodology comes with some limitations. These are described in the next section.

After assessing the robustness of the methodology, the next sections will describe in detail the sources used to perform the quantification as well as how the two scenarios were constructed.

9.3.4 Assessment of reliability and robustness of methodology and data sources

The BAU and SEU scenarios have been designed based on employment estimates per MW of installed capacity, recent trends in installed capacity, and projections sourced from the most recent scientific papers as well as reports from well-recognised international organisations such as the International Renewable Energy Agency (IRENA) and the World Resource Institute (WRI).

While these secondary sources provide a solid basis for the adopted methodology, many data gaps have been identified and partially limit the width of the performed analysis.

Besides the lack of data, additional limitations can be summarised as follows:

- The projected values are based on current estimates of jobs created per unit of renewable installed; these estimates will likely change in the future due to changes in productivity levels and economies of scale;
- We relied on a single figure of jobs per MW which might be specific for a certain geographical location; ideally, a more developed analysis would rely on country- or region-specific estimates (where available);
- We calculated the number of jobs per MW of installed wind capacity assuming that there are no differences between onshore and offshore wind; this is due to the absence of data on offshore wind employment from the IRENA Statistics[1048];
- The projected increase in the installed capacity of marine and ocean renewable energy is based on additional capacity currently in the pipeline and available forecasts; many factors could potentially influence the yearly installation rate of each technology in the future e.g. evolution in CAPEX and OPEX costs, national policies, technological progress, but these factors were not taken into account due to the associated high level of uncertainty.

[1046] Megawatt (MW).

[1047] Terawatt (TW).

[1048] Irena Statistics (2022). Available at: https://irena.org/Statistics.

9.3.5 Description of the baseline (method and results)

Estimates of the number of jobs generated per unit of installed marine and ocean renewable energy were calculated using the installed capacity and employment estimates from IRENA Statistics (2022). These are reported in the table below.

Table 5.16 Sourced job estimates for marine and ocean renewable energy

Technology	Geographical level	Installed capacity in 2020 (MW)	Jobs in 2020	Jobs per MW
Ocean energy (incl. tide, wave, etc.)	Global	526.840	1,288	2.445
Wind energy (onshore and offshore)	Global	732,410.170	1,254,206	1.712

Once job estimates have been calculated, we collected data on the existing and projected installed capacity of all marine and ocean renewable energy. These are reported in the next table, which also shows the maximum global resource potential for each renewable technology and the literature sources.

Table 5.17 Resource potential, current installed capacity and market outlook for marine and ocean renewable energy

Technology	Global resource potential (TWh/a)	Current installed capacity (GW)	Additional capacity in the pipeline (GW)	Source(s)
Offshore wind	420,000	23	413	IEA (2019)[1049], IRENA (2019)[1050], RenewableUK (2021)[1051]
Tidal	1,200	0.542	7.9	IRENA (2020)[1052]
Wave	29,500	0.0023	0.1	IRENA (2020)
Ocean thermal	44,000	-	-	Nihous (2007)[1053]
Salinity Gradient	1,650	-	-	Skråmestø et al. (2009)[1054]

There is still significant uncertainty on the renewable generation potentials of marine and ocean renewable energy, and the Table reports the theoretical maximum potential. Nonetheless, the feasible maximum potential for each technology will likely be lower due to technical, geographical and economic constraints[1055].

[1049] IEA (2019). Offshore wind outlook 2019

[1050] IRENA (2019). Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation paper), International Renewable Energy Agency, Abu Dhabi

[1051] RenewableUK (2021). Global offshore wind project pipeline exceeds 400 gigawatts. Available at: https://www.renewableuk.com/news/581596/Global-offshore-wind-project-pipeline-exceeds-400-gigawatts-.htm.

enewableUK (2021). Global offshore wind project pipeline exceeds 400 gigawatts. Available at: https://www.renewableuk.com/news/581596/Global-offshore-wind-project-pipeline-exceeds-400-gigawatts-.htm.

[1052] IRENA (2020). Innovation outlook : Ocean energy technologies, International Renewable Energy Agency, Abu Dhab

[1053] Nihous GC (2007). A preliminary assessment of ocean thermal energy conversion resources. J Energy Resour Technol, 129(1): 10-7.

[1054] S Skråmestø, Ø. et al. (2009): Power Production based on Osmotic Pressure. Waterpower XVI, July 2009. http://www.statkraft.de/images/Waterpower_XVI_-_Power_production_based_on_osmotic_pressure_tcm21-4795.pdf

[1055] Borthwick (2016). Marine renewable energy seascape. Engineering 2, 69-78.

9.3.6 Description of the" business as usual" (BAU) scenario (method and results)

In the BAU scenario, it is assumed that the installed capacity of marine and ocean renewable energy will grow in line with the additional capacity currently in the pipeline. This scenario is consistent with recent trends in the expansion of renewable energy and reflects the case in which no additional efforts are made to exploit renewable energy from the oceans.

Our calculations indicate that, by 2030, ocean and marine renewable energy could bring about an opportunity for the creation of more than 250,000 jobs, increasing by up to 725,000 by 2050.

9.3.7 Description of the "scaled up efforts" scenario (method and results)

The SEU scenario describes a future with significant scaling up harnessing and use of offshore wind and renewable ocean energies with the view of achieving the climate neutrality goal by 2050. The electricity generated from ocean-based energy sources is also used to support other abiotic flows such as the abstraction of seawater to be desalinated[1056] or to support fisheries and aquaculture operations.

In this case, offshore wind installed capacity is projected to increase in line with the IRENA's renewable energy roadmap (REmap), which limits the rise in global temperature to well below 2 degrees and closer to 1.5 degrees above pre-industrial levels[1057]. By 2050, the total offshore wind installed capacity will reach up to 1,000 GW worldwide. For ocean renewable energy, we rely on deployment numbers from the Policy and Innovation Group[1058], estimating 115 GW of wave energy and 77 GW of tidal stream installed capacity by 2050.

Our calculations indicate that, by 2030, ocean and marine renewable energy could generate more than 700,000 additional jobs in the SEU scenario, increasing by more than 2 million by 2050.

9.3.8 Comparison of results from the two scenarios

The increased ambition of the SEU scenario compared to the BAU scenario allows to achieve much larger employment benefits due to rapid deployment of marine and ocean renewable energy.

10. Spatial functions

10.1 Maritime Transportation

10.1.1 Description of Ecosystem Service / Benefit and Impact

Maritime transportation is a spatial function, which is not treated as either an ecosystem service or abiotic flow. Rather, it is identified as the use of the environment for transportation and

[1056] US Department of Energy (2019). Powering the blue economy: Exploring opportunities for marine renewable energy in maritime markets. Washington, DC.

[1057] IRENA (2019). Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation paper), International Renewable Energy Agency, Abu Dhabi.

[1058] Supergen Offshore Renewable Energy Hub (2021). What is the value of innovative offshore renewable energy deployment to the UK economy?

movement on water.[1059] Coastal and maritime areas are a means of transportation and support a number of industries and activities, including maritime shipping (trade), cruise liners, military vessels, ferries, fishing boats, and recreational boats.[1060] All of these contribute to a range of different pressures that affect the environment, air quality, and human welfare. Nevertheless, maritime transportation is largely dominated by trade. In fact, maritime shipping is the backbone of international trade, as over 80% of the volume of global trade is carried by sea.[1061] Since maritime shipping dominates the maritime transportation sector, it will be the focus of this section.

Maritime shipping is responsible for:

- Driving 80-90% of global trade, moving 10 billion tonnes shipments across the oceans annually.[1060] Maritime shipping underpins the global supply chain linkages and economic interdependencies.[1062] Each year, the industry transports nearly 2 billion tons of crude oil, 1 billion tons of iron ore (the raw material needed to create steel), and 350 million tons of grain. These shipments would not be possible by road, rail, or air.[1063]
- Generating $5.4 trillion in global economic activity every year, with $1.5 trillion of goods moving through the US ports alone.[1064]
- Causing a host of negative impacts on the marine and coastal ecosystem, including: air pollution, greenhouse gas (GHG) emissions, releases of ballast water with potential to contain aquatic invasive species, historical use of polluting antifoulants, risks of oil and chemical spills, dry bulk cargo accidental releases, the accidental and purposeful release of garbage, underwater noise pollution; accidental ship-strikes with marine megafauna, risk of ship grounding or sinkings, and widespread contamination of ports during transhipment or ship breaking activities.[1060]
- Contributing over 600 Mt of CO_2 to global GHG emission annually, which is at least 2.5% of the world's total CO_2 emissions.[1065]

10.1.2 Overview of which drivers, activities, pressures and state changes affect the ecosystem service/ benefit

There are many activities within the maritime shipping industry, including the movement of marine vessels and the operation of the ports, in addition to activities needed to support it. For the purposes of clarity and depth, marine shipping in this assessment focuses solely on the global movement of vessels, and how they affect marine and terrestrial ecosystem quality,

[1059] Committee of Experts on Environmental-Economic Accounting, 'System of Environmental Accounting – Ecosystem Accounting: Final Draft,' March 2021, 121.

[1060] Walker, Tory et al. 'Environmental Effects of Marine Transportation.' In *World Seas : an Environmental Evaluation II,* ed. Charles Sheppard (Academic Press, 2019), 505-530.

[1061] United National Conference on Trade and Development, 'Review of Maritime Transport 2021,' 2021, https://unctad.org/system/files/official-document/rmt2021_en_0.pdf.

[1062] United National Conference on Trade and Development, 'Review of Maritime Transport 2018,' a2018, https://unctad.org/system/files/official-document/rmt2018_en.pdf.

[1063] International Chamber of Shipping, 'Shipping and world trade: driving prosperity,' https://www.ics-shipping.org/shipping-fact/shipping-and-world-trade-driving-prosperity/#:~:text=As%20of%202019%2C%20the%20total,than%2014%20trillion%20US%20Dollars.

[1064] MacLean, Craig. 'Government action and the new blue economy.' In *Preparing a Workforce for the New Blue Economy*, ed. Liesel Hotaling, Richard Spinrad (Elsevier, 2021), 513-525.

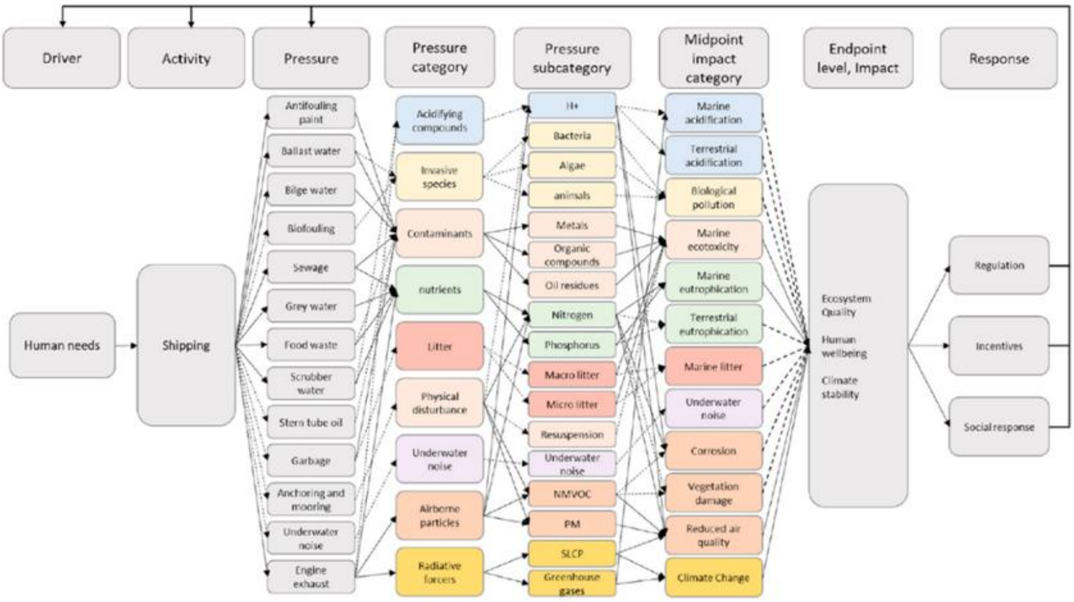
[1065] UK Research and Innovation, 'Shipping industry reduces carbon emissions,' August 2021, https://www.ukri.org/news/shipping-industry-reduces-carbon-emissions-with-space-technology/#:~:text=The%20shipping%20industry%20is%20responsible,the%20world's%20total%20CO2%20emissions.

impacts on human welfare, and climate change. There are several categories within vessels, ranging from passenger ships to oil tankers. The following includes RoPax vessels, Vehicle carriers, Cargo ships, Container ships, Tankers, Passenger ships, Cruisers, Fishing vessels and Service ships.

Maritime shipping drives the global economy, as every country is dependent on maritime trade and commerce. Maritime shipping is critical due to its ability to internationally transport a high volume of goods for an economical cost (compared to other modes of transportation). Thus, the primary driver for maritime shipping is basic human need.[1066] In order to achieve basic human needs (including food, shelter, security, goods, and services) maritime shipping is critical to societies around the world.[1067]

However, there are multiple environmental and human health damages associated with maritime shipping. Erik Ytreberg et al. (2021) developed a conceptual framework to illustrate how the pressure of difference emission sources from maritime shipping can be structured to assess the environmental impact. The pressure sources include 'antifouling paints, ballast water, bilge water, biofouling, sewage, grey water, food waste, scrubber water, stern tube oil, garbage, anchoring and mooring, underwater noise and engine exhaust.'

Figure 5.80 Maritime shipping environmental drivers and pressures



Source : Ytreberg, Erik et al. (2021)[1068]

Climate change pressures are affecting maritime shipping. A positive pressure includes the fact that melting sea ice in the Arctic during the summer months is allowing for increased shipping and vessel traffic. In addition to creating shorter shipping routes, this would also substantially

[1066] Ytreberg, Erik et al. (2021) 'Valuating environmental impacts from ship emissions – The marine perspective,' Journal of Environmental Management 282 (2021).

[1067] Patrício, Joana et al. 'DPSIR – Two Decades of Trying to Develop a Unifying Framework for Marine Environmental Management?' *Frontiers in Marine Science* (2016).

[1068] Ytreberg, Erik et al. (2021) 'Valuating environmental impacts from ship emissions – The marine perspective,' Journal of Environmental Management 282 (2021).

reduce fuel consumption and emissions. At present, vessels navigating through Arctic waters require icebreaker escorts, however projections estimate that by as early as 2030, travels without icebreaker escorts will be viable, and by 2050, very likely.[1069] In contrast, climate change also delivers negative pressures for marine shipping, such as the increased frequency extreme weather, which puts vessels and cargo at an increased risk.[1070] Despite the negative environmental pressures, as a spatial function, changes in the state of ecosystems do not have an impact on the extent to which maritime transportation provides benefits.

10.1.3 Description of methodology for monetisation incl. indicators used and data sources

Monetisation for this benefit is operationalised on the basis that as a spatial function, maritime shipping provides a contribution to the economy. In order to determine the economic impact of maritime shipping, we examine:

- The value added of the maritime shipping industry to the economy at present, and its environmental impact. This is based on data sourced from:
- The United Nation's Conference on Trade and Development (UNCTAD) Review of Maritime Transport (volumes 2018-2021), an annual publication aimed at fostering transparency of the maritime shipping industry through an analysis of markets and relevant developments.
- The International Energy Association's International Shipping annual tracking report (2021) which explores GHG emissions trends and scenario pathways for the industry.

We examine the cost of decarbonizing the maritime shipping industry in the future by:

- Examining the IMO's Initial Greenhouse Gas Strategy (2018), which sets out a vision to decarbonizing international shipping.
- Assessing the cost of the decarbonization strategy based on a study performed by UMAS, in partnership with UCL and the Energy Transitions Commission (a panel of global experts.) The study was conducted on behalf of the non-profit organization Getting to Zero Coalition, which also includes the Global Maritime and World Economic Forums.

Following the initial analysis of baseline conditions and of the decarbonisation forecasts, a qualitative analysis will discuss the benefits and challenges of decarbonizing the maritime shipping industry, and the effects it will have on the environment.

10.1.4 Assessment of reliability and robustness of methodology and data sources

The data has been extracted from reliable sources, however, it is important to note that due to the recent nature of the IMO's decarbonization strategy, there is limited information available. Upon revision of the IMO's strategy (2023), it is likely that date for decarbonization estimates and forecasts will be more readily available.

10.1.5 Description of the baseline (method and results)

Maritime shipping is essential to the global economy. The industry generates $5.4 trillion in global economic activity every year, with $1.5 trillion of goods moving through the US ports alone.[1071] Globally, there are approximately 1.9 seafarers million seafarers employed by the

[1069] Boylan, Brandon. 'Increased maritime traffic in the Arctic: Implications for governance of Arctic sea routes.' *Marine Policy* 131 (2021).

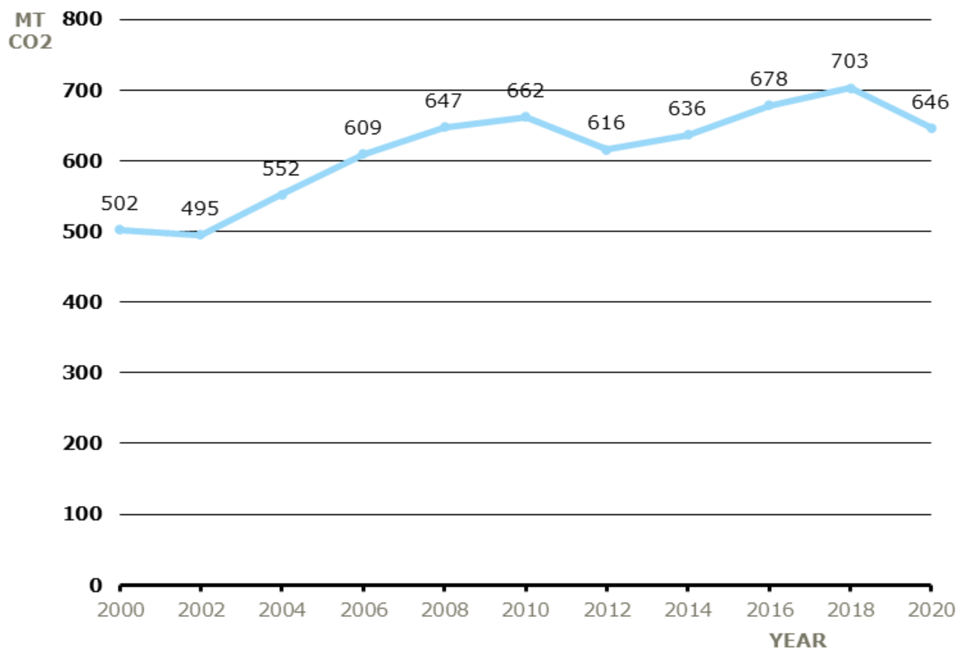
[1070] Christodoulou, Aris et al. 'Sea-level rise in ports: a wider focus on impacts.' *Maritime Economics and Logistics* 21 (2019): 482-496.

[1071] MacLean, Craig. 'Government action and the new blue economy.' In *Preparing a Workforce for the New Blue Economy*, ed. Liesel Hotaling, Richard Spinrad (Elsevier, 2021), 513-525.

industry. In 2021, the five largest seafarer supplying countries included the Philippines, the Russian Federation, Indonesia, China, and India; together representing 44% of the global seafarer workforce.[1061]

Maritime shipping contributes millions of tonnes of CO2 to global GHG emission annually. The industry's CO_2 emission have been steadily increasing over the past two decades, from 502 Mt CO_2 in 2000, to 707 Mt CO_2 in 2019, before a sharp drop to 646 Mt CO_2 in 2020, largely attribute to the COVID pandemic.[1072] In addition to CO_2, the maritime shipping industry is also responsible for emitting significant amounts of NO_x, SO_x and particulate matter.

Figure 5.81 Emissions from International Maritime Shipping 2000-2020 CO2



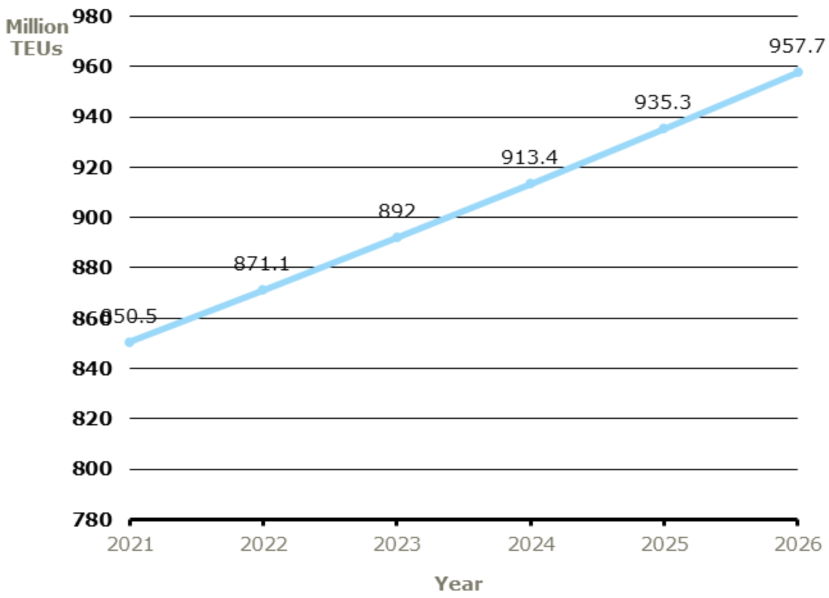
10.1.6 Description of the" business as usual" (BAU) scenario (method and results)

International maritime trade growth decreased -3.8% in 2020 following a weak pre-pandemic growth of 0.5% in 2019, however UNCTAD expects the industry to recover by 4.3% in 2021, with growth volumes expected to moderate and expand at an average annual rate of +2.4% until 2026.[1062] As the global population continues to increase (9.7 billion in 2050, up from 7.9 billion presently) the volume of trade will also rise due to increased demand.[1073]

[1072] International Energy Association. 'International Shipping – Tracking Report.' 2021. https://www.iea.org/reports/international-shipping

[1073] United Nations. 'Population Facts.' 2019. https://www.un.org/en/development/desa/population/publications/pdf/popfacts/PopFacts_2019-6.pdf

Figure 5.82 Forecasted Maritime Trade Volume Growth 2021-2026



Note: Twenty-foot equivalent unit (TEUs)

The International Maritime Organization (IMO) is the United Nations specialized agency that regulates international shipping. The organization is focused on managing the safety and security of shipping, in addition to the reduction of GHG emissions produced by ships. The IMO has created a decarbonization strategy (2018) for the international shipping sector, which aims to phase out GHG emissions 'as soon as possible in this century'.[1074] The aim of the strategy is to reduce GHG emissions by at least 50% by 2050 (compared to 2008 levels) by improving energy efficiency, decreasing carbon intensity of new ships, and strengthening the Energy Performance Index.[1075] The IMO's decarbonization strategy currently drives international maritime shipping policy development, and is expected to have a significant impact on the design and operation of all ships.[1076]

The strategy's quantitative reduction targets include:

- A minimum 40% reduction in carbon intensity by 2030, while pursuing efforts towards a 70% reduction by 2050 (using 2008 levels)
- To peak the sector's GHG emissions as soon as possible to achieve at least 50% reduction by 2050, while continuing efforts to phase them out (in line with the Paris Agreement temperature goals)

Under the BAU scenario, emissions of the maritime shipping industry are projected to continue to increase. (See Figure 4) Until 2015, the emissions in the BAU scenario are based on historical data (Smith et al. 2015; Olmer et al. 2017), and emissions in 2016 and beyond were projected using the International Council on Clean Transportation's fleet turnover model (Wang and Lutsey 2013). The analysis also considers historical and projected future demand for

[1074] The International Council on Clean Transportation. 'The International Maritime Organization's Initial Greenhouse Gas Strategy.' April 2018, https://theicct.org/sites/default/files/publications/IMO%20GHG%20strategy%20rapid%20analysis%20vf.pdf.

[1075] Joung, Tae-Hwan et al. 'The IMO initial strategy for reducing Greenhouse Gas (GHG) emissions, and its follow up actions towards 2050.' *Journal of International Maritime Safety, Environmental Affairs, and Shipping* 4 (2020).

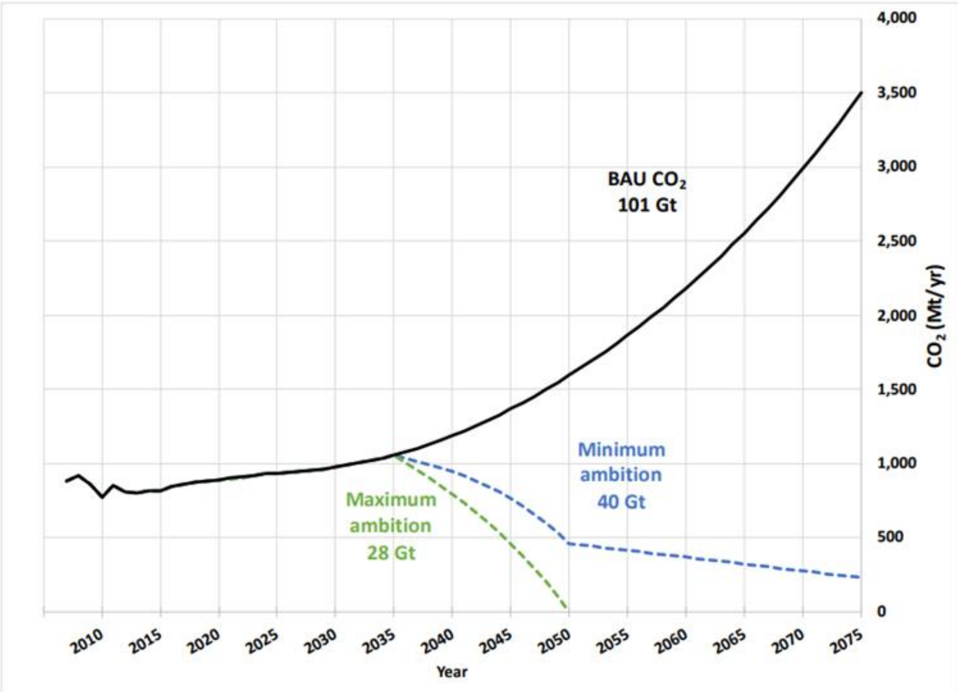
[1076] DNV Maritime. 'Maritime Forecast to 2050: Energy Transition Outlook 2021.' 2021.

international shipping from the United Nations Conference on Trade and Development (UNCTAD). Based on this data, the BAU situation projects cumulative emissions exceeding 100 GT CO_2 between 2015 and 2075.[1074]

10.1.7 Description of the "scaled up efforts" scenario (method and results)

Two SUE scenarios have been modelled based on the IMO's strategy: the minimum ambition and maximum ambition scenario. The minimum ambition scenario projects a 40% carbon intensity reduction by 2030, and an emissions reduction of 50% by 2050, with full decarbonisation by 2100. In comparison, the maximum ambition scenario is driven by the goal to phase out GHG emissions entirely by 2050, at a pace consistent with the Paris agreement.

Figure 5.83 CO2 emissions from the IMO's initial GHG strategy – BAU vs. minimum ambition (green) and maximum ambition (blue), with cumulative emissions from 2015 – 2075.



Both of the decarbonization scenarios under the IMO's strategy require intensive investment. A study conducted (2020) estimates that for the minimum ambition scenario, the cumulative investment required would be between $1 trillion to $1.4 trillion, which is an average of between $50-70 billion annually from 2030-2050. For the maximum ambition scenario, the estimates increase to between $1.4 trillion to $1.9 trillion, which means an addition $400 billion is would be needed to fully decarbonize the sector by 2050.[1077]

Table 5.18 Estimated cost of decarbonization

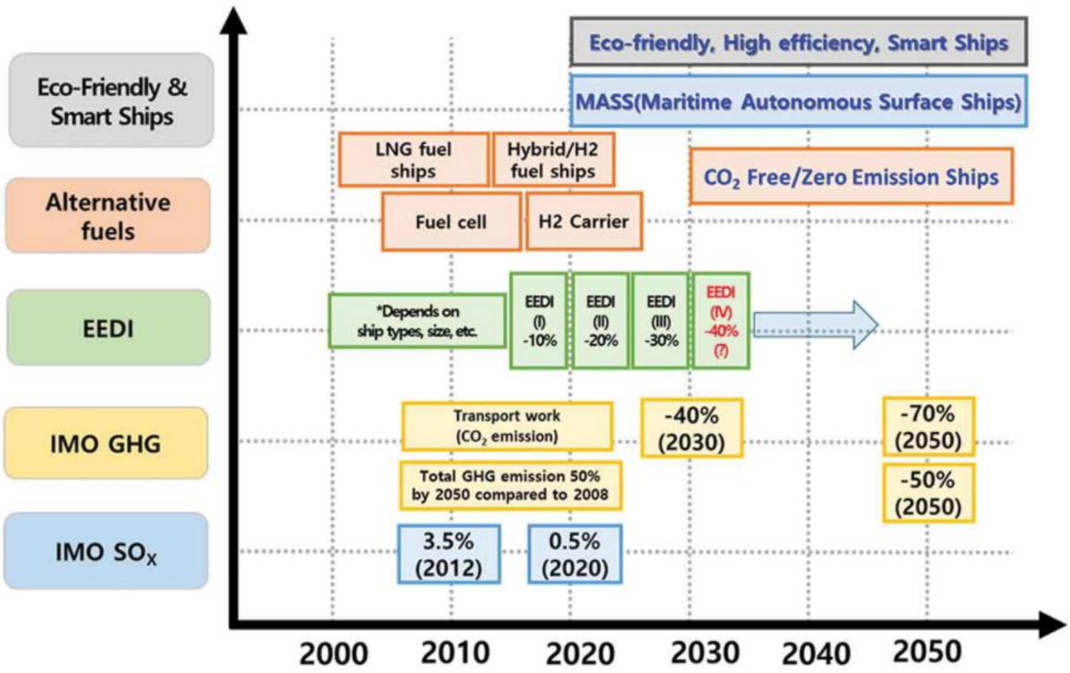
Estimate	Minimum Ambition SUE	Maximum Ambition SUE
Low	$1 trillion	$1.4 trillion
High	$1.4 trillion	$1.9 trillion

[1077] Saul, Jonathan. 'UN's decarbonization target for shipping to cost over $1 trillion: study.' *Reuters*, January 2020. https://www.reuters.com/article/us-shipping-environment-cost-idUSKBN1ZJ0D4

10.1.8 Comparison of results from the two scenarios

There is stark contrast between the BAU and SUE efforts scenarios. The BAU scenario will result in over 100 Gt of CO_2 emissions, whereas the SUE scenarios project between 28-40 Gt of CO_2 emissions. There are many measures that ocean governance can look into in order to promote the reduction of emissions in the maritime shipping economy, thereby reducing both the negative impacts on ocean ecosystems and human welfare. Some of the preliminary measures in the IMO's strategy include energy efficiency design standards, vessel speed reduction, alternative low-carbon fuels, market based measures, as well as fossil-free fuels.

Figure 5.84 Regulation and technology trend, as per the IMO strategy.



Source: Joung et al. (2020)

Together, these measures will help contribute to the emission reductions needed for the industry to meet its decarbonization goals. A study by Bouman et al. (2017) determined that as long as these measures are well prepared, a combination of the existing technologies available is expected to reduce up to 75% of GHG emissions by 2050.[1078]

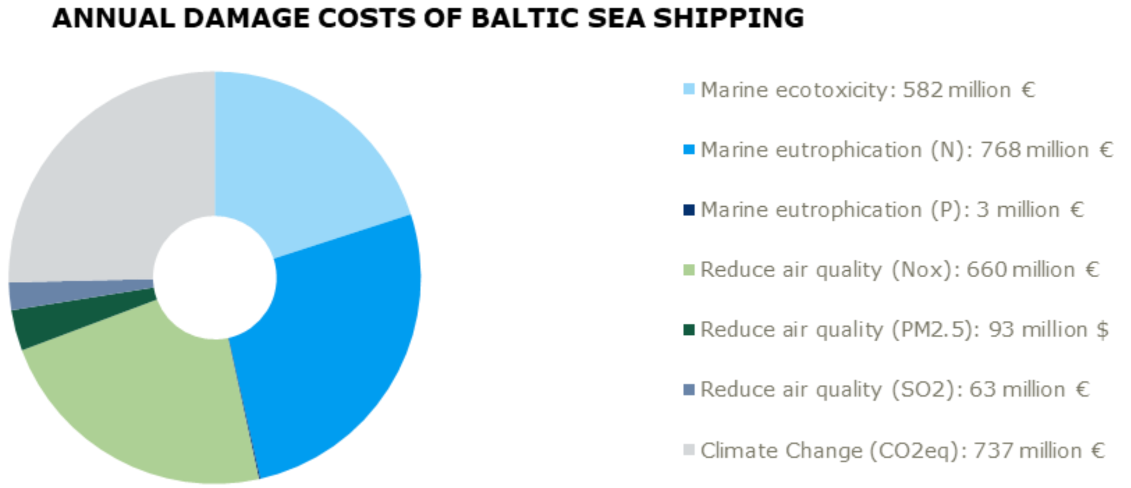
Baltic Sea Case Study: Alterative ways of estimating environmental damage ($) of maritime shipping

Erik Ytreberg et al. (2021) conducted a study to develop a framework to assess how different pressures from maritime shipping degrade marine ecosystems, air quality and human welfare in order to monetize the impacts. A case study of the Baltic Sea shipping put the framework into practice. The results of the Baltic Sea case showed the total annual damage costs of Baltic Sea shipping is €2.9 billion. The 2018 damage costs (mean values) caused by shipping in the

[1078] Bouman, E. A., E. Lindstad, A. I. Rialland, and A. H. Strømman. 2017. "State-of-the-art Technologies, Measures, and Potential for Reducing Ghg Emissions from Shipping–a Review. Transportation Research Part D." Transport and Environment 52: 408-421

Baltic Sea were divided into the Impact categories of marine ecotoxicity, marine eutrophication, reduced air quality and climate change. The framework from this study can be used globally, but the damage costs presented on the marine environment are restricted to emissions on the Baltic Sea and Kattegat region, as they are based on willingness to pay studies conducted on citizens around the Baltic Sea.

Figure 5.85 Annual damage costs of Baltic Sea shipping



APPENDIX 7. – DETAILED DESCRIPTION OF POSSIBLE RESPONSES

This Annex contains the potential responses that can be taken to reduce pressures in detail.

Importantly, it contains responses which are within the competence of international ocean governance but also others which are land-based and thus outside the direct influence of ocean governance. However, given the importance of those activities leading to those pressures the responses are nevertheless listed.

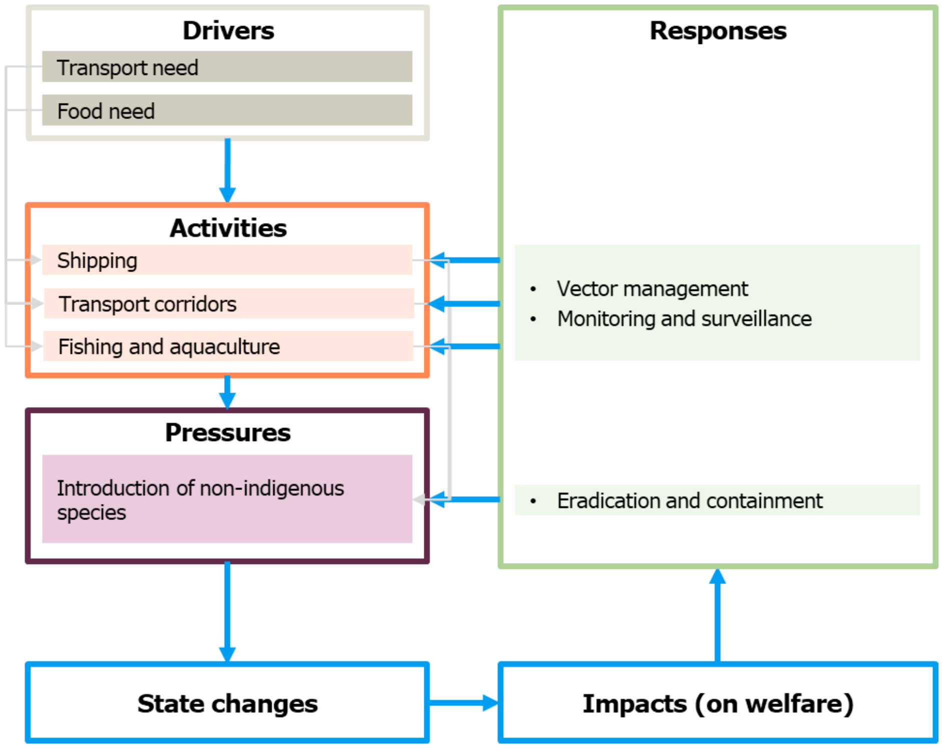
In the overview tables, they are highlighted in green in the header.

Biological pressures

Introduction of non-indigenous species

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Vector management

Vector management is considered to be the most effective way to prevent the translocation of non-indigenous species (NIS)[1079], and various options are currently available. For instance, technical measures can be applied on ships to prevent translocation through ballast water and hull fouling. For instance, open water transfer of ballast water[1080], or sterilisation of the ballast water, including with the introduction of treatment plants for such waters in ports[1081] can be implemented, the use of anti-fouling paints, fouling inspections and removal of fouling organisms are also other options[1082]. For intentional translocation through aquaculture

[1079] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1080] Vessels can be required to transfer ballast water in the open ocean before arriving at their destination, and this would kill species that are adapted to estuarine or river conditions. Then, vessels can refill their ballast tanks with water from the open ocean and organisms picked up there should not be able to survive in ports and harbours

[1081] https://www.iucn.org/downloads/marine_menace_en_1.pdf

[1082] Idem

development, the use of invasive alien species can be discouraged tout court, or the accurate assessment of the risk of using alien species before intentionally introducing them can be promoted[1083]. For unintentional transfer through transport corridors such as canals, technical solutions include the insertion of strong saline barriers or lock systems where water is treated to kill indigenous organisms[1084].

Currently, the implementation of these management options is limited[1085] – despite the risks posted by NIS.

Legislation addressing vector management worldwide is fragmentary, addressing only certain types of vectors (mainly shipping), and has been adopted mostly in a reactive fashion, following costly outbreaks of NIS.

Instruments at the international level include the International Convention for the Control and Management of Ships' Ballast Water and Sediments[1086], the Aichi Target 9[1087] on putting measures in place to manage NIS pathways, as well as the Marine Strategy Framework Directive, at the EU level, whose Descriptor 2[1088] addresses the introduction of non-indigenous species and requires that this is done at levels that do not adversely alter ecosystems. These targets should have been achieved by 2020, but this has not been the case[1089]. In additional to these binding instruments, there exists also a series of international guidelines, for instance the Convention on Biological Diversity and the Food and Agriculture Organisation's Code of Conduct for Responsible Fisheries, International Council for the Exploration of the Sea's Code of Practice on the Introduction and Transfer of Marine Organisms, and IMO's Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species[1090]. However, besides the management of ballast water and sediments, there is an absence of a legally binding and strictly monitored framework regulating unintentional introductions from most pathways, such as biofouling, the cultivation of and trade in live organisms, and transport corridors[1091] - and this limits progress in addressing this pressure. Increased IOG action could promote the exploration of legal instruments and tools to address NIS in a comprehensive way, that promote the implementation of vector management options for all different types of vectors.

Monitoring and surveillance

Information on non-indigenous species is "either very poorly documented or completely lacking" worldwide[1092]. Since NIS can pose a significant threat for biodiversity and consequently for human well-being, there is a need to document and monitor this pressure to improve understanding of the distribution of such species and the potential mechanisms by which their range is extended, in order to propose appropriate and efficient responses. There is a need for validated, detailed georeferenced inventories of NIS accessible in searchable databases.

[1083] https://www.iucn.org/downloads/marine_menace_en_1.pdf

[1084] Idem

[1085] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1086] Adopted in 1991 and entered into force in 2017.

[1087] https://www.cbd.int/sp/targets/

[1088] https://mcc.jrc.ec.europa.eu/main/dev.py?N=20&O=119&titre_chap=D2%20Non-indigenous%20species

[1089] See footnote 1085

[1090] https://www.imo.org/en/OurWork/Environment/Pages/Biofouling.aspx

[1091] See footnote 1085

[1092] See footnote 1085

However, currently, there is limited, incomplete or no understanding of NIS in many locations around the world, including in relation to the date of their first detection and the likely introduction vectors. In addition, the most important invasion vectors (i.e., ballast water, biofouling, aquaculture, trade in live specimens, canals and plastic or other debris) lack characterization and understanding at the global, and sometimes regional, levels[1093].

The identification of the main pathways through which non-indigenous species are introduced in a given sea basin is an important first step to develop tailor-made responses that address the cause of the introduction. This is because this pressure varies based on the sea basin: different species can be introduced via different pathways. The identification of the main pathways of introduction should then be followed by a prioritisation for intervention, based on the volume of species entering as well as the potential impact of those species on the marine ecosystem[1094]. Impact is to be determined based on the spread capacity, biology, ecology and life cycle of the target species, as well as type and fragility of the recipient environment and habitat type.

Beyond this, improved documentation and monitoring of NIS could also facilitate early detection of introductions, which could be key to enable rapid eradication before the invasion becomes large scale. Such monitoring can make use of existing monitoring systems, and also rely on "citizen science" and observations[1095]. Monitoring and surveillance can also involve official controls from responsible authorities, based on documentary and physical checks of vessels[1096].

Eradication and containment

Once the introduction of non-indigenous species has been verified, and classified as harmful, measures should be implemented to either eradicate or contain the population.

"Eradication" involves the complete and permanent removal of a population of invasive alien species by lethal or non-lethal means. The earlier eradication takes place, the better it is to prevent the most negative impacts of the unintentional introduction, as well as to contain the costs of the intervention. Common eradication measures include manual removal, use of biological and chemical methods[1097]. "Containment" refers to the reduction of further spread of an introduced species. Unfortunately, these methods are often "futile" and ineffective once marine organisms becomes established[1098], as these efforts are rarely successful.

The costs of eradiation and containment produced by the spread of NIS has been documented in few occasions. A study[1099] found that the total invasion costs in the Mediterranean basin amount toto $27.3 billion, out of which ($1.7 billion attributed to management expenditure (and the rest for the damages caused by the NIS).

[1093] Forrest, Barrie M., and Grant A. Hopkins (2013). Population control to mitigate the spread of marine pests: insights from management of the Asian kelp Undaria pinnatifida and colonial ascidian Didemnum vexillum.

[1094] https://ec.europa.eu/environment/pdf/nature/invasive_alien_species_implementation_report.pdf

[1095] Idem

[1096] Idem

[1097] Idem

[1098] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1099] https://neobiota.pensoft.net/article/58926/

Comparison of Responses

	Vector management	Monitoring and surveillance	Eradication and containment
Costs and benefits			
General society[1100]	/	/	/
National public authorities	***(-)*** *Public authorities could face costs related to the setting up and enforcing legal instrument(s) regulating vector management.* *Vector management is likely to reduce translocations, and therefore potential associated eradication costs (to be borne by public authorities).*	***(-)*** *Public authorities would bear costs related to increased monitoring and surveillance activities. It was not possible to estimate the costs, as these would be variable depending on the baseline.*	***(- to --)*** *Public authorities would have to pay for eradication or containment measures. It was not possible* *The majority of the costs related to NIS invasions are usually covered by damage and losses, while management and control-related expenditure represents usually*

[1100] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

	Vector management	Monitoring and surveillance	Eradication and containment
			around 20% of all costs[1101]*.*
International community	***(/ to -)*** *International community could potentially bear the costs of setting up international legal instrument(s) regulating vector management (for activities for which this does not exist yet) – these are likely to be minimal.*	***/***	***/***
Industry	***(- to --)*** *Shipping, transport and fishing/aquaculture industries might bear costs to implement vector management techniques and strategies e.g. onboard ships, on transport corridor, in terms of aquaculture practices. It was not possible to estimate these costs, but they are likely to be minimal.* *The aquaculture and fishery industry would benefit from the reduction of NIS invasion: damages of these invasions on fisheries and aquaculture are substantial (average annual costs connected to NIS invasions have been estimated at $975.5 million for the period 1990-2017 – in the Mediterranean alone)*[1102]*.*	*/*	*/*
Other	*/*	*/*	*/*
Analysis			
Geographical distribution of costs and benefits	*Costs would be mainly localised in the country(ies) where actions leading to NIS translocation are concentrated - though with globalisation this likely to be spread globally.* *Benefits of prevention would be mainly felt in areas that are potential hotspots for NIS invasion.*	*Costs and benefits would be mainly localised in the country(ies) where the*	*Costs and benefits would be mainly localised in the country(ies) where the*

1101 Paris-Saclay et al (2021) Economic costs of invasive alien species across Europe.

1102 https://neobiota.pensoft.net/article/58926/

	Vector management	Monitoring and surveillance	Eradication and containment
		NIS has been translocated.	*NIS has been translocated.*
Assessment of cost-effectiveness	**++** *Vector management is the most cost-efficient option, as eradicating is not successful and very costly. Countries with a higher proportion of money spent on biosecurity and prevention measures experience generally lower damage costs[1103].*	**++** *Monitoring and rapid response are the most cost-effective means to avoid or mitigate the damage caused by NIS[1104], in particular in cases where vector management is not feasible.*	***(- to ---)*** *Eradication and containment are not very cost-efficient, as they are expensive but rarely successful when a species has spread – and the damages of invasions are substantial.*

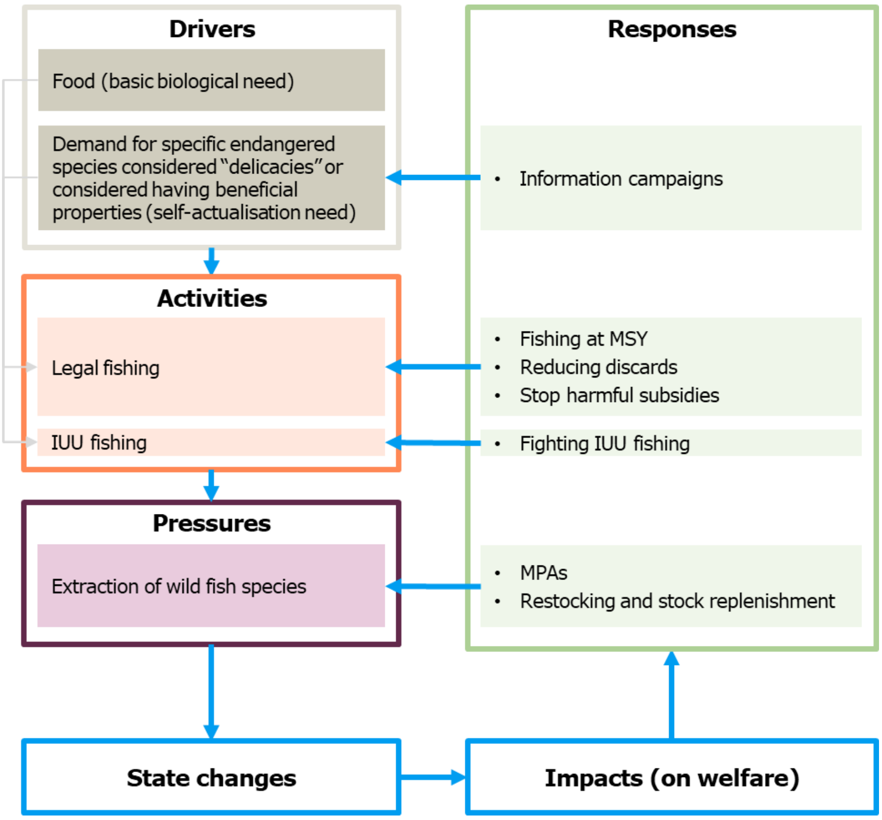
/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

[1103] Paris-Saclay et al (2021) Economic costs of invasive alien species across Europe.
[1104] https://www.reabic.net/journals/mbi/2017/3/MBI_2017_Piria_etal.pdf

Extraction of wild fish species

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Information campaigns to affect cultural practices

Some fish species continue to be fished due to their perceived medical properties and/or since they are considered a delicacy even though they are endangered.[1105] One way to try and tackle ongoing illegal trade of those is to try and address demand through information campaigns to change cultural practices.

Such campaigns should be developed in the target regions to ensure that the respective local drivers, believes and practices are fully understood and thus can be addressed effectively.

Fishing at maximum sustainable yield

Maximum sustainable yield (MSY) is the maximum yield that may be taken year after year. It is characterized by a level of fishing mortality that will, on average, result in a stock size that

[1105] Examples include Totoaba macdonaldi (Ong, E., Teng, C. (2022). A rapid assessment of online trade in sea cucumber and fish maw in Malaysia and Singapore. See: https://www.traffic.org/site/assets/files/16797/a_rapid_assessment_of_online_trade_in_sea_cucumber_and_fish_maw_in_malaysia_and_singapore_final.pdf) or different species of seahorses (see Rosa, I., et al (2013). Seahorses in Traditional Medicines: A Global Overview. See: https://www.researchgate.net/publication/278655134_Seahorses_in_Traditional_Medicines_A_Global_Overview) produces the maximum sustainable yield over unlimited time. It is a long-term management system that focuses on obtaining the best from the productive potential of living marine resources, without compromising its use by future generations.

Recent scientific research suggests that, despite the overall negative trends, with appropriate governance, the median time required to rebuild overfished stocks could be less than 10 years, and, if reforms were implemented, most of the currently overfished stocks could be considered healthy by the middle of the century[1106]. However, it is important to note that there is no consensus on whether these recovered ecosystems and populations could come back to their original states and functions. In addition, for some extremely depleted stocks, e.g., the Atlantic cod, potential recovery times are projected to be much longer[1107].

For an MSY to be implemented, data and models of fish stocks are needed. Also, the implementation needs to be enforced.

At a global level, the FAO monitors the state of the world's fishery stocks by focusing on around 445 stocks, which account for about 75 % of global catch, which thus provides a good picture of the overall status of global fish stocks.[1108] Of those monitored fish stocks, the share of stocks fished at sustainable levels has decreased significantly over the last 50 years from 90% to 66%, with the share of fish stocks fished at unsustainable levels increasing accordingly. However, there are large regional differences. Among the regions with the lowest share of sustainably fished fish stocks (around 40%) are the Mediterranean and Black Sea, Southeast Pacific, and Southwest Atlantic. The regions with the highest shares of fish stocks fished at sustainable levels (above 90%) are the Eastern Central Pacific as well as the Southwest and Northeast Pacific.

This response includes a) defining total allowable catch (TAC)[1109] leading to MSY and monitoring for all commercially fished fish stocks (from the current 75%) and b) enforcing that TAC is followed for all fish stocks.

The recent World Ocean Assessment II points out that, after implementing measures for fishing at sustainable levels, the median time required to rebuild overfished stocks could be less than 10 years; however, this also depends on the depletion status of the respective fish stocks.[1110]

Reducing discards

Discards are caught fish which are not kept but are thrown back, often dead, in to the sea. It may occur for a number of reasons, including the perceived poor quality and lack of value of fish compared to others, or because landing or retention is prohibited by regulation. Discarding constitutes a substantial waste of resources. While exact numbers are not available, it is assumed that global discard levels accounted for 11% of world catches[1111]

[1106] Garcia, Serge M., and others, eds. (2018). Rebuilding of marine *fisheries* – Part 1: Global review. FAO Fisheries and Aquaculture Technical Paper, No. 630/1. See: www.fao.org/3/ca0161en/CA0161EN.pdf

[1107] Neuenhoff, Rachel D., and others (2019). Continued decline of a collapsed population of Atlantic cod (Gadus morhua) due to predation-driven Allee effects. *Canadian Journal of Fisheries and Aquatic Sciences* vol. 76, pp. 168–184. https://doi.org/10.1139/cjfas-2017-0190 .

[1108] FAO (2020). The State of World Fisheries and Aquaculture 2020. Sustainability in action. https://doi.org/10.4060/ca9229en

[1109] Total allowable catches (TACs), or fishing opportunities, are catch limits.

[1110] UN (2021). Chapter 15 Changes in capture fisheries and harvesting of wild marine invertebrates. In: The Second World Ocean Assessment. See: https://www.un-ilibrary.org/content/books/9789216040062

[1111] FAO (2019). A third assessment of global marine fisheries discards. See: https://www.fao.org/responsible-fishing/resources/detail/en/c/1317018/

Reducing or stopping the practice of discarding has large potential for supporting the sustainable exploitation of marine biological resources and marine ecosystems and the financial viability of fisheries: discarding is wasteful of the energy and cost used to catch the fish. It also represents a waste of wealth and resources, given the importance of fish as a source of protein[1112].

Several responses (or combinations of responses) can be envisaged to reduce discards, including soft measures (e.g., awareness raising, training), technical responses (e.g. modifications to fishing gear or fishing practices), and legal responses such as discard bans or bycatch limits.[1113] According to the World Ocean Assessment II report, at the global level progress is being made in policies and management measures for fighting discards[1114].

Stop harmful subsidies

This response is in line with SDG14.6 which urges states to prohibit harmful fisheries subsidies. In 2018, annual world fishery subsidies were estimated to be around USD 35.4 billion, with a slight declining trend compared to past years[1115].

According to SDG14.6, harmful fisheries subsidies are financial contributions that stimulate overcapacity and overfishing and IUU fishing. Some subsidies in well-managed fisheries can be beneficial, such as investments in stock assessments. However, a major part of those subsidies are "capacity-enhancing subsidies" which are often harmful[1116]. E.g., they can lead to increased- and overfishing. This, in turn, can lead to reduced profits and income for fishers and reduced amounts of fish for customers, and puts marine ecosystems at risk.[1117]

The World Trade Organisation (WTO) fisheries subsidies negotiations are a lynchpin in working towards banning such capacity-enhancing subsidies. A uniform and global approach would avert competition and trade distortion issues arising from differing disciplines in this area at national level. Building on this understanding and following the adoption of the 2001 Doha Ministerial Declaration[1118], WTO parties agreed to regulate the issue of fisheries subsidies by 2019. In June 2022, a first agreement was found which now needs to be further developed and implemented.

Fighting IUU fishing

In June 2016, the Agreement on Port State Measures to Prevent, Deter and Eliminate IUU Fishing[1119], which was the first binding international agreement to target illegal, unreported or

[1112] Agnew, D. et al (2011). DRAFT FINAL REPORT Studies in the Field of the Common Fisheries Policy and Maritime Affairs. Lot 4: Impact Assessment Studies related to the CFP. Impact Assessment of Discard Reducing Policies. See: https://www.researchgate.net/profile/Sarah-Martin-73/publication/333421065_European_Commission_Studies_in_the_Field_of_the_Common_Fisheries_Policy_and_Maritime_Affairs_Lot_4_Impact_Assessment_Studies_related_to_the_CFP/links/5ced086a458515026a614845/European-Commission-Studies-in-the-Field-of-the-Common-Fisheries-Policy-and-Maritime-Affairs-Lot-4-Impact-Assessment-Studies-related-to-the-CFP.pdf?origin=publication_detail

[1113] UN (2021). Chapter 15 Changes in capture fisheries and harvesting of wild marine invertebrates. In: The Second World Ocean Assessment. See: https://www.un-ilibrary.org/content/books/9789216040062

[1114] Idem

[1115] Idem

[1116] Sumaila, U., et al. (2019). Updated estimates and analysis of global fisheries subsidies. See: https://www.sciencedirect.com/science/article/pii/S0308597X19303677?via%3Dihub

[1117] OECD (2018). Relative Effects of Fisheries Support Policies. See: https://www.oecd-ilibrary.org/agriculture-and-food/relative-effects-of-fisheries-support-policies_bd9b0dc3-en

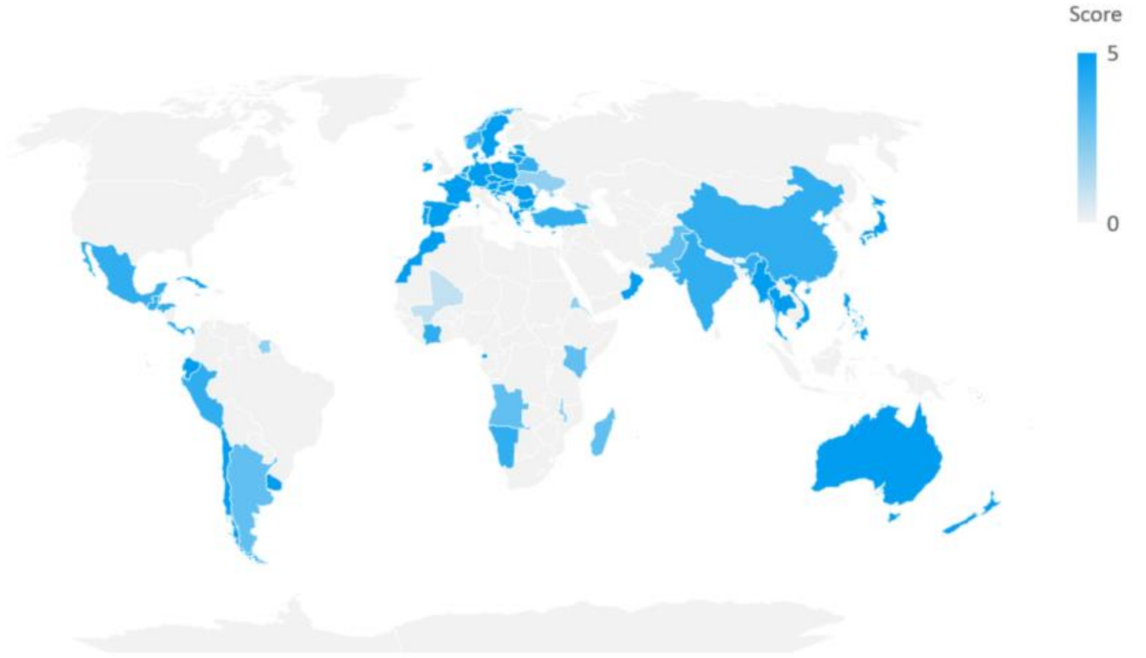
[1118] Doha Ministerial Declaration, adopted on the 14 Nov 2001 at the Fourth Ministerial Conference of the WTO. See https://www.wto.org/english/thewto_e/minist_e/min01_e/mindecl_e.htm

[1119] See: https://www.fao.org/port-state-measures/en/

unregulated fishing specifically, entered into force. Stopping or reducing IUU fishing would contribute greatly to global efforts of maintaining fishing at sustainable levels. Currently, as of beginning of 2022, 73 countries are parties to the Agreement[1120].

A more granular overview is available from indicator 14.6.1[1121] which is one of the indicators reporting progress on SDG target 14.6[1122]. The indicator measures Progress by countries in the degree of implementation of international instruments aiming to combat illegal, unreported and unregulated fishing on a scale from 1 (lowest) to 5 (highest). The map below presents the data from this indicator based on 2020 data. It should be noted that for a wide range of countries no data is available.

Figure Indicator 14.6.1 - Progress by countries in the degree of implementation of international instruments aiming to combat IUU fishing



Source: own illustration based on FAO data from https://www.fao.org/sustainable-development-goals/indicators/1461/en/

[1120] See https://www.fao.org/treaties/results/details/en/c/TRE-000003/ for a detailed and updated overview. Accessed on 11 Jan 2022.

[1121] See: https://www.fao.org/sustainable-development-goals/indicators/1461/en/

[1122] "By 2020, prohibit certain forms of fisheries subsidies which contribute to overcapacity and overfishing, eliminate subsidies that contribute to illegal, unreported and unregulated fishing and refrain from introducing new such subsidies, recognizing that appropriate and effective special and differential treatment for developing and least developed countries should be an integral part of the World Trade Organization fisheries subsidies negotiation" See: https://sdgs.un.org/goals/goal14

Comparison of Responses

	Information campaigns to affect cultural practices	Fishing at MSY	Reducing discards	Stop harmful subsidies	Fighting IUU fishing
Costs and benefits					
General society[1123]	/	+ *More sustainable fishery management would lead in general to healthier stocks, leading ultimately to lower prices for customers because costs for fishers decrease.*	+ *More sustainable fishery management would lead in general to healthier stocks, leading ultimately to lower prices for customers because costs for fishers decrease.*	+ *More sustainable fishery management would lead in general to healthier stocks, leading ultimately to lower prices for customers because costs for fishers decrease.*	+ *More sustainable fishery management would lead in general to healthier stocks, leading ultimately to lower prices for customers because costs for fishers decrease.*
National public authorities	**-** *Limited costs for developing and rolling out campaigns*	**--** *Costs for data collection as well as for enforcement of total allowable catch (TAC)*	**- to ---** *Costs depend on the specific responses used. Soft measures such as awareness raising, or training are relatively low-cost to implement. Legal responses such as discard bans or bycatch limits or expensive when it comes to control and enforcement (which could also be done in different ways, including observers on board, or maintaining a fleet of inspection vessels)*	**+** *Public authorities would save the costs of providing the subsidies.*	--Costs for enforcing and controlling the measures; including follow ups

[1123] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

	Information campaigns to affect cultural practices	Fishing at MSY	Reducing discards	Stop harmful subsidies	Fighting IUU fishing
International community	/	(-) *Potential costs for supporting countries which cannot stem costs for data collection themselves as well as for fish stocks which fall not within a national territory* *Also, potentially regional fisheries management organisations could require additional funding*[1124]	/	/	
Industry	/[1125]	**-- to ++ (time-dependent)** *It can be assumed that the introduction or lowering of TAC can lead to reduced income of the fleet in the short-term.*[1126] *In the mid-to long-term it is expected that fishing at MSY levels reduce costs and increase profits for the fishing industry, as the*	**- to ++ (time-dependent)** *The changes in fishing behaviour, and the reduction of landing small fish, can largely be expected to occur through*	**(-) to ++ (time dependent)** *If the livelihoods of fishers benefited from the subsidies in the first place depends on the design of those subsidies and there may be several instances where this is not the*	**++ (time dependent)** *healthier fish stocks and increased average size of fish BECAUSE less is taken out through those means and management is more effective*

[1124] The recent World Ocean Assessment II found that "*Some regional fisheries management organizations or arrangements covering the high seas were not effective enough in assessing stocks, enforcing catch limits or providing observer coverage to account for catches, by-catches or discards*".

[1125] This would lead to reduced incomes in the respective value chains; however, since those are illegal activities, this is not further considered

[1126] Agnew, D. et al (2010). FINAL REPORT Fish / 2006 / 09 Studies in the Field of the Common Fisheries Policy and Maritime Affairs. Lot 4: Impact Assessment Studies related to the CFP. Environmental, Economic, Social and governance impacts of the 2012 CFP revision. Impact Assessment Phase II. See: https://www.vliz.be/en/imis?module=ref&refid=225597&printversion=1&dropIMIStitle=1

	Information campaigns to affect cultural practices	Fishing at MSY	Reducing discards	Stop harmful subsidies	Fighting IUU fishing
		amount of effort (and associated costs, such as fuel) required per tonne of fish caught decreases[1127]	*gear modifications, i.e., investments into gear.*[1128] *In terms of revenue, this can also be expected to decrease in the first years after the implementation of effective measures due to the landing of all fish, including small and undersized fish. However, this trend can be expected to reverse in the medium- to long-term due to selectivity improvements & fishing patterns to avoid catching smaller fish; and due to healthier stocks.*[1129]	*case*[1130]*. Where this was the case, they would those face some costs through removed subsidies initially. However, in the long term, fishers would benefit from healthier fish stocks and increased average size of fish, which in turns would lead to increased income*[1131]*.*	*Healthier fish stocks also because of improved data quality*[1132]
Other	**/**	**++**	**()**	**/**	*A range of potential tourism impact can be*

[1127] COM(2006) 360 final COMMUNICATION FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT Implementing sustainability in EU fisheries through maximum sustainable yield. See: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2006:0360:FIN:EN:PDF

[1128] Agnew, D. et al (2011). DRAFT FINAL REPORT Studies in the Field of the Common Fisheries Policy and Maritime Affairs. Lot 4: Impact Assessment Studies related to the CFP. Impact Assessment of Discard Reducing Policies. See: https://www.researchgate.net/profile/Sarah-Martin-73/publication/333421065_European_Commission_Studies_in_the_Field_of_the_Common_Fisheries_Policy_and_Maritime_Affairs_Lot_4_Impact_Assessment_Studies_related_to_the_CFP/links/5ced086a458515026a614845/European-Commission-Studies-in-the-Field-of-the-Common-Fisheries-Policy-and-Maritime-Affairs-Lot-4-Impact-Assessment-Studies-related-to-the-CFP.pdf?origin=publication_detail

[1129] Idem

[1130] OECD (2018). Relative Effects of Fisheries Support Policies. See: https://www.oecd-ilibrary.org/agriculture-and-food/relative-effects-of-fisheries-support-policies_bd9b0dc3-en

[1131] See footnote 1128

[1132] It should be noted that one effect of this would obviously also be reduced income for fishers involved in IUU fishing; however, since those are illegal activities they are not listed here

	Information campaigns to affect cultural practices	Fishing at MSY	Reducing discards	Stop harmful subsidies	Fighting IUU fishing
		Additional expenses from authorities for research and data collection would translate into additional benefits and resources for research institutions	*Potential additional costs depend highly on the selected form of discard reduction. E.g., the landing obligation in the EU also entails costs for producer organisations (who have to help their members find adequate outlets for undersized catches) and national authorities (who have the obligation to assist fishers by facilitating the storage of undersize fish and finding possible outlets)*		*identified[1133], including a reduction in attractiveness, a reduction of availability of local products which the respective regions are renowned for, a wider impact on ecosystems with ripple effects, and a loss of game species.*
Analysis					
Geographical distribution of costs and benefits	*Costs would only apply in the regions where the fishery products are demanded, and campaigns are launched*	*Costs and benefits should be higher in regions with low shares of fish stocks at sustainable levels (e.g. Mediterranean and Black Sea, Southeast Pacific, and Southwest Atlantic)*	*Research suggests that discard is much lower in fisheries where most, if not all, of the catch has a value and is fully utilised. This typically occurs in small-scale/artisanal/traditional fisheries and there preliminarily in developing countries[1134]. Thus, costs*	/	*IUU fishing from industrial fishing can be conducted by fleets far away from home which bring economic benefits to the home countries of the fleets while having*

[1133] Eftec (2008) Costs of Illegal, Unreported and Unregulated (IUU) Fishing in EU Fisheries. See: https://www.fishsec.org/app/uploads/2011/03/1226500267_66037.pdf

[1134] Karp, W., et al (2019). Chapter 1 Strategies Used Throughout the World to Manage Fisheries Discards – Lessons for Implementation of the EU Landing Obligation. In: The European Landing Obligation. See: https://link.springer.com/chapter/10.1007/978-3-030-03308-8_1

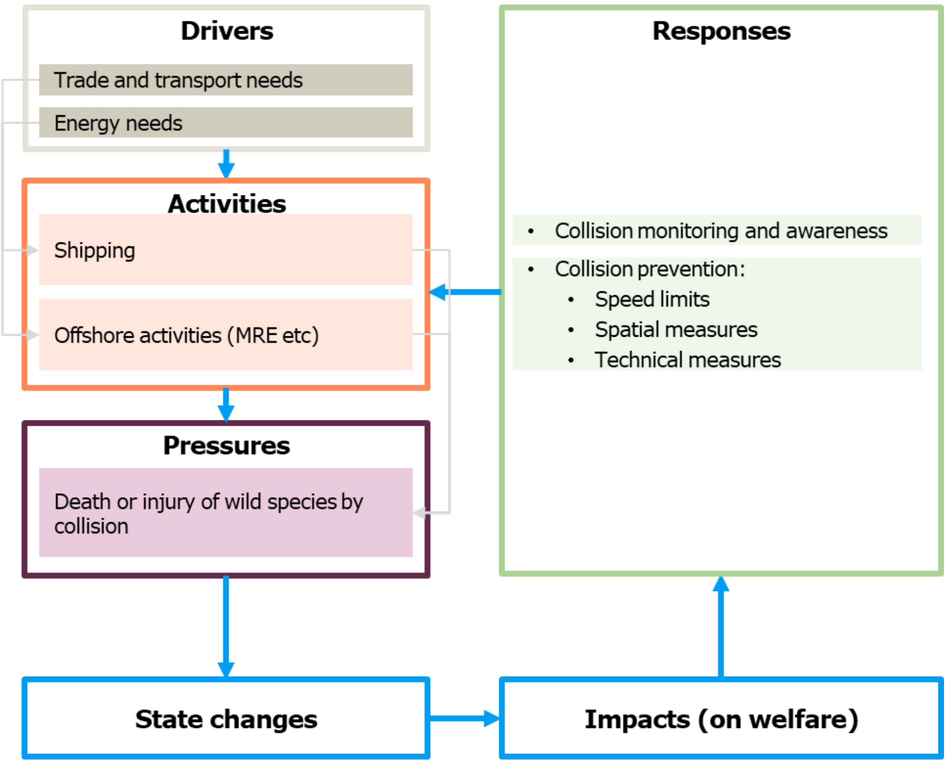
	Information campaigns to affect cultural practices	Fishing at MSY	Reducing discards	Stop harmful subsidies	Fighting IUU fishing
			would rather apply in developed countries.		
Assessment of cost-effectiveness	**++ to +++** *Can be expected to be very cost effective due to low costs. However, this also depends on how well the respective campaigns manage to address the drivers leading to demand.*	**++** *Can be expected to be cost-effective since, even though in short-term costs are high (especially for industry due to catch limits), this allows for stable income at maximum sustainable levels in the future.*	**+ to ++** *Cost-effectiveness depends on how well the responses manage to reduce discards which is challenging to track and to enforce. Due to likely high costs for the public sector for enforcing responses the cost-effectiveness would likely not be very high.*	**+++** *This can be considered highly cost-efficient since, at least in the long run, the option only reaps benefits while saving costs.*	

/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

Death or injury of wild species by collision

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Collision monitoring and awareness

Data is crucial to assess the risk of collision as well as to design appropriate mitigation measures to reduce it. Collision risk assessments require information on animal and vessel distribution patterns, installation location as well on specific vessel and installation-specific factors (e.g. size and speed) and animal-related factors (e.g., time spent at or near the surface and behavioural response to vessels)[1135]. The aim of this process should be to identify high-risk areas, where the probability of collision between a vessel or an installation and marine animal is higher, so that suitable mitigation measures are identified and put in place[1136].

For vessels-related collisions, data and information systems can be developed to alert mariners that they are entering areas with high density of animals prone to collisions, to inform them of recent animal sightings, as well as to gather data on vessel abundance and distribution, or vessels compliance with mitigation measures. These systems include Mandatory Ship Reporting, Early Warning Systems[1137]. It can take a considerable amount of time to compose and distribute internationally relevant data.

[1135] See: https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[1136] Idem

[1137] Idem

Local efforts to educate mariners on the risk of collision with a specific species or within a specific area are a faster way to create awareness and help mitigate collisions in local hotspots. Education is the fundamental basis for the implementation of mitigation measures and for compliance with regulations, because people need to understand the risk to animals, vessels, and vessel crew as well as the locations where vessel crew are likely to encounter marine animals, and what they can do to avoid a collision. It is difficult to assess quantitatively how education and awareness reduce collision risk, but it is generally known that education leads to active engagement[1138].

Collision prevention – spatial measures

For vessel collision, re-routing measures can be implemented to avoid areas where greatest collision risk has been identified. Routing measures can be permanent or seasonal, mandatory or recommended, and may apply to all vessels or a sub-set of certain vessel type(s). Notably, these measures need to be approved by IMO when these involve areas beyond territorial waters. Rerouting vessel traffic is considered to be an effective mitigation measure to reduce collision risk with whales: when compliance is high, the risk can be reduced by 60-95%[1139]. Vessel traffic exclusion zones can also be established to reduce the risk of collision. This measure involves the reduction of the number of vessels in a given area.

Studies have shown that compliance and effectiveness can be low when measures are voluntary. In the case of mandatory measures, assessing compliance can be challenging, especially for small-scale and fast vessels, or when large areas are interested. In addition, several studies have indicated that rerouting measures assisting one species could increase the risk of collision for other species, highlighting the need for a multi-species research approach when assessing the efficacy of rerouting measures[1140]. Finally, rerouting is not always feasible, for reasons of navigation safety, and some rerouting measures only apply to large commercial vessels[1141].

Spatial measures can also be introduced to reduce collision risk with offshore installations. In particular, it is effective to avoid building offshore installations in areas of high animal abundance, especially where threatened species or species particularly prone to collision are present. Siting decisions are taken in the planning phase, and therefore do not represent a possible preventative measure in most cases[1142].

No baseline for the implementation of this response has been identified.

Collision prevention - speed restrictions

Vessel speed reductions can be introduced to provide animals and vessel crew with more time to detect and avoid each other, as well as to reduce the severity of the injury. Studies have found that that the probability of lethal injury decreased to <50% when vessels travelled at speeds ≤ 10 knots. Similar to rerouting measures, proposals from coastal states to implement vessel speed restrictions outside territorial waters need to be submitted to and endorsed by the IMO. Vessel speed reductions can also be voluntary or mandatory as well as permanent or

[1138] Idem

[1139] Idem

[1140] Idem

[1141] Idem

[1142] See: https://docs.wind-watch.org/marques2014.pdf seasonal[1143]. A reduction in vessel speed is the only mitigation measure that has been recommended for a variety of smaller marine species. However, compliance with vessel speed restrictions can be low in the absence of effective enforcement[1144].

No baseline for the implementation of this response has been identified.

Collision prevention - technical measures

Technical measures can be applied to vessels, to reduce the risk of collision[1145], including:

- Installing deterrent devices, such as devices that emit acoustic signals;
- Installing propeller guards, such as cages and ducts that act a physical boundary between the propeller blades and an animal;
- Installing systems to enable early detection of animals, such as Passive Acoustic Buoy Systems, Real Time Plotting of Cetaceans (REPCET), Mobile Phone Alerting Systems;

Early animal detection onboard the vessel can also be implemented by identifying a dedicated observer that has been trained to detect and identify marine animals onboard the ship.

Technical measures to reduce collision risk and impact can be taken on offshore installations. These measures include[1146]:

- Turbine shutdown on demand in case collision risk is identified in advance;
- Restriction of turbine operation to specific times of the day, seasons or weather conditions;
- Increasing turbine visibility e.g. by using patterns and colors;
- Optimising the operation of turbines e.g. by increasing or decreasing the velocity of the blade to stimulate avoidance behaviours in animals;
- Regulating turbine height e.g. by increasing clearance of turbines blades above water, to reduce collision risk with birds[1147];
- Introducing ground devices or deterrent devices to warn animals, as well as to divert and distract their route;

Other measures include habitat modification techniques, such as vegetation management or the creation of alternative feeding areas. The selection of the measures, as well as the resulting effectiveness in preventing or reducing collision risk, is highly dependent on the context: the type of threatened species, the location as well as the type of installation or vessel involved.

No baseline for the implementation of this response has been identified.

[1143] https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[1144] https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[1145] https://www.frontiersin.org/articles/10.3389/fmars.2020.00292/full

[1146] https://docs.wind-watch.org/marques2014.pdf

[1147] https://tethys.pnnl.gov/sites/default/files/publications/ICES_2012_Turbine_Height_Management_Tool.pdf

Comparison of Responses

	Monitoring and awareness	**Collision prevention**
Costs and benefits		
General society[1148]	**/**	**(/ to -)** *When measures such as re-routing or reducing vessel speed are implemented, it is possible that the price of transporting goods would increase (e.g. additional fuel is used). If these costs are transferred to consumers, this could entail the increase in the price of certain goods. This is likely to be minimal.*
National public authorities	**(-)** *Public authorities would bear costs related to the monitoring of collisions from different activities. These are likely to be minimal, as shared with industry.*	**(/ to -)** *When spatial measures are taken to prevent collision, this could entail some costs relating to enforcement and surveillance for national authorities.*
International community	/	/
Industry	**(- to +)** *Shipping and offshore industry would have to bear costs related to the monitoring of collisions, to be shared with national authorities.* *When monitoring enables collision avoidance, in particular in the case of large mammals, this can lead to avoided costs for the industry – in relations to the damages that the collision would impose on the vessel/platform and crew.*	***(- to --) (measure-dependent)*** *Shipping and offshore industry would have to bear the costs of implementing collision-prevention measures. The costs depend on the type of measure implemented.* *For instance, it was estimated imposing a vessel speed limit of 10 knots along the US east coast would have an average estimated cost of $1.3 million/year (borne by the ports). The average cost per affected ship call would be $2,350*[1149]*.* *The cost of implementing a Real-Time Plotting of Cetaceans System in the Mediterranean is estimated at $120,000 over the ship's lifetime (around 25 years) – and this does not take into account additional fuel costs caused by actions to avoid whales, as well as costs due to delays in ports of call*[1150]*.*

[1148] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1149] https://www.whoi.edu/cms/files/RW_Ship_Strike_Econ_Final_Report_April02_24303.pdf

[1150] https://www.sciencedirect.com/science/article/abs/pii/S0048969722013286

	Monitoring and awareness	Collision prevention
Other	/	/
Analysis		
Geographical distribution of costs and benefits	*Costs and benefits would be localised to areas where there is high collision risk (i.e. major shipping routes in the Atlantic, Indian and Pacific oceans).*	*Costs and benefits would be localised to areas where there is high collision risk (i.e. major shipping routes in the Atlantic, Indian and Pacific oceans).*
Assessment of cost-effectiveness	**(+ to -) (collision risk and damage dependent)** *When real-time monitoring enables collision avoidance (i.e. when it is possible to rapidly change vessel route to avoid collision, or to stop operations to avoid collisions), in particular in the case of large mammals, this can lead to avoided costs for the industry – in relations to the damages that the collision would impose on the vessel/platform and crew. This would thus be a cost-effective measure.*	**(+ to -) (collision risk and damage dependent)** *When collision risk prevention measures enable collision avoidance, in particular in the case of large mammals, this can lead to avoided costs for the industry – in relations to the damages that the collision would impose on the vessel/platform and crew. This would thus be a cost-effective measure.* *The cost-effectiveness depends on the animal as well as type of measure.* *A study on the cost-effectiveness of management measures to avoid collision with whales in the Mediterranean, showed that Real-Time Plotting of Cetaceans System is not cost-effective – though there are many uncertainties and caveats concerning the additional costs as well as the evaluation of the cost of averting a whale fatality[1151].*

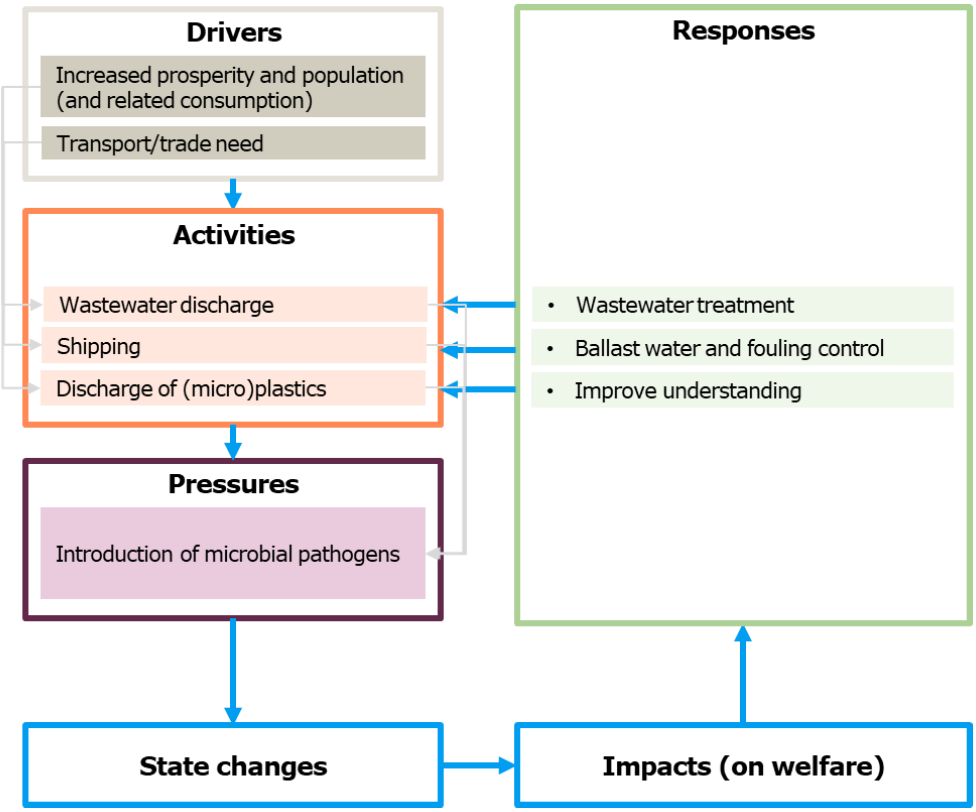
/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

[1151] https://www.sciencedirect.com/science/article/abs/pii/S0048969722013286

Introduction of microbial pathogens

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

In general, prevention is considered as the only effective measure to address the introduction of microbial pathogens in the oceans. This is because once established, the spread of these pathogens is difficult to control and eradicate, and it can have devastating effects. For instance, when pathogens are spread in aquaculture and fisheries, stock losses can be up to 100%. For example, the spread of Bonamia ostreae and Marteilia refringens drastically reduced European production of cultured flat oysters (Ostrea edulis) from 29,595 t in 1961 to 5,921 t in 2000. "Between 1980 and 1983 alone, estimated losses in France included a 20% reduction of employment within the industry, US$ 240 million turn-over, and US$ 200 million of added value"[1152].

Wastewater treatment

Microbial pathogens found in wastewater generally derive from the intestinal tract in human faeces and are associated with waterborne diseases such as diarrhoea, cholera, and dysentery. Other sources are industrial waste from food production, particularly from animal processing,

[1152] Georgiades et al (2021) The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges.

that can also be a source of pathogenic microorganisms[1153]. When this water is discharged untreated into water bodies, it can travel in the oceans.

Wastewater can be treated to remove pathogenic microorganisms. This can be done through a combination of physical (e.g., sedimentation and filtration), chemical (e.g., adsorption to substrates or particles, UV radiation by sunlight, and exposure to root exudates), and biological (e.g., predation, natural die-off, and retention in biofilm) mechanisms[1154]. Notably, different levels of efficiency are associated with different mechanisms, and many factors influence efficiency[1155], and some sources consider that "most wastewater treatment plants existing today do not eliminate pathogens satisfactorily"[1156].

No complete overview of applying standards for microbial pathogens removal from wastewater in all world regions could be identified. However, wastewater treatment in general is a challenge in certain world regions, and this can provide an indication of the magnitude of the problem. As shown in previous chapters, around 44% of household wastewater is not safely treated worldwide[1157], and over 80% of wastewater is released into the environment without adequate treatment[1158]. Moreover, it appears that incomplete disinfection of faecal waters, even in effluents from wastewater treatment plants with tertiary treatment (the most advance form of treatment) is "commonplace"[1159]. Further efforts should be undertaken to ensure that wastewater is safely treated for the removal of pathogens in all world regions.

Ballast water and fouling control

Ballast water and hull fouling can be controlled or treated, to eliminate the microbial pathogens that colonise them, or to avoid colonisation in the first place.

Ballast water control and management is regulated at the international level by IMO. The International Convention for the Control and Management of Ships' Ballast Water and Sediments[1160] (2004, entered into force in 2017) aims to prevent the spread of harmful aquatic organisms from one region to another, by establishing standards and procedures for the management and control of ships' ballast water and sediments. For instance, all ships are required to implement a Ballast Water and Sediments Management Plan, and to implement certain standards for ballast water exchange and performance, including the requirement to exchange ballast water as far as possible from the shore[1161], as well as to exchange and release

[1153] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7126130/

[1154] Wang et al (2021) Removal of Pathogens in Onsite Wastewater Treatment Systems: A Review of Design Considerations and Influencing Factors.

[1155] Wang et al (2021) Removal of Pathogens in Onsite Wastewater Treatment Systems: A Review of Design Considerations and Influencing Factors.

[1156] https://pubmed.ncbi.nlm.nih.gov/9018686/

[1157] https://www.unwater.org/app/uploads/2021/12/SDG-6-Summary-Progress-Update-2021_Version-July-2021a.pdf

[1158] http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/

[1159] https://www.sciencedirect.com/science/article/pii/B9780128137369000040?via%3Dihub

[1160] https://www.imo.org/en/About/Conventions/Pages/International-Convention-for-the-Control-and-Management-of-Ships%27-Ballast-Water-and-Sediments-(BWM).aspx

[1161] Ballast water exchange should take place at least 200 nautical miles from the nearest land and in water at least 200 metres in depth, taking into account Guidelines developed by IMO. In cases where the ship is unable to conduct ballast water exchange as above, this should be as far from the nearest land as possible, and in all cases at least 50 nautical miles from the nearest land and in water at least 200 metres in depth. When these requirements cannot be met areas may be designated where ships can conduct ballast water exchange. All ships shall remove and dispose of sediments from spaces designated to carry ballast water in accordance with the provisions of the ships' ballast water management plan.

95% of ballast volume under specified conditions, and to have ballast water management systems on board, to treat ballast water. As of 31 July 2021, the BWM Convention had 86 Contracting States representing 91% of the GT of the world's merchant fleet[1162].

Ballast water management systems include treatments using UV, ozonation, deoxygenation, biocides, electrochemical systems, ultrasound and heat[1163]. The uptake of these systems differs by ship types and only 18.8% of the total global fleet is fitted with ballast water management system, representing 59.5% of total gigatons (GT) capacity[1164]. Though this represents an increase from 2019, when the only 7.66% of the total global fleet was fitted with these systems[1165], more needs to be done to ensure all vessels manage ballast water adequately – in particular for microbial pathogens. In fact, the BWM Convention focuses on the treatment of ballast water for organisms that are >50 µm, meaning that this may have little to no effect on microbiota[1166]. Controlling and removing microorganisms from ballast water is challenging, therefore additional management measures have also been suggested, such as focusing on inspections for long-term duration stays in ports, screening of vessels coming from ports with high vessel traffic, which tend to be major hotspots for translocations[1167]. Adequate and widespread enforcing of current regulations on ballast water management, as well as identification of gaps and new strategies to address those are crucial to address this pressure. Vessel biofouling on the other hand remains largely unregulated both domestically and internationally[1168]. Measures aimed at managing the introduction of microbial pathogens into the marine environment should focus on limiting the volume and frequency of pathogen translocations via ongoing vessel transportation (i.e., propagule pressure) and avoiding pathogen releases by reactive management activities. Common management measures include using antifouling paints and proactive and reactive in-water cleaning (PIC), reactive in-water cleaning with capture (RICC)[1169]. Each of these solutions offer benefits and trade-offs. For instance, antifouling paints have been identified as a source of microplastics. These trade-offs need to be evaluated before implementation, so that the most suitable approach is selected. No baseline for the implementation of measures against vessel biofouling was identified.

Improve understanding of (micro)plastics as a vector

(Micro)plastics have only recently been identified as a potential vector of microbial pathogens. As such, there are critical knowledge gaps that need to be filled. For instance, research on factors that promote bacterial attachment to (micro)plastics, as well as factors that promote antibiotic resistance of pathogens found on (micro)plastics. The implications on the aquaculture sector, as well as human health and marine life in general also need to be better understood[1170].

An improved understanding is the first step to developing tailor-made responses to manage this vector of microbial pathogens.

[1162] https://unctad.org/system/files/official-document/rmt2021_en_0.pdf

[1163] Georgiades et al (2021) The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges.

[1164] https://unctad.org/system/files/official-document/rmt2021_en_0.pdf

[1165] https://unctad.org/system/files/official-document/rmt2019_en.pdf

[1166] Georgiades et al (2021) The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges.

[1167] Idem

[1168] Idem

[1169] Idem

[1170] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

Comparison of Responses

	Wastewater treatment	Ballast water and fouling control	Improve understanding
Costs and benefits			
General society[1171]	**-** *As already mentioned wastewater treatment in general is expensive[1172], both in terms of CAPEX and OPEX and it is important that locally adapted systems are selected, considering aspects such as cost-effectiveness, long-term sustainability, and availability of space.*	/	/
National public authorities	***/ to -*** *In cases where user charges for new and/or updated infrastructure would create affordability issues, public authorities can support, either by subsidising the operations themselves[1173] or by subsidising affordable tariffs for poorer parts of the population. In the case of microbial pathogens, it is also likely that infrastructure updates (and additional investments) would be needed as most wastewater treatment plants existing today are deemed to*	**(-)** *Public authorities are likely to bear costs for the enforcement of ballast water legislation, as well as surveillance monitoring. Additional costs could be borne in relations to the adoption/enforcement/surveillance of fouling control legislation (in those countries where this does not exist).*	**(- to --)** *Public authorities would bear costs related to financing additional research and monitoring programmes aimed at deepening understanding of microplastics as a vector for microbial pathogens. It was not possible to estimate costs.*

[1171] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1172] For example, total annual costs for wastewater treatment in the EU are estimated at around EUR 18 billion. See: SWD(2019) 700 final PART 1/2 COMMISSION STAFF WORKING DOCUMENT EVALUATION of the Council Directive 91/271/EEC of 21 May 1991, concerning urban waste-water treatment. https://ec.europa.eu/environment/water/water-urbanwaste/pdf/UWWTD%20Evaluation%20SWD%20448-701%20web.pdf

[1173] Which is, however, not fully aligned with the polluter pays principle.

	Wastewater treatment	Ballast water and fouling control	Improve understanding
	mot eliminate pathogens satisfactorily"[1174].		
International community	***- to --*** *As already mentioned, given the considerable capital investments needed to establish wastewater treatment infrastructure (with a particular attention on additional treatment for microbial pathogens) it can be expected that some regions would need considerable financial support.* *Implementation of low tech and extensive solutions could be an opportunity as the support could take the form of implementation of pilots and training of local stakeholders.*	/	**(- to --)** *In case resource efforts are shared internationally – the international community would bear costs related to financing additional research and monitoring programmes aimed at deepening understanding of microplastics as a vector for microbial pathogens. It was not possible to estimate costs.*
Industry	***/ to --*** *In countries where no standards for the concentration of microbial pathogens in wastewater effluents are in place yet, industry (e.g. food processing industry) would have to invest for meeting newly introduced standards.*	**- to -- (solution dependent)** *The shipping industry is likely to incur costs for the implementation of technical solutions for ballast water and fouling control. Costs would vary based on the type of solution and scale of application.*	/
Other	/	/	/
Analysis			

[1174] https://pubmed.ncbi.nlm.nih.gov/9018686/

	Wastewater treatment	**Ballast water and fouling control**	**Improve understanding**
Geographical distribution of costs and benefits	*Regarding municipal wastewater, costs would be highest in regions with currently a low level of treatment, usually low-income and lower middle-income countries[1175], such as central and Southern Asia or Sub-Saharan Africa.* *Benefits are likely to be felt worldwide, as the introduction of microbial pathogens can potentially lead to the spread of epidemics which can have different scales of impact (even global).*	*Costs would be borne by countries where seaborne trade and transport are most frequent.* *Benefits are likely to be felt worldwide, as the introduction of microbial pathogens can potentially lead to the spread of epidemics which can have different scales of impact (even global).*	*Costs are likely to be borne by countries with research capacity.* *Benefits are likely to be felt worldwide, as the introduction of microbial pathogens can potentially lead to the spread of epidemics which can have different scales of impact (even global).*
Assessment of cost-effectiveness	**++** *Prevention is considered the only effective measure to address the introduction of microbial pathogens[1176].* *Despite the high costs this can be considered cost-effective, given that treatment can be effective in reducing microbial pathogens from wastewater (if these are targeted), and that the potential impacts of microbial pathogens introduction and spread are significant.*	**(++) (solution dependent)** *Prevention is considered the only effective measure to address the introduction of microbial pathogens[1177].* *Costs would vary based on the type of solution and scale of application, and so would cost-effectiveness.*	**++** *Prevention is considered the only effective measure to address the introduction of microbial pathogens[1178].* *Given the significant potential impacts of microbial pathogens introduction, also in light of the univocal presence of microplastics, improving understanding can be considered cost-effective.*

/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially

[1175] https://unesdoc.unesco.org/ark:/48223/pf0000247553

[1176] Georgiades et al (2021) The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges.

[1177] Georgiades et al (2021) The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges.

[1178] Georgiades et al (2021) The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges.

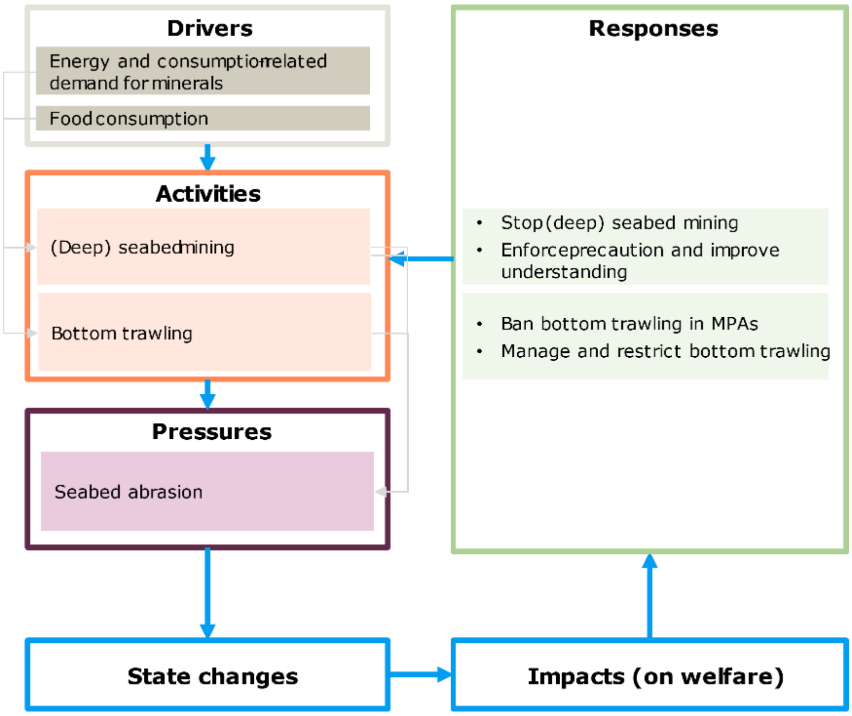
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

Physical pressures

Seabed abrasion

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Stop (deep)seabed mining

The impacts of seabed mining are not well understood to date, in particular when it comes to mining in the deep seabed. The scientific community however indicates that this activity risks to cause irreversible damage, in particular on deep-sea ecosystems[1179]. An option to prevent this risk, could be to stop (deep) seabed exploration and mineral extraction. Notably, in the case of seabed mining in the Area, commercial exploitation has not started yet[1180].

It is widely argued that seabed mining will play a crucial role in the green transition[1181], but other sources[1182] argue that there are considerable uncertainties concerning these projections, and that estimates could be re-assessed taking into account additional factors e.g. a focus on

[1179] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1180] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1181] https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions/executive-summary

[1182] Miller et al (2021) Challenging the Need for Deep Seabed Mining From the Perspective of Metal Demand, Biodiversity, Ecosystems Services, and Benefit Sharing.

research and product design to enhance the sustainability and life span of future "green" technologies that will enable the transition, among others.

Enforce precaution and improve understanding

Additional research is required to better understand the extent to which deep-sea mining could lead to environmental problems and how they best could be avoided.

In the waiting of evidence concerning these impacts, the precautionary principle could be widely adopted and adequately enforced when it comes to permitting of (deep)seabed mining.

It has been argued[1183] that the ISA has not been implementing the precautionary principle and related protective measures in practice, in that it "continued to grant exploration contracts in areas around vulnerable ecosystems without assessing the potential impacts"; that it has "not yet given effect to preservation reference zones or utilised safety margins in the form of quotas"; and that "the ISA is at present unprepared to deal with environmental emergencies". The implementation of all aspects of the precautionary principle could be further strengthened by the ISA and the members of the international community.

Ban bottom trawling in MPAs

Bottom trawling, and in particular certain techniques within it, are recognised as major pressures for the seabed, and it is also practiced within Marine Protected Areas[1184]. One of the possible responses to consider to address this issue is establishing a permanent ban on bottom trawling i.e. to prohibit all types of bottom trawling in a specific area, such as MPAs[1185]. Different NGOs in Europe have called for the ban of these practices in MPAs[1186]. The EU has already banned bottom trawling in the Deep Sea (prohibition to fish below 800 meters with bottom trawls). According to the evaluation of the related Regulation, the ban has proved effective in protecting deep-sea fish, according to the evaluation of the Deep-sea Access Regulation (DSAR) released today[1187]. Due to the delayed adoption of the VMEs closures, the DSAR has not been effective so far to ensure vulnerable marine ecosystems (VMEs) protection in EU waters[1188].

Studies estimate that seabed biota takes around 1.9 to 6.4 years to recover after bottom trawling ceases[1189]. The resilience and recovery dynamics of deep-sea habitats impacted by bottom trawling are poorly known[1190]. In light of this, banning bottom trawling, at least in specific (vulnerable) areas can be an effective measure to prevent, or mitigate the effects of, seabed abrasion. Notably, establishing a ban on bottom trawling in specific areas can lead to the displacement of the fishing activity elsewhere, outside the protected area. The impact of

[1183] A. L. Jaeckel (2017) The International Seabed Authority and the Precautionary Principle. Chapter 6: Implementing the Precautionary Principle: Protective Measures. See: https://brill.com/view/title/33967

[1184] https://seas-at-risk.org/wp-content/uploads/2021/05/Valuing-impacts-of-potential-ban-on-bottom-contact-fishing_NEF_-FINAL-for-publication.pdf

[1185] Evidence shows that 59% of the 727 EU MPAs designated in 2017 still permit trawling and that trawl fishing effort within these sites was 46% higher than outside the MPAs.

[1186] https://act.wemove.eu/campaigns/bottom-trawling?utm_campaign=bottomtrawling&utm_medium=video&utm_source=partners

[1187] https://ec.europa.eu/oceans-and-fisheries/news/deep-sea-fisheries-increased-protection-deep-sea-species-2021-05-12_it

[1188] https://ec.europa.eu/oceans-and-fisheries/fisheries/rules/deep-sea-fisheries_en

[1189] https://www.pnas.org/doi/epdf/10.1073/pnas.1618858114

[1190] https://www.frontiersin.org/articles/10.3389/fmars.2019.00063/full this displacement needs to be taken into consideration when deciding to implement such measure.

A study[1191] showed that banning mobile bottom-contact fishing gear (trawls and dredges) across EU MPAs is cost-effective in the long term (though many uncertainties persist in the assessment). The costs of implementing the ban outweigh the benefits (e.g. in terms of ecosystem services) in terms of annual net impact for the first two years but starting from year three onwards there is an annual net benefit, which rises sharply up to year 5, as the ecosystem service impacts become increasingly more pronounced. The benefits for many of the ecosystem services increase until year 13, where the habitat reaches a theoretical maximum of annual ecosystem service value. For the period between year 13 and year 20, they record an average annual cost benefit ratio for a potential ban on bottom-contact fishing in MPAs of €3.41 returned for every €1 spent[1192].

Manage and restrict bottom trawling

According to ICES, "some level of bottom trawl fishing can be compatible with achieving seabed conservation objectives"[1193]. For this to happen, a series of conditions need to be satisfied. For instance, it would be important to determine thresholds beyond which continued bottom trawling will have adverse effects[1194].

Management of bottom trawling includes different measures, including technical measures, effort and spatial control and impact quotas. An overview of management options is provided below, as compiled by ICES.

[1191] https://seas-at-risk.org/wp-content/uploads/2021/05/Valuing-impacts-of-potential-ban-on-bottom-contact-fishing_NEF_-FINAL-for-publication.pdf

[1192] New Economics Foundation (2021) Valuing the impact of a potential ban on bottom-contact fishing in EU Marine Protected Areas.

[1193] https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

[1194] https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

Figure Management options to reduce the impact of mobile bottom-contact fishing gears

Measure/action	Objective
Technical measure	
Gear design and operations	Reduce impacts and maintain or increase catchability of target species
Gear switching	Use alternative gear with reduced impacts to catch target species
Effort control	
Reduction of effort	Reduce impacts by reducing fishing activity
Spatial control	
Prohibitions by gear type	Prohibit high-impact gears in a defined area
Freeze trawling footprint	Confine impacts to currently disturbed areas
Nearshore restriction and zoning	Reduce trawling in shallow sensitive habitats and minimize gear conflicts.
Prohibitions by small-scale habitat type	Protect small-scale sensitive habitat
Multipurpose habitat management	Broadly protect essential, representative and vulnerable habitats, i.e. MSFD broad habitat types
Impact quotas	
Invertebrate bycatch quotas	Reduce bycatch of benthic invertebrates
Habitat impact quotas	Habitat conservation to protect benthic biota

Source: ICES, from McConnaughey et al. (2020)[1195]

Spatial control measures are considered to be the most effective for the biogeochemical functioning of the seabed[1196]. Effort and spatial controls can involve the closing of certain areas to bottom trawling. These can be most trawled areas, as well as least trawled areas. It is considered that "intensively bottom trawled areas are where the largest impact reduction is realized when they are closed, but the cost to the fishery is often large. Closing lightly trawled areas may cost the fishery very little but can also be perceived as having little improvement because so little of the fishing effort, and the resulting impact, is removed"[1197]. For example, the results show that collectively for the Baltic Sea, Greater North Sea, Celtic Seas and Bay of Biscay and Iberian Coast, the removal of less than 10% of the total bottom trawling effort from peripheral fishing grounds will increase the overall extent of un-trawled area to more than 40% in each MSFD broad habitat type in each subdivision[1198]. ICES advises the future use of spatial optimization techniques to find solutions that are both practical and allow management objectives to be reached[1199].

[1195] https://ices-library.figshare.com/articles/report/A_series_of_two_Workshops_to_develop_a_suite_of_management_options_to_reduce_the_impacts_of_bottom_fishing_on_seabed_habitats_and_undertake_analysis_of_the_trade-offs_between_overall_benefit_to_seabed_habitats_and_loss_of_fisheries_revenue_/18621737

[1196] McConnaughey et al. (2020), cited in ICES. See: https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

[1197] Idem

[1198] https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

[1199] https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

Comparison of Responses

	Stop (deep)seabed mining	Precaution and understanding	Ban bottom trawling in MPAs	Manage and restrict bottom trawling
Costs and benefits				
General society[1200]	**(-) to unknown (transformative change)** *In case mineral stocks on land are not sufficient to satisfy the demand, stopping (deep) seabed mining could potentially lead to an increase in the price of energy/goods that require minerals for their production.* *As there are many uncertainties concerning future mineral demand, it is not possible to assess the costs and benefits of this measure.*	/	/	/
National public authorities	**(– to unknown (transformative change)** *This could imply consequences on energy supply and security, in case of shortage of land-based minerals.* *Economic losses could be suffered by those countries that have invested in (deep) seabed exploration so far.*	**- to --** *Public authorities and the international community are the ones who would bear most of the costs for additional research on potential effects from deep-sea mining. Given the difficulty of conducting research in this area it is likely that such costs could be substantial; however, given*	*(-)* *The process of banning bottom trawling in MPAs involves public costs, both in the administration of setting up and enforcement of the bans in these areas.*	*(- to - -)* *Managing and restricting bottom trawling is likely to impose costs on public authorities, mostly related to adopting and enforcing related legislation. Monitoring and surveillance costs can be substantial (especially for large areas of interest).*

[1200] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

	Stop (deep)seabed mining	Precaution and understanding	Ban bottom trawling in MPAs	Manage and restrict bottom trawling
	As there are many uncertainties concerning future mineral demand, it is not possible to assess the costs and benefits of this measure.	*the importance of the potentially affected ecosystems such research seems to be crucial for ensuring a safe (or somewhat safe) conduct in deep-sea mining.*		
International community	**/**	*See above.*	/	/
Industry	**(– to unknown (transformative change)** *Economic losses could be suffered by those companies that have invested in (deep) seabed exploration so far.*	*(-)* *It is likely that some of the research would also be financed and/or conducted by the industry itself.* *If the enforcement of the precautionary principle involves delays in permitting for exploitation (or additional efforts to obtain the permitting) - Losses could be suffered by those companies that have invested in (deep) seabed exploration so far or are hoping to do so in the future.*	**-** *Banning bottom trawling in MPAs would impose costs on the fishery industry. These would mainly relate to the foregone revenue from catches in those areas, as well as costs related to the displacement of the activity.* *However, over time, commercial fishery could accrue benefits by fishing outside the MPA - through MPA spill-over benefits.*	*- to + (solution dependent)* *Managing and restricting bottom trawling is likely to impose a financial burden on the fishery industry.* *At the same time, when fishing effort is reduced, fish abundance will increase and the catch per unit effort will go up in line with this, which is beneficial to the fishers in areas that remain open.*[1201]
Other	/	/	(+) *The recreational and tourism industry could benefit from increase ecosystem health in MPAs – through the increased*	/

[1201] https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

	Stop (deep)seabed mining	Precaution and understanding	Ban bottom trawling in MPAs	Manage and restrict bottom trawling
			touristic attractiveness of these areas.	
Analysis				
Geographical distribution of costs and benefits	*In the case of deep seabed mining, benefits could be felt worldwide – given the potentially significant and irreversible impacts of this pressure.* *Costs would mostly borne by countries that rely seabed mining for satisfying their energy supply (and other). These costs could potentially reflect globally.*	/	*Costs and benefits would most likely be localised in the areas where the MPAs are located – therefore countries that implement the ban would benefit the most.*	*Costs and benefits would most likely be localised in the areas where the MPAs are located – therefore countries that implement the ban would benefit the most.*
Assessment of cost-effectiveness	**+ to unknown (transformative change)** *Stopping (deep) seabed mining would constitute a transformative change, and it can be expected that this would be effective in reducing the pressure on seabed habitats. However, since this would include a paradigm shift with many uncertainties on social and economic impacts, cost-effectiveness cannot be assessed.*	+++ *Despite potentially high budgets for additional research such costs are nevertheless highly cost-effective, given the novel nature of deep-sea mining activities and the major unknowns regarding effects on marine ecosystems.*	++ *Banning bottom trawling in MPAs is cost effective, in particular in the long term*[1202] *- taking into consideration the wider benefits of MPAs.*	+ ***(solution dependent)*** *Cost-effectiveness is largely dependent on the type of measure implemented. For instance spatial control measures are considered to be the most effective for the biogeochemical functioning of the seabed*[1203].

1202 https://seas-at-risk.org/wp-content/uploads/2021/05/Valuing-impacts-of-potential-ban-on-bottom-contact-fishing_NEF_-FINAL-for-publication.pdf

1203 McConnaughey et al. (2020), cited in ICES. See: https://www.ices.dk/sites/pub/Publication%20Reports/Advice/2021/Special_Requests/eu.2021.08.pdf

	Stop (deep)seabed mining	**Precaution and understanding**	**Ban bottom trawling in MPAs**	**Manage and restrict bottom trawling**
	In the case of deep seabed mining, it must be noted that this activity is likely to be very expensive (and is not implemented at commercial scale yet), so might be cost-effective to stop before commercial exploitation starts.			

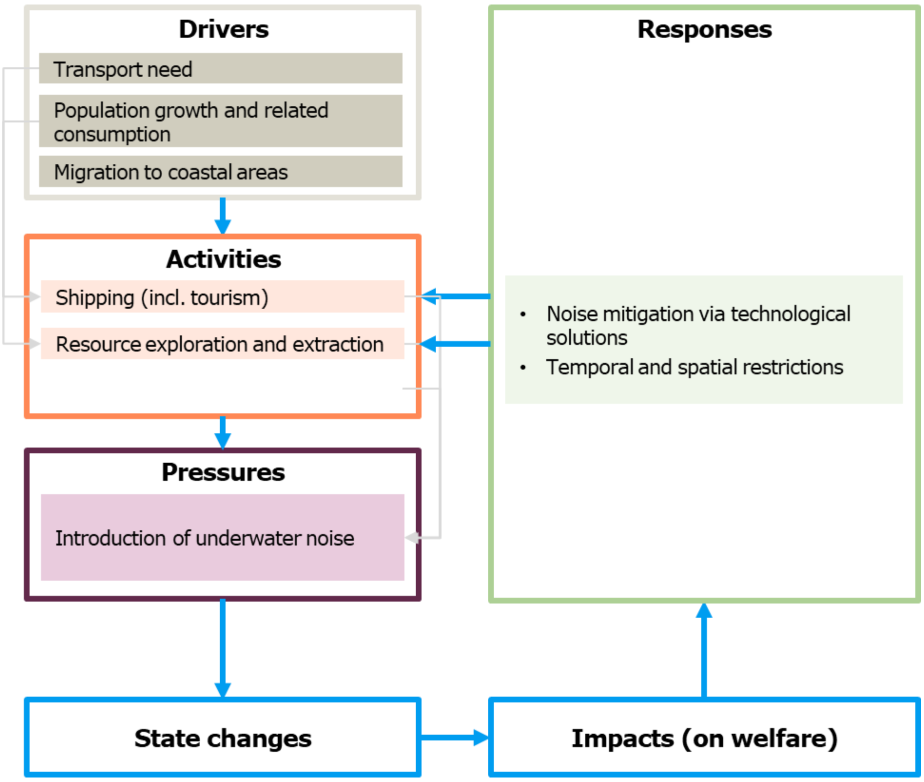
/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to

Pollution pressures

Introduction of underwater noise

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Anthropogenic underwater noise is not persistent in the marine environment and ceases once the sources that cause it are removed. For this reason, measures to stop and mitigate the production of this noise can have "near-immediate, positive effects"[1204]. In general, considering the uncertainties relating to the impacts of underwater noise, the application of a precautionary approach to the management of impacts is advised[1205].

Noise mitigation via technological solutions

Technological solutions can be implemented to reduce the noise produced by different human activities. In this context, it is considered easier to foster noise reduction of activities that

[1204] https://www.science.org/doi/10.1126/science.aba4658

[1205] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

produce sound unintentionally (e.g. shipping, construction) rather than intentionally (e.g. seismic surveys or military activities)[1206].

For instance, different design features of ships can be adapted to reduce sources of underwater noise, such as propellers, hull form and on-board machinery. These measures can be applied mainly on new constructions[1207], though examples of retrofits of existing vessels have also been signalled[1208]. The use of electric motors is also considered as a promising option. Notably, the implementation of such solutions can be expensive, because of high material and maintenance costs[1209]. In 2014, the IMO adopted Guidelines for the reduction of underwater noise for shipping[1210], which are currently under review[1211].

For other sources of underwater noise (e.g. offshore energy and construction) rapid advances in noise-dampening technology have been registered[1212]. A number of technologies can be applied, such as bubble curtains and casings, the use of airguns in exploration surveys, marine vibrator technologies, among others. Operational measures such as ramp-up or soft-start procedures can also be applied to reduce noise input[1213].

For emerging activities, such as deep-seabed mining, regulators and technology developers have an opportunity to take underwater noise into consideration for future developments at an early stage and investigate options that would reduce impact on noise levels[1214].

No baseline for the implementation of these measures was identified.

Temporal and spatial restrictions

Temporal and spatial restrictions to the human activities that produce underwater noise can be applied and can be particularly relevant when the mitigation of the noise source via technological means is more challenging[1215].

For shipping, this can entail regulating vessel speed to reduce noise, as well as re-routing, to divert impacts away from biologically sensitive areas. For instance, it has been proven that "reducing steaming speeds for noisy vessels in the major shipping route(s) in the eastern Mediterranean from 15.6 to 13.8 knots led to an estimated 50% reduction in the broadband noise from these vessels between 2007 and 2013[1216]. Moreover, a study showed that half of the total noise radiated by the shipping fleet comes from just 15% of the ships, particularly those with source levels above 179 dB re 1 mPa at 1m – therefore measures specifically aimed at tackling this type of ships could be very effective in reducing overall levels of underwater noise[1217]. Ship-rerouting measures are usually undertaken to protect marine animals from

[1206] See: https://www.science.org/doi/10.1126/science.aba4658

[1207] See: https://www.marineboard.eu/publications/addressing-underwater-noise-europe-current-state-knowledge-and-future-priorities

[1208] See: https://www.science.org/doi/10.1126/science.aba4658

[1209] See footnote 1213

[1210] See: https://wwwcdn.imo.org/localresources/en/MediaCentre/HotTopics/Documents/833%20Guidance%20on%20reducing%20underwater%20noise%20from%20commercial%20shipping,.pdf

[1211] Idem

[1212] See: https://www.science.org/doi/10.1126/science.aba4658

[1213] See footnote 1213

[1214] See: https://www.science.org/doi/10.1126/science.aba4658

[1215] See footnote 1213

[1216] See: https://www.science.org/doi/10.1126/science.aba4658

[1217] https://www.science.org/doi/10.1126/science.aba4658 collision, and can be proposed to the IMO, including in connection to the designation of Particularly Sensitive Sea areas[1218].

For other sources (e.g. offshore energy and oil and gas exploration), these measure could entail the prohibition of construction or operation in areas that are deemed to be particularly sensitive to underwater noise, as well as time limits for the undertaking of noisy operations. Mitigation zones can also be established around sound sources. These aim to ensure that no animals of certain species are present before starting or continuing operations. This can involve the use of real-time monitoring of marine mammals' presence using marine mammal observers, as well as the use of acoustic deterrent devices[1219].

No baseline for the implementation of these measures was identified.

Comparison of Responses

	Noise mitigation via technological solutions	**Temporal and spatial restrictions**
Costs and benefits		
General society[1220]	/	**(-)** *The price of certain goods could increase, in case temporal and spatial restriction measures impose higher costs for shipping industry, and these are reflected on consumers. These are likely to be minimal.*
National public authorities	**/ to (-)** *Public authorities might incur costs related to the adoption and enforcement of legislation regulating noise pollution from different activities and imposing the use of noise mitigation solutions.*	**(- to --)** *Public authorities might incur costs for the adoption and enforcement of legislation imposing temporal and spatial restrictions for activities generating underwater noise. Monitoring compliance over large areas (e.g. for spatial restrictions) can be costly.*
International community	/	*/ to (-)* *These measures are likely to have impacts on international shipping routes, and require the intervention of IMO for implementation, and collaboration within the international community for decision (PSSA).*
Industry	*- to - - (solution dependent)* *Shipping and offshore industry incur costs related to installing*	*- to --* *Shipping industry could incur costs related to re-routing (if*

[1218] https://www.imo.org/en/OurWork/Environment/Pages/PSSAs.aspx

[1219] https://www.marineboard.eu/publications/addressing-underwater-noise-europe-current-state-knowledge-and-future-priorities

[1220] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

	Noise mitigation via technological solutions	**Temporal and spatial restrictions**
	and maintenance of noise-dampening solutions. These are considered to be high in many cases.	*alternative route is longer) or if speed restrictions impose higher costs (e.g. in terms of fuel consumption).*
Other	*(+)* *Developers of noise mitigating technological solutions could have increased revenues from the widespread use of technologies.*	*(+)* *The fishery industry could incur economic benefits from avoided loss in catch and displacement of marine mammals (in areas where the noise leads animals to move)*[1221]*.*
Analysis		
Geographical distribution of costs and benefits	*Main costs for countries relying on shipping if costs are translated to consumers.* *Benefits in areas with high levels of noise.*	*Main costs for countries relying on shipping if costs are translated to consumers.* *Benefits in areas with high levels of noise.*
Assessment of cost-effectiveness	**+ to - (solution dependent)** *Technological solutions are not feasible for every source. Some of these solutions are considered expensive, though they are very effective. It is particularly cost effective if these measures target the major sources of noise as a priority (e.g. large ships).*	**++ (measure dependent)** *Measures aimed at restricting activities that provoke underwater noise are very effective, as the disturbance ceases when the activity ceases (unlike other pressures). The cost-effectiveness of temporal/spatial restrictions depends on the type/duration of the measure. It is particularly cost effective if these measures target the major sources of noise as a priority (e.g. large ships).*

/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

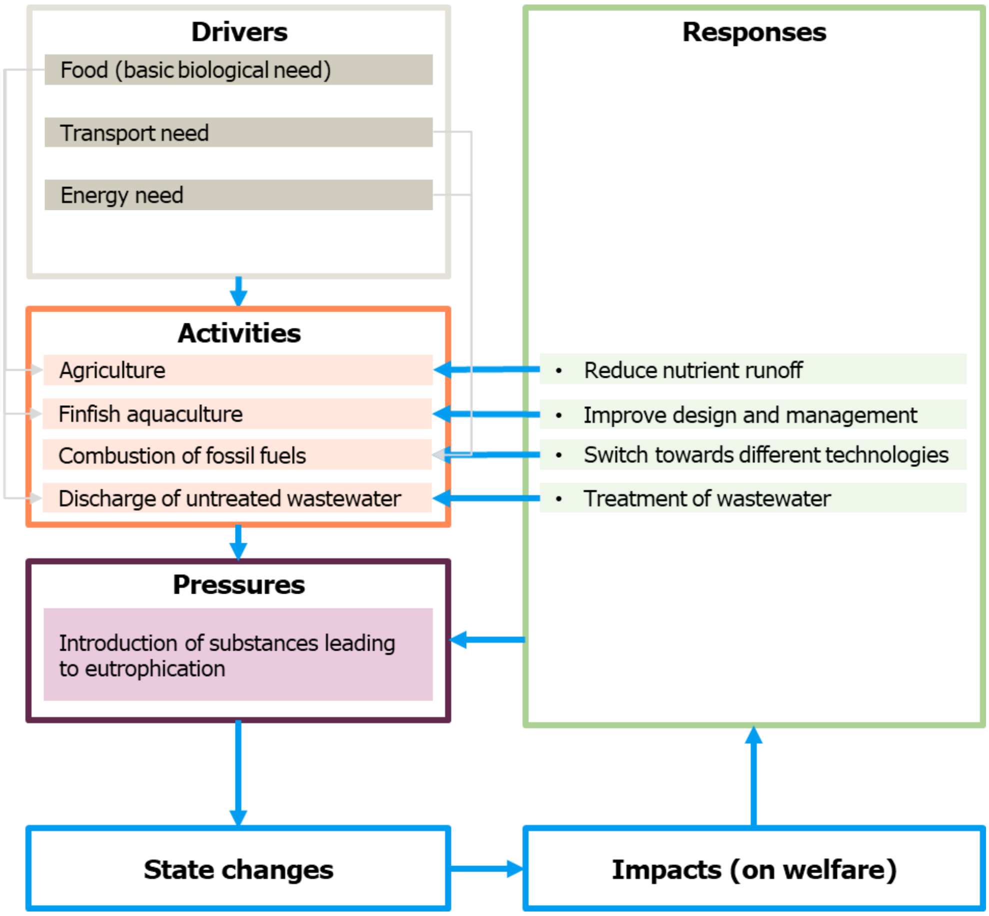
Introduction of substances leading to eutrophication

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure. It should be noted that many national and international policies are in place to address the reduction of nutrient releases; however, as

[1221] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

mentioned earlier, it appears that those efforts are not sufficient as recent trends are still increasing[1222].

Figure Flowchart for the pressure including responses



Source: Own illustration

Reduce nutrient emissions from agriculture

Reducing nutrient runoff from agricultural areas would reduce eutrophication in coastal waters since less nutrients would be transported.

There are two main strategies that can be pursued to this end which can be understood as being at two different ends of an effort spectrum: one the one hand this includes better management of nutrients within current agricultural practices, and on the other hand a structural change of the agro-food system, limiting the use and load of fertilisers in agricultural practice.

Better nutrient management can be achieved through a number of practices, including planting of catch crops preventing bare soils outside main growing seasons, creation of buffer strips, more strategic fertilising, minimising tillage to reduce erosion and runoff, or practices such as contour tillage. However, in areas with high use of fertilisers the application of such responses

[1222] GESAMP (2018). Global Pollution Trends: Coastal Ecosystem Assessment for the Past Century. See: http://www.gesamp.org/publications/global-pollution-trends-coastal-ecosystem-assessment-for-the-past-century alone might not be sufficient to reduce input of nutrients into marine waters to levels that do not lead to eutrophication.[1223]

Structural changes of the agro-food system include, in addition to significant changes in agricultural practices which include significant reduction of fertiliser use (e.g., turning towards de-intensified and organic farming), also changes to human diet towards more vegetal and less animal-based diet (also taking into account that eutrophication is also often observed in regions with high density of animal husbandry).

Improve design and management of finfish aquaculture

Environmental impacts from aquaculture in marine waters such as eutrophication can be reduced through a wide range of sustainable techniques which can reduce the input of nutrients into water.

Those techniques could e.g., include waste recycling, biofloc technology[1224], improved selection of aquaculture sites, use of use of efficient feeding systems and good quality feed types or others.[1225] [1226]

Despite the existence of such technologies, however, finfish aquaculture is still among the leading causes of marine eutrophication.

Reduce emissions from combustion of fossil fuels

For both, power generation and transport, there are in general two main strategies for reducing the emissions which are summarised in the Table below.

Table Overview of general responses

	Power generation	Transport
Technical solutions for reducing emissions	*Implementation of better technologies to reduce emissions from fossil fuel power plants.*	*Implementation of better technologies to reduce emissions from fossil fuel vehicles.*
Paradigm change	*Moving away from fossil fuels in power generation and fully towards other energy sources such as renewable energies.*	*Phasing out vehicles using fossil fuels and fully moving towards other technologies.*

[1223] Desmit, X., et. Al (2018). Reducing marine eutrophication may require a paradigmatic change. Science of the Total Environment. See: https://www.sciencedirect.com/science/article/pii/S0048969718313603

[1224] Biofloc is suspended material in the water column, constituted by microorganisms, micro- and macroinvertebrates, filamentous organisms, exocellular polymers, faeces and uneaten feed.

[1225] Braña, C., et al. (2021). Towards Environmental Sustainability in Marine Finfish Aquaculture. See: https://www.frontiersin.org/articles/10.3389/fmars.2021.666662/full

[1226] Jeffrey, K., et al. (2014). Background information for sustainable aquaculture development, addressing environmental protection in particular: Sustainable Aquaculture Development in the context of the Water Framework Directive and the Marine Strategy Framework Directive. See: https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp?FormPrincipal:_idcl=FormPrincipal:_id1&FormPrincipal_SUBMIT=1&id=24623b37-8a0d-47f3-9ebb-b63dc5e37a70&javax.faces.ViewState=RczvK8qUmMBKhPYHvS%2B%2FeFl7ckXuQuFIIO1xQMh7ImKYdmD%2Fh2lMMuNAU%2FvkM904y4HNrsgdIwLqHdvfec2EeAzabEjgbYstaYMIbqQyQh6eGKExM2MbzhzoK4XnmODGMw9bo1blGm8TKRkK6v%2FWGmrlZPU%3D

For technical solutions for reducing emissions from power generation, experience has shown that a regulatory framework setting strict legally binding emission limit values can be a strong driver for reducing emissions and that the necessary technologies are available, e.g. in the EU, NOx emissions from those sources have decreased by 60% between 2004 and 2019.[1227] Also other regions implemented ambitious emission reduction strategies, such as China leading to a decrease of NOx emissions by 60% between 2014 and 2017[1228]. Several technologies and process optimisations are available to this end[1229].

Regarding road transport and the use of better technology for increasing efficiency and for reducing emissions and as mentioned in chapter 4, diesel cars emit considerably more NOx than petrol cars. Newer vehicle diesel standards for heavy-duty vehicles and light-duty vehicles are more effective in reducing NOx emissions than older ones. However, it should be noted that the diesel emissions scandal that most cars following the latest standards had considerably higher NOx real-world emissions than the regulatory limits. Thus, globally, most diesel vehicles would have to be replaced with cars following the very latest standards which could nearly eliminate real-world diesel related NOx emissions.

A paradigm shift in electricity generation towards other energy sources such as renewable energies would lead to a full reduction of NOx emissions from this sector, besides other positive benefits (such as reduction of GHG). Also, phasing out vehicles using fossil fuels would significantly reduce NOx emissions worldwide besides other positive effects. However, it should be noted that it is also crucial that the energy sources are also sustainable, e.g. in case of electric cares, that electricity is not generated from fossil fuels.

Treatment of wastewater

Treatment of household wastewater can be highly effective in reducing nutrient discharges into the environment since it is a point-source pollution which can be relatively well contained.

Well-proven and effective technologies exist for the treatment of household wastewater which can broadly categorised as treatment plants to which wastewater is transported through sewers and/or other means, and individual and other appropriate systems (IAS), which are waste water treatment systems for one or a few households. Also, solutions can vary between technologically very advanced solutions (e.g. with several treatment steps) or extensive, such as pond systems or constructed wetland systems. In developing countries, extensive technologies are generating interest as they require fewer human resources and less energy consumption than intensive systems. Energy consumption is not only a key cost factor but also has environmental and risk implications especially in locations where electricity supply is not continuous.[1230] They also rely more on natural processes up to the level of Nature Based Solutions in some cases and provide more robust performances together with generating lower quantities of by products (sludge). There is also a difference of applicability of those solutions,

[1227] EEA indicator "Emissions and energy use in large combustion plants in Europe". See: https://www.eea.europa.eu/ims/emissions-and-energy-use-in

[1228] Tang, L., et al. (2019). Substantial emission reductions from Chinese power plants after the introduction of ultra-low emissions standards. See: https://www.nature.com/articles/s41560-019-0468-1

[1229] See e.g. chapter 10.2.1 in JRC (2017). Best Available Techniques (BAT). Reference Document for Large Combustion Plants. See: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC_107769_LCPBref_2017.pdf

[1230] UN (2015). Economic Valuation of Wastewater - The cost of action and the cost of no action. See: https://wedocs.unep.org/bitstream/handle/20.500.11822/7465/-Economic_Valuation_of_Wastewater_The_Cost_of_Action_and_the_Cost_of_No_Action-2015Wastewater_Evaluation_Report_Mail.pdf.pdf?sequence=3&isAllowed=y

since extensive solutions require more land use which may not be relevant for highly urbanised areas with land constraints. However, currently only 56 % of household wastewater flows are safely treated (2020 numbers). The regions with the lowest shares of safely treated household wastewater include Central and Southern Asia (25%), Sub-Saharan Africa (28%), and the regions with the highest shares Northern America and Europe (80%) and Australia and New Zealand (79%)[1231].

[1231] UN (2020). Progress on Wastewater Treatment – 2021 Update. See: https://www.unwater.org/publications/progress-on-wastewater-treatment-631-2021-update/

Comparison of Responses

	Reduce nutrient emissions from agriculture	**Improve design and management of finfish aquaculture**	**Reduce emissions from combustion of fossil fuels**	**Treatment of wastewater**
Costs and benefits				
General society[1232]	***/ to (-)*** *Better nutrient management would have no or only very limited specific impacts on the general society since it can be assumed that such responses would not lead to higher costs in food production and thus would have no impacts on food prices and habits.* *Regarding the structural changes, there is very little certainty on specific costs and benefits relating to this. For example, it is unclear to what extent this could impact farm productivity and profitability and thus on food prices. An increase in organic farming may result in increased cost of food as food producers attempt to recoup costs associated with the new systems and this may influence the availability of crops potentially pushing cost of food higher. Increases in food prices force people to adjust as consumer purchasing power decreases and this is likely to have a*	***/***	**Power generation** **/ to - to + (time-dependent)** *Improved technologies (stemming from more stringent emission standards through regulations) for reducing emissions from power generation would lead to no to very little increases in*	**-** *Wastewater treatment in general is expensive*[1236]*, both in terms of CAPEX and OPEX. To keep costs low, implementing new systems requires thorough consideration of costs for different options (e.g., central system or IAS).* *For central treatment, OPEX costs are usually recovered through user charges while the situation for CAPEX is more diverse (which can potentially pose a threat to the long-term sustainability of the infrastructure). For IAS involving one or a few households, low tech solutions can be implemented but there is no general rule to recover cost which in some cases can represent a threat to their implementation, sustainability and performance.*

[1232] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1236] For example, total annual costs for wastewater treatment in the EU are estimated at around EUR 18 billion. See: SWD(2019) 700 final PART 1/2 COMMISSION STAFF WORKING DOCUMENT EVALUATION of the Council Directive 91/271/EEC of 21 May 1991, concerning urban waste-water treatment. https://ec.europa.eu/environment/water/water-urbanwaste/pdf/UWWTD%20Evaluation%20SWD%20448-701%20web.pdf

	Reduce nutrient emissions from agriculture	Improve design and management of finfish aquaculture	Reduce emissions from combustion of fossil fuels	Treatment of wastewater
	negative impact on household dietary choices and nutrition. If food prices increase, this could thus exacerbate social inequalities[1233]*. Poor nutrition caused by unhealthy diet is contributing to the burden of non-communicable diseases such as cardiovascular diseases, type 2 diabetes and some types of cancers.*[1234]		*electricity prices*[1235]*.* *If a transformational change of the electricity sector leads to increased electric prices to be borne by the customers is dependent on several parameters, incl. the time frame for the change and the way that national authorities choose to finance the change.* *In the medium- to long term, the price for producing electricity*	

[1233] James, W., et. al (1997). Socioeconomic determinants of health. The contribution of nutrition to inequalities in health. See: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2126753/

[1234] See: https://www.euro.who.int/en/health-topics/disease-prevention/nutrition/nutrition

[1235] See e.g., the Impact Assessment report for the Directive on industrial emissions in the EU, Annex 7. COMMISSION STAFF WORKING DOCUMENT Accompanying document to the Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on industrial emissions (integrated pollution prevention and control) (recast) IMPACT ASSESSMENT. See: https://ec.europa.eu/smart-regulation/impact/ia_carried_out/docs/ia_2007/sec_2007_1679_en.pdf

	Reduce nutrient emissions from agriculture	Improve design and management of finfish aquaculture	Reduce emissions from combustion of fossil fuels	Treatment of wastewater
			(levelized costs of energy or LCOE) from renewable energies is getting lower than the one from fossil fuels power generation, a trend that can already be seen today. ***Transport*** ***- to + (time-dependent)*** *While electric cars are currently still more expensive than conventional, fossil fuel cars, they are predicted to be cheaper to produce in the near future.*	
National public authorities	**/ to (-)** *The same as for the general public applies.* *Better nutrient management would not have specific impacts on national public*	**-** *Governments could face some additional costs for updating their regulatory and administrative*	**Power generation** **-- to / (time-dependent)**	**/ to –** *In cases where user charges for new and/or updated infrastructure would create affordability issues, public*

	Reduce nutrient emissions from agriculture	Improve design and management of finfish aquaculture	Reduce emissions from combustion of fossil fuels	Treatment of wastewater
	authorities. Some limited costs would apply to raise farmers awareness on the issue of eutrophication and improve their technical knowledge. Also, some costs would occur for monitoring and enforcement of policies. *Regarding the structural changes, government-led initiatives to increase affordability and availability of healthy food options, could be considered to offset a potential rise in agricultural production costs.*	*frameworks to ensure a better green transition of the sector.* *This includes enforcement costs in cases where a stricter policy framework is introduced for technologies used in aquaculture.*	*Public authorities could face costs for financing or supporting to finance the transition, including by investing into the sector, as well as by subsidising electricity tariffs in case increases impede affordability and to ensure a just transition.* *In the mid- to long run, after the transition phase is over, no additional costs would occur.* **Transport** **-- to / (time-dependent)** *Several governments subsidise purchases of*	*authorities can support, either by subsidising the operations themselves[1238] or by subsidising affordable tariffs for poorer parts of the population.*

[1238] Which is, however, not fully aligned with the polluter pays principle.

	Reduce nutrient emissions from agriculture	Improve design and management of finfish aquaculture	Reduce emissions from combustion of fossil fuels	Treatment of wastewater
			electric cars in order to increase uptake, and the subsidies have constantly increased over the past years[1237]. Those subsidies will phase out over time. Also, governments have to ensure that a relevant charging infrastructure is in place.	
International community	**/** *Even though a structural change of agriculture might result in costs as discussed above, those would predominantly occur in developed countries which would not have to rely on international funding to finance structural changes.* *There could be trade impacts stemming from de-intensifying agriculture in some world regions; however, also this is subject to large uncertainties.*	**-** *Aquaculture is a complex activity being governed by a wide range of policy fields, including spatial planning, water pollution, animal welfare, rules on non-native species, and food standards.* *To ensure effective regulation of aquaculture within this complex constellation, the international community could support countries asking for assistance in developing the framework. E.g., the EU could*	**/** *Under Article 9 of the Paris Agreement developed country Parties have the obligation to provide financial resources to assist developing country Parties with respect to*	**- to --** *Given the considerable capital investments needed to establish wastewater treatment infrastructure it can be expected that some regions would need considerable financial support.* *Implementation of low tech and extensive solutions could be an opportunity as the support could take the form of implementation of pilots and training of local stakeholders.*

[1237] IEA (2021). Global EV Outlook 2021. See: https://iea.blob.core.windows.net/assets/ed5f4484-f556-4110-8c5c-4ede8bcba637/GlobalEVOutlook2021.pdf

	Reduce nutrient emissions from agriculture	Improve design and management of finfish aquaculture	Reduce emissions from combustion of fossil fuels	Treatment of wastewater
		provide lessons learned based on the recent process for updating the strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030[1239]	*both mitigation and adaptation; transformative changes in both sectors would already be within the scope of this.*	
Industry	/ *For the agricultural sector, the same as for the general public and national authorities applies.* *Better nutrient management would not have specific impacts since costs would be limited. Some limited costs could occur e.g., for investments for storing manure, or innovative precision tools for spreading manure. However, those investments could actually lead to savings in the long run since the costs for fertiliser input are reduced.* *Regarding the structural changes, there are large uncertainties linked to the extent to which this might impact farm income and profitability. However, even if expenses increase of profitability decreases, it can be assumed that this would be recovered through higher food prices and/or government subsidies.*	- *Industry would face some costs for upgrading their facilities.*	/ *It can be expected that R&D costs as well as capital costs for transforming the sectors would be recovered through charges (electricity) and prices for vehicles.*	/

[1239] COM/2021/236 final COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Strategic guidelines for a more sustainable and competitive EU aquaculture for the period 2021 to 2030. See: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:236:FIN

	Reduce nutrient emissions from agriculture	Improve design and management of finfish aquaculture	Reduce emissions from combustion of fossil fuels	Treatment of wastewater
Other	**/**	/	/	
Analysis				
Geographical distribution of costs and benefits	*As mentioned above, costs would mainly apply in developed countries with a very intensified agricultural production.*	*No information could be identified on the current environmental performance of different aquaculture producers across this globe and thus it could not be estimated where the highest costs would occur.*	*Regarding technical solutions for reducing emissions for transport, costs would be spread equally across regions, given that current standards have considerable real-world emissions of NOx.* *Regarding technical solutions for reducing emissions for power generation, regions with currently low standards would face highest costs; this*	*Costs would be highest in regions with currently a low level of treatment such as central and Southern Asia or Sub-Saharan Africa.* *To keep costs as low as possible and ensure sustainability, it is important that adapted solutions are built. This requires consider CAPEX and OPEX of both wastewater treatment and sludge treatment but also ability of local people to maintain facilities in good operation. If a central system with a wastewater treatment plant is more beneficial (keeping in mind, that the sewers are usually the most important/costly part of such a system) or rather IAS including correct management of sludge; or if intensive or extensive systems are more relevant; as well as training needs.* *It could be relevant to first focus on big cities and settlements since they produce in many cases large shares of the overall wastewater loads.*[1241]

[1241] E.g., in the EU, 1,000 large agglomerations out of the 26,000 total agglomerations covered by the UWWTD produce 50% of the overall generated wastewater.

	Reduce nutrient emissions from agriculture	Improve design and management of finfish aquaculture	Reduce emissions from combustion of fossil fuels	Treatment of wastewater
			includes e.g. South Africa, Philippines or Vietnam[1240]. *Regarding transformative changes in both sectors, costs would occur globally with some notable exceptions of countries which are currently already far advanced in this regard, such as Norway.*	
Assessment of cost-effectiveness	**+ to unknown (transformative change)** *Changes in managerial practices can be considered cost effective sine the involved costs are relatively low. However, it should be kept in mind that it is unclear to what extent those responses would be sufficient to stop agricultural runoff of nutrients and thus eutrophication.* *Regarding the structural change, it can be expected that this would be effective in reducing and stopping coastal*	**++** *Given, that this sector is among the biggest polluters leading to eutrophication and that commercially available solutions can be applied to effectively reduce nutrient pollution, a good cost-effectiveness can be assumed.*	**++ *to* unknown (transformative change)** *Technological solutions can be considered cost-effective.* *Given the transformative change, it could be expected that*	**++** *Despite the high costs this can be considered very cost-effective, given that treatment is very effective in reducing pollutions from this point-source pollution. Also, other considerable benefits are attached to better wastewater treatment, such as avoiding health-issues and deaths from polluted water.*

[1240] Zhang, Y., et al. (2019). Chapter 2 Coal-fired power plants emission standards. In: Advances in Ultra-low Emission Control Technologies for Coal-Fired Power Plants. See: https://www.sciencedirect.com/book/9780081024188/advances-in-ultra-low-emission-control-technologies-for-coal-fired-power-plants

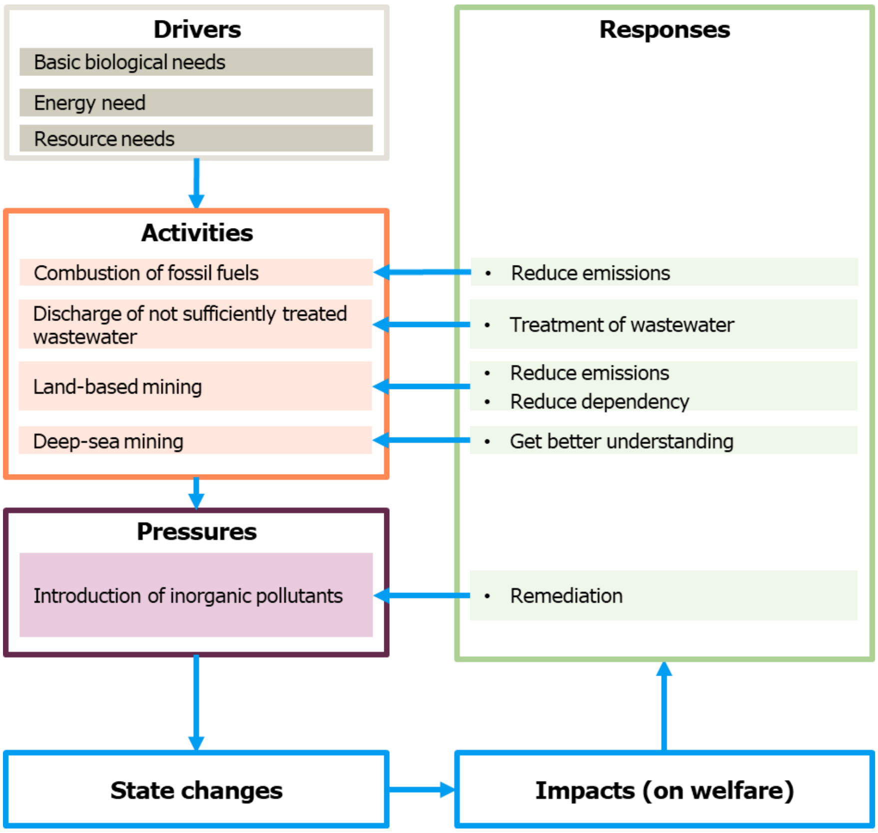
	Reduce nutrient emissions from agriculture	Improve design and management of finfish aquaculture	Reduce emissions from combustion of fossil fuels	Treatment of wastewater
	eutrophication. However, since this would include a paradigm shift with many uncertainties on social and economic impacts and thus cost-effectiveness cannot be assessed.		*purely from a "NOx perspective" the cost-effectiveness would be limited; however, given that those responses are in line with crucial needs to halt climate change and the considerable impacts of climate change, it can still be considered highly cost-effective.*	

/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

Introduction of inorganic pollutants

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Reduce emissions from combustion of fossil fuel

The discussion on the responses is similar to the ones presented for reducing emissions from combustion of fossil fuels under the section on eutrophication.

In general, there are two main pathways for reducing the emissions, technical solutions for reducing emissions from fossil fuel power plants, and a paradigm change away from fossil fuels and towards other sources of energy.

Several technologies and process optimisations are available to reduce heavy metal emissions from fossil fuel combustion power plants.[1242]

For technical solutions for reducing emissions from power generation, experience has shown that a regulatory framework setting strict legally binding emission limit values can be a strong driver for reducing emissions and that the necessary technologies are available, e.g. in the EU, NOx emissions from those sources have decreased by 60% between 2004 and 2019.[1243] Also

[1242] See e.g. chapter 10.2.1 in JRC (2017). Best Available Techniques (BAT). Reference Document for Large Combustion Plants. See: https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC_107769_LCPBref_2017.pdf

[1243] EEA indicator "Emissions and energy use in large combustion plants in Europe". See: https://www.eea.europa.eu/ims/emissions-and-energy-use-in other regions implemented ambitious emission reduction strategies, such as China leading to a decrease of NOx emissions by 60% between 2014 and 2017[1244].

A paradigm shift in electricity generation towards other energy sources such as renewable energies would lead to a full reduction of heavy metal reductions from this sector, besides other positive benefits (such as reduction of GHG and reduction of emission of substances leading to eutrophication).

Treatment of wastewater

Several technologies are available for removing heavy metals from wastewater during the treatment process. The effectiveness of this depends also on the treatment processes in place; e.g., there is good potential for removing heavy metals through primary[1245] treatment[1246] while a more complete removal can be achieved through tertiary treatment[1247] which is, however, also the costliest due to the additional steps.

Heavy metals do not degrade and thus they will mostly accumulate in either the sludge (i.e., the residual material consisting of the solid residuals) or some remaining parts of it in the discharged treated water. The effectiveness of the removal of heavy metals is important since sludge is often used as fertiliser in agriculture due to its high percentage of nutrients while the most common option for reuse of water is for irrigation and landscaping.

Limits for heavy metal concentrations in municipal and industrial exist in some world regions for discharged treated wastewater[1248] and in sludge used for agriculture[1249]. However, no complete overview of applying standards in all world regions could be identified.

Reduce emissions from land-based mining

A wide range of techniques exist that can avoid heavy metal emissions into waterbodies. This includes remediation techniques remove heavy metals from soils, from mine wastewaters (see also above), and from waterbodies. The techniques can be either physical, chemical, or biological[1250].

As mentioned, small-scale gold mining plays a special role since it is one e of the global main sources of mercury atmospheric emissions. To remedy this, alternative techniques could be applied which do not rely on mercury in the process of extracting gold from ores. One technique

[1244] Tang, L., et al. (2019). Substantial emission reductions from Chinese power plants after the introduction of ultra-low emissions standards. See: https://www.nature.com/articles/s41560-019-0468-1

[1245] Primary treatment removes litter and suspended solids by mechanical means; additional steps in secondary treatment degrade organic material through micro-organisms; tertiary treatment adds steps for further purification of wastewater.

[1246] Sylwan, I., et al. (2021). Removal of Heavy Metals during Primary Treatment of Municipal Wastewater and Possibilities of Enhanced Removal: A Review. See: https://www.mdpi.com/2073-4441/13/8/1121

[1247] Gerba, C., et al. (2019). Chapter 22 Municipal Wastewater Treatment. In: Environmental and Pollution Science (Third Edition). See: https://www.sciencedirect.com/science/article/pii/B9780128147191000227

[1248] E.g., in the EU through the Water Framework Directive and the EQS Directive which govern for which substances emissions need to completely stop or must be reduced, including Cadmium, Mercury, Nickel, and Lead.

[1249] E.g., in the EU the Sewage Sludge Directive (currently under revision) or in the USA through the Process Design Manual for land application of sewage sludge and domestic septage. EPA/625/R-95/001

[1250] See e.g. here for a recent overview: Karn, R., et al. (2021). A review on heavy metal contamination at mining sites and remedial techniques. See: https://iopscience.iop.org/article/10.1088/1755-1315/796/1/012013 suggested in a 2018 EEA report on mercury[1251] and based on a Danish study uses borax instead of mercury, is simple and does not require specialist equipment or expertise and takes approximately the same amount of time as the mercury method, besides other benefits.[1252]

The legal framework in place globally for governing environmental performance of mining is complex and entails domestic legal frameworks, mining contracts, hard and soft international laws and industrial voluntary standards[1253]. Thus, a global general overview about emission standards regarding heavy metals is difficult to get.

Looking at specific international treaties, one with direct relevance for the gold mining industry is the 2013 Minamata Convention on Mercury[1254]. Regarding current implementation, a number of countries have identified small-scale gold mining as a challenge in meeting the objectives of the convention (to protect human health and the environment from the adverse effects of mercury), among others due to a perceived lack of alternatives[1255].

Reduce dependency on land-based mining

As mentioned above, mining is done to the extract valuable materials from the Earth. Currently, several of the mined materials (e.g., metals or cement) are land-filled at the end-of-life of the products they were used in (e.g. electronic devices or houses) and thus new raw-materials need to be mined in order to manufacture new products.

Circular economy approaches have enormous potential of reducing this need for raw materials by promoting recycling and reuse of those materials instead of landfilling them.

Get better understanding about the impacts from deep-sea mining

As mentioned, there still seems to be limited understanding about the potential emissions of pollutants such as heavy metals from deep-sea mining activities we well as their impact on specific ecosystems.

Thus, additional research would be required to better understand the extent to which deep-sea mining could lead to environmental problems and how they best could be avoided.

Remediation of heavy metals in the oceans

If despite efforts to heavy metal stop emissions they still are transported into the oceans, there are a range of approaches that can be used to remedy those pollutants.

One possible approach entails the capping the polluted sediments in-situ with other materials to immobilise the contaminants[1256]. Another approach includes the dredging and treatment

[1251] EEA (2018). Mercury in Europe's environment. A priority for European and global action. See: https://www.eea.europa.eu/publications/mercury-in-europe-s-environment

[1252] Appel, P., et al. (2014). Mercury-free gold extraction using borax for small-scale gold miners. See: https://www.researchgate.net/publication/276495769_Mercury-Free_Gold_Extraction_Using_Borax_for_Small-Scale_Gold_Miners

Environmental Protection, 5, pp. 493-499

[1253] UN (2018). Managing mining for sustainable development. A sourcebook. See: https://www.undp.org/publications/managing-mining-sustainable-development

[1254] United Nations. 2013. Minamata Convention on Mercury. No. 54669. See: https://www.mercuryconvention.org/en/resources/minamata-convention-mercury-text-and-annexes

[1255] According to the 2021 note on national reporting under the Minamata Convention on Mercury

[1256] Taneez, M., et al. (2018). Capping of marine sediments with valuable industrial by-products: Evaluation of inorganic pollutants immobilization. See: https://www.sciencedirect.com/science/article/abs/pii/S0269749117344081 (e.g., through soil washing, electrokinetic treatment, or landfarming) of polluted marine sediments.[1257]

Those approaches, however, can only be applied effectively in heavily polluted and limited areas. Also, they should be seen as least priority solution and possibly for the remediation of legacy waste dumping sites in the marine environment. Higher priority should be given to the solutions discussed above focusing on avoiding heavy metal pollution in the first place.

[1257] Pasciucco, F. et al. (2021). Recovery Strategies of Contaminated Marine Sediments: A Life Cycle Assessment. See: https://www.researchgate.net/publication/353640177_Recovery_Strategies_of_Contaminated_Marine_Sediments_A_Life_Cycle_Assessment

Comparison of Responses

	Reduce emissions from combustion of fossil fuel	Treatment of wastewater	Reduce emissions from land-based mining	Reduce dependency on land-based mining	Get better understanding about the impacts from deep-sea mining
Costs and benefits					
General society[1258]	**/ to - to + (time-dependent)** *Improved technologies for reducing emissions from power generation would likely lead to no to very little increases in electricity prices.* *If a transformational change of the electricity sector leads to increased electric prices to be borne by the customers is dependent on several parameters, incl. the time frame for the change and the way that national authorities choose to finance the change.* *In the medium- to long term, the price for producing electricity (levelized costs of energy or LCOE) from renewable energies is getting lower than the one from fossil*	**-** *As already mentioned, wastewater treatment in general is expensive*[1259]*, both in terms of CAPEX and OPEX and it is important that locally adapted systems are selected, considering aspects such as cost-effectiveness, long-term sustainability, and availability of space.*	/ *It is unclear to what extent the implementation of more strict environmental standards in the mining sector would result in higher prices for products. Given the high fluctuation of prices of most raw materials on international markets which are only to a limited extent linked to changes in production costs, it can be assumed that the effects, if any, would be very limited.*	() *Circular economy approaches are plentiful and there is a large diversity in the effectiveness and cost-effectiveness of them; thus, it is unclear to what extent this would lead to costs or benefits for consumers.*	**/**

[1258] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1259] For example, total annual costs for wastewater treatment in the EU are estimated at around EUR 18 billion. See: SWD(2019) 700 final PART 1/2 COMMISSION STAFF WORKING DOCUMENT EVALUATION of the Council Directive 91/271/EEC of 21 May 1991, concerning urban waste-water treatment. https://ec.europa.eu/environment/water/water-urbanwaste/pdf/UWWTD%20Evaluation%20SWD%20448-701%20web.pdf

	Reduce emissions from combustion of fossil fuel	**Treatment of wastewater**	**Reduce emissions from land-based mining**	**Reduce dependency on land-based mining**	**Get better understanding about the impacts from deep-sea mining**
	fuels power generation, a trend that can already be seen today.				
National public authorities	**-- to / (time-dependent)** *Public authorities could face costs for financing or supporting to finance the transition, including by investing into the sector, as well as by subsidising electricity tariffs in case increases impede affordability and to ensure a just transition.*	*In cases where user charges for new and/or updated infrastructure would create affordability issues, public authorities can support, either by subsidising the operations themselves*[1260] *or by subsidising affordable tariffs for poorer parts of the population.*	**-** *As for all environmental standards and legislation, public authorities would face some limited costs for enforcement and monitoring.*	**/** *It is likely that public authorities would need to take coordinating actions for the transition; however, those can be considered negligible*	**- to –** *Public authorities and the international community are the ones who would bear most of the costs for additional research on potential effects from deep-sea mining. Given the difficulty of conducting research in this area it is likely that such costs could be substantial; however, given the importance of the potentially affected ecosystems such research seems to be crucial for ensuring a save (or somewhat save) conduct in deep-sea mining.*
International community	**/** *Under Article 9 of the Paris Agreement developed country Parties have the obligation to provide financial resources to assist developing country*	*Given the considerable capital investments needed to establish wastewater treatment infrastructure it can be expected that some*	/	**/**	*See above.*

[1260] Which is, however, not fully aligned with the polluter pays principle.

	Reduce emissions from combustion of fossil fuel	Treatment of wastewater	Reduce emissions from land-based mining	Reduce dependency on land-based mining	Get better understanding about the impacts from deep-sea mining
	Parties with respect to both mitigation and adaptation; transformative changes in energy generation, including switching away from coal and other fossil fuels to renewable energies, would already be within the scope of this.	*regions would need considerable financial support.*			
Industry	/ *It can be expected that costs for switching as well as capital costs for transforming the sectors would be recovered through charges for electricity.*	-- *If no emission standards are in place yet, industry would have to invest for meeting newly introduced standards.*	- *Some compliance costs would apply for mining industries through higher environmental standards; however, those are in general limited and often depend strongly on good design and implementation of environmental regulation.*[1261]	() *Same as for the general society; circular economy approaches are plentiful and there is a large diversity in the effectiveness and cost-effectiveness of them; thus, it is unclear to what extent this would lead to costs or benefits for consumers.*	(-) *It is likely that some of the research would also be financed and/or conducted by the industry itself.*
Other	/	/	/		/
Analysis					
Geographical distribution of costs and benefits	*Regarding technical solutions for reducing emissions for power generation, regions with currently low standards would face highest costs; however,*	*As mentioned above, it is unclear to what extent emission standards for industrial wastewaters regarding heavy metal*	/	/	/

[1261] Söderholm, K., et al. (2014). Environmental Regulation and Mining Sector Competitiveness. See: https://www.ltu.se/cms_fs/1.124549!/file/rapport%20Environmental%20Regulation%20and%20Mining_low.pdf

	Reduce emissions from combustion of fossil fuel	Treatment of wastewater	Reduce emissions from land-based mining	Reduce dependency on land-based mining	Get better understanding about the impacts from deep-sea mining
	no comparative assessment of heavy metal emission standards for fossil fuel plants could be identified. *Regarding transformative changes, costs would occur globally with some notable exceptions of countries which are currently already far advanced in this regard, such as Norway.*	*emissions already exist in most world regions; where they do not exist yet or are very lax, industry would face considerable costs for investments.* *Regarding municipal wastewater, costs would be highest in regions with currently a low level of treatment such as central and Southern Asia or Sub-Saharan Africa.*			
Assessment of cost-effectiveness	***+ to +++*** *Technological solutions can be considered cost-effective; however, little information (including on emission standards in different world regions) seems to be available on the extent to which the implementation of standards would effectively reduce heavy metal emissions to acceptable levels.* *Given the transformative change, it could be expected that purely from a "heavy*	**++** *Despite the high costs this can be considered cost-effective, given that treatment is very effective in reducing pollutions from this point-source pollution. Also, other considerable benefits are attached to better wastewater treatment, such as avoiding health-issues and eutrophication.*	++ *Given the limited costs it can be assumed that such solutions would be cost-effective. However, it should also be noted that only very little literature seems to exist on the actual effectiveness of environmental regulations regarding heavy metal pollution, and more specifically into*	***(/ to ++)*** *As mentioned, there is some uncertainty attached about the extent to which this would save money for society and industry. However, in the worst case scenario it doesn't while at the same time there are still environmental benefits. In the best case, the benefits from reduced raw material needs would*	**+++** *Despite potentially high budgets for additional research such costs are nevertheless highly cost-effective, given the novel nature of deep-sea mining activities and the major unknowns regarding effects on marine ecosystems.*

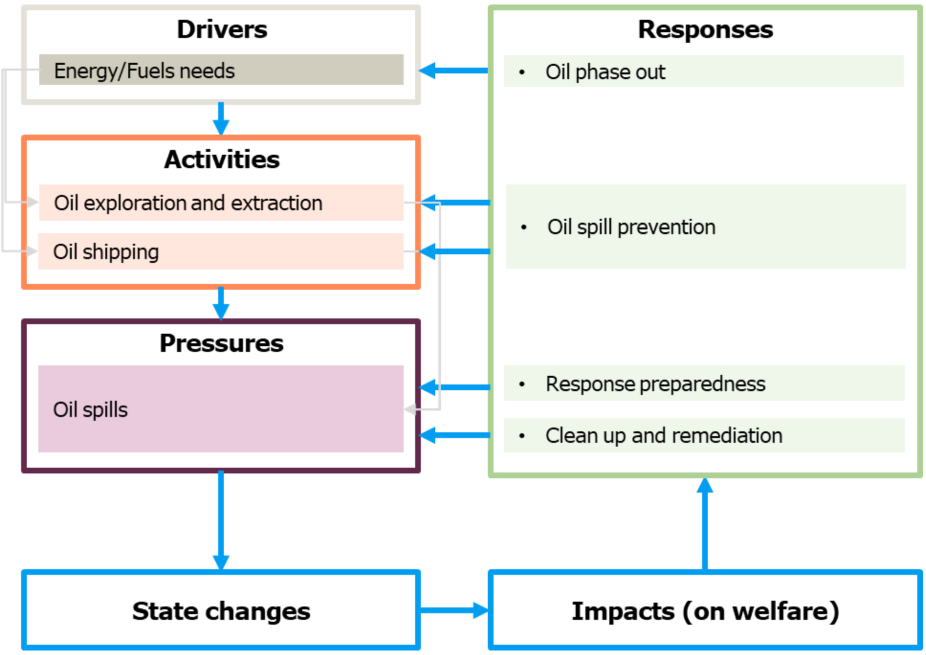
	Reduce emissions from combustion of fossil fuel	Treatment of wastewater	Reduce emissions from land-based mining	Reduce dependency on land-based mining	Get better understanding about the impacts from deep-sea mining
	metal perspective" the cost-effectiveness would be limited; however, given that those responses are in line with crucial needs to halt climate change and the considerable impacts of climate change, it can still be considered highly cost-effective.		*water bodies and the oceans.*	*outweigh the costs of additional processing.*	

/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

Oil spills

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Oil phase out

Reducing reliance on oil as a fuel, or oil phase out, would reduce the likelihood of oil spills into the environment, as less oil extraction and shipping activities would be undertaken. Reducing the reliance on oil is in line with the commitments made by all signatories to the Paris Agreement, and namely the commitment to align their long-term climate change mitigation efforts with limiting global temperature increases to within 2°C of pre-industrialisation levels, pursue efforts to limit the increase to 1.5°C, and to achieve a balance between emissions of GHGs from sources and the removal of GHGs from the atmosphere by sinks by the second half of this century. Moreover, this would be in line with the Net Zero and Carbon Neutrality commitments made by different countries. According to the IEA, the pathway towards net zero means that "no exploration for new resources is required and, other than fields already approved for development, no new oil fields are necessary"[1262]. Another report found that "limiting warming to 1.5°C requires the richest countries to phase out oil and gas production by 2034, to give lower income nations longer to replace their income from fossil fuel production. The poorest countries should be given until 2050 to end production, but they will also need significant financial support to transition their economies within that time frame"[1263]. It is challenging to quantify the costs and benefits of the implementation of this response. Available

[1262] https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

[1263] https://www.iisd.org/articles/analysis/phase-out-oil-gas-production projections estimate that the investments needed to transform the global energy system to achieve net zero emissions in 2050 would require a large expansion in investments, as well a shift in what capital is spent on. Investments in energy could go from "USD 2 trillion globally on average over the last five years to almost USD 5 trillion by 2030 and to USD 4.5 trillion by 2050"[1264].

Proactive oil spill prevention

"Once oil is spilled there are no good outcomes, and every response technology involves trade-offs."[1265] The most effective response to oil spills is their prevention.

A global study reviewing oil tanker spills from 1970s to 2017[1266], indicated that the main causes of oil spill were stranding, collision, hull damages, and fire/explosion, followed by equipment failure, bad weather conditions and human errors. Therefore, government agencies and companies should pay attention to these factors and adopt targeted measures to prevent such accidents.

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international legal instrument aimed at preventing and minimising the pollution of the marine environment by oil-carrying ships. It covers both spills from operational and accidental causes. The Convention, including its Annex I on Regulations for the Prevention of Pollution by Oil has been ratified by around 160 countries worldwide, including all major producers and exporters of oil. The Convention includes regulations aimed at preventing and minimizing pollution from ships - both accidental pollution and that from routine operations[1267]. Spill prevention includes guidance on how to safely build and operate oil tankers, so that the amount of oil spilled in the event of an accident is reduced. For instance, the Convention establishes technical requirements such as the requirement for oil tankers to be fitted with a double hull[1268], as well as standards concerning the oil discharge and monitoring systems.

Oil spill prevention moreover includes measures such as vessel crew training and licensing requirements, port state control inspections and other technical measures to prevent oil spills from pipeline and offshore platforms. These mainly concern the application of design standards and rules for oil storage, transfer and containment facilities, including avoiding filling fuel tanks to the maximum levels[1269],[1270].

The implementation of prevention legislation has been effective in reducing the incidence of oil spills, in particular from ships, as these have substantially decreased over time, from about 79 oil spills per year, on average in the 1970s, to around 5 oil spills per year in the last decade[1271].

Notably, to date, oil spill prevention regulation has in most cases been "passive", as it is usually developed following an accident[1272]. Efforts could be undertaken to identify gaps in the current legal framework and to fill them proactively, to avoid further accidents taking place in the future.

1264 https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

1265 https://response.restoration.noaa.gov/about/media/what-have-we-learned-about-using-dispersants-during-next-big-oil-spill.html

1266 Jihong et al (2019) Oil spills from global tankers: Status review and future governance.

1267 https://www.imo.org/en/OurWork/Environment/Pages/OilPollution-Default.aspx

1268 Ships with double hulls have two watertight layers on the bottom and sides of the ship.

1269 https://sci-hub.mksa.top/10.1016/s1353-2561(02)00057-9

1270 https://ecology.wa.gov/Spills-Cleanup/Spills/Oil-spill-prevention/Preventing-spills

1271 https://www.itopf.org/knowledge-resources/data-statistics/statistics/

1272 Jihong et al (2019). Oil spills from global tankers: Status review and future governance.

Table Typical oil spill accidents and development of related treatment laws and regulations

Year	Ship Name	Ship Flag	Oil Spillage (10,000tons)	Location	Event Description	Some Related Laws and Regulations	Constitutor
1967	Torrey Canyon	Cameroon	11.9	The English Channel	Hull broke after the ship hit rocks	International Convention Relating to Intervention in the High Seas in Cases of Oil Pollution Casualties in 1969 (INTERVENTION, 1969), International Convention on Civil Liability for Oil Pollution Damage (CLC69) in 1969 and the Maritime Agreement Regarding Oil Pollution of Liability (MARPOL 73/78)	IMO
1978	Amoco Cadiz	Liberia	22.3	The English Channel	Multiple oil tanks broke after the hydraulic steering gear malfunctioned in the bad weather	Paris Memorandum of Understanding on Port State Control (Paris MoU)	EU
1989	Exxon Valdez	United States	3.7	The Prince William Sound in Alaska	The ship ran aground on a reef and the oil tanks broke	1990 Oil Pollution Act International Convention on Oil Pollution Preparedness, Response and Cooperation, 1990	The United States IMO
1999	Erika	Malta	2	Near the coastline of northwest France	The ship grounded as the weather was dry, and the oil tanker maintenance was poor	Erika I and II packages	EU
2002	Prestige	Bahamas	6.3	Waters off northwest Spain	A wide opening appeared on the hull because of a storm, and fuel oil leaked	3rd Maritime Safety Package: MSP3 Hazardous and Noxious Substances by Sea Convention in 1996	EU IMO

Source: Jihong et al (2019)[1273]

For instance, international legislation concerning liability attribution could be strengthened. Correctly attributing the liability for the damages caused by an oil spill accident can be an important means to ensure compliance with existing regulations for owners and operators involved in oil operations.

When oil tankers are registered with flags of convenience[1274], flag states' supervision responsibility for ship-caused pollution basically fails, because the supervision efforts in these states are often low. This means that in the case of oil spills, the flag states find it difficult to play a supervising role[1275]. Notably, vessels flying flags of states that have exhibited consistent patterns of failure in compliance with international obligations, often flags of convenience, were found to be significantly more common amongst the vessels that have been involved in spill incidents[1276]. To address this issue, measures should be taken up at the global level to deter vessel owners from registering with flags of convenience, as well as to pressure flag states to improve effective jurisdiction over ships flying these flags[1277].

Response preparedness

The International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC)[1278] provides a global framework for international co-operation in combating major incidents or threats of marine pollution related to oil. Parties to the Convention are required to

[1273] Jihong et al (2019). Oil spills from global tankers: Status review and future governance.

[1274] Flags of convenience are defined as ""the flags of certain countries whose laws allow. . . and indeed, make it easy for. . ships owned by foreign nationals or companies to fly these flags". Flags of convenience are often chosen because a) it is easy to obtain registration in them; b) tax benefits; c) reduction of costs; d) freedom from control by the country of registry. Available at: https://ilo.primo.exlibrisgroup.com/discovery/fulldisplay/alma991564853402676/41ILO_INST:41ILO_V2

[1275] Chen, Jihong; Zhang, Weipan; Wan, Zheng; Li, Sifan; Huang, Tiancun; Fei, Yijie (2019). Oil spills from global tankers: Status review and future governance. Journal of Cleaner Production, 227(), 20–32. doi:10.1016/j.jclepro.2019.04.020

[1276] https://www.cambridge.org/core/journals/environmental-conservation/article/abs/largescale-oil-spills-and-flaguse-within-the-global-tanker-fleet/4ED595ADA950BB71C832DDEE76B4CE3A

[1277] https://www.cambridge.org/core/journals/environmental-conservation/article/abs/largescale-oil-spills-and-flaguse-within-the-global-tanker-fleet/4ED595ADA950BB71C832DDEE76B4CE3A

[1278] https://www.imo.org/en/About/Conventions/Pages/International-Convention-on-Oil-Pollution-Preparedness,-Response-and-Co-operation-(OPRC).aspx establish measures for dealing with pollution incidents, either nationally or in co-operation with other countries. These measures involve:

- Carrying a shipboard oil pollution emergency plan;
- Reporting incidents of pollution to coastal authorities;
- Establishing stockpiles of oil spill combating equipment;
- Holding oil spill combating exercises;
- Developing detailed plans for dealing with pollution incidents.

States which are party to OPRC 90 and OPRC-HNS Protocol are required to establish a national system for responding to oil and HNS pollution incidents, including a designated national authority, a national operational contact point and a national contingency plan. This needs to be backstopped by a minimum level of response equipment, communications plans, regular training and exercises. Parties to the Convention are also required to provide assistance to others in the event of a pollution emergency and provision is made for the reimbursement of any assistance provided[1279].

Although it is known that 117 states have ratified OPRC, no comprehensive overview of the national contingency plans developed worldwide is available[1280], nor an assessment of their effectiveness for oil spill response. Obtaining an overview of the status quo could be useful to identify and address potential gaps in response preparedness.

Clean up and restoration

Clean up following an oil spill can involve both mechanical and manual techniques. The main types of clean-up techniques involve the use of booms, skimmers, sorbents, chemical dispersants, in-situ burning and bioremediation[1281]. Booms and skimmers form part of mechanical recovery, but they do not work well in rough seas and take time to deploy. Dispersants are chemicals designed to remove oil from the water surface, and they can be sprayed over the contaminated surface with aircrafts. Notably, no solution completely removes the oil from the marine ecosystem, and even in the best-case scenario, only 40 per cent of oil from a spill can be cleaned up by mechanical means. Moreover, the potential negative impacts of chemical dispersants in the long-run are still being studied[1282]. The ability of natural recovery to restore the environment can play an important role, and actions to enhance its effectiveness needs to be considered[1283].

Restoration can also involve the reintroduction of species affected by the spill, erosion control, if damage from the spill has sped up erosion, and a change in management practices, such as controlling fishing and hunting, in impacted areas[1284].

[1279] https://www.imo.org/en/OurWork/Environment/Pages/Pollution-Response.aspx

[1280] A scattered overview of the adoption of National Contingency Action Plans is provided by the Global Initiative, and related regional programmes. See: https://www.ipieca.org/our-work/nature/oil-spill-preparedness-and-response/the-global-initiative/

[1281] https://www.witpress.com/Secure/elibrary/papers/WRM07/WRM07049FU1.pdf

[1282] https://response.restoration.noaa.gov/about/media/what-have-we-learned-about-using-dispersants-during-next-big-oil-spill.html

[1283] https://www.unep.org/news-and-stories/story/how-manage-damage-oil-spills

[1284] https://www.unep.org/news-and-stories/story/how-manage-damage-oil-spills

Comparison of Responses

	Oil phase out	Oil spill prevention	Response preparedness	Clean up and remediation
Costs and benefits				
General society[1285]	***(- to - -)*** *General society could bear costs associated with the transition to alternative sources of energy, if industry transfers these costs to consumers. There is uncertainty as regards to the specific costs, but these are likely to be substantial in the short-medium term*[1286]*. Measures to support a just transition could alleviate this negative impact. Moreover, the benefit of phasing out oil would go beyond the reduction of the likelihood that natural disasters such as oil spills take place, as this would contribute to GHG emission reductions and to addressing anthropogenic climate change.*	**/ to (-)** *Potentially, general society could experience increased costs for goods that are shipped, as the shipping industry could transfer down costs. However, these additional costs on consumers would be minimal.*	**/**	**/**
National public authorities	***(- to --)*** *Public authorities would bear the costs of supporting society (and industry) with the*	***(/ to ++)*** *Public authorities could face some costs for enforcing the*	**(- to --)** *Developing and implementing response preparedness contingency plans requires an*	***(- to --)*** *Those responsible for the pollution (e.g. industry, in case of malfunctioning or non-*

[1285] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1286] https://www.resolutionfoundation.org/press-releases/costs-of-net-zero-transition-for-low-and-middle-income-households-must-be-addressed-rather-than-used-to-derail-decarbonisation/

	Oil phase out	Oil spill prevention	Response preparedness	Clean up and remediation
	transition to alternative sources of energy. This is likely to require substantial investments e.g. in terms of R&D and infrastructure development costs, as well as welfare support for general society. It is estimated that investments in energy could go from "USD 2 trillion globally on average over the last five years to almost USD 5 trillion by 2030 and to USD 4.5 trillion by 2050, if net zero emissions globally"[1287]. *Oil phase out would reduce the risk of oil spills, and therefore the clean-up and remediation costs to be borne by public authorities. In addition, this would contribute to GHG emission reductions and to addressing anthropogenic climate change.*	*measures, but they can be considered minimal.* *Prevention would reduce the risk of oil spills, and therefore the clean up and remediation costs (the part borne by public authorities).*	*investment on the part of national public authorities.* *It is not possible to estimate costs associated with response preparedness.* *The benefits mainly relate to the reduction of negative environmental impacts of the oil spill, and potentially a reduction in clean up and remediation costs (the part borne by public authorities).*	*compliance with safety measures) should pay for clean-up and restoration[1288], which are substantial. If the polluter is found non-liable, or it reaches the limit for liability under law, the Oil Spill Liability Trust Fund can intervene[1289].* *Costs for public authority relate to the development of trained group of professional emergency response and restoration experts[1290].*
International community	**/**	**/**	**/**	**/**
Industry	**-- to ---**	**- to +**	**-**	**---**

[1287] https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

[1288] The present international regime of compensation for damage caused by oil pollution is based on two conventions: International Convention on Civil Liability for Oil Pollution Damage (1969) International Convention on Civil Liability for Oil Pollution Damage (1969), International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage (1971).

[1289] https://response.restoration.noaa.gov/about/media/who-pays-oil-spills.html

[1290] https://response.restoration.noaa.gov/about/media/who-pays-oil-spills.html

	Oil phase out	Oil spill prevention	Response preparedness	Clean up and remediation
	Oil industry would have to bear the costs of phase out and decommissioning of platforms/transport networks. It is likely that these costs would be substantial, also in terms of foregone revenue from exploiting oil reserves.	*Costs for the industry relate to the implementation of oil spill prevention measures and protocols on oil platforms, as well as oil shipping vessels. If the adaptation of the platforms/vessels to high safety standards requires the replacement of machinery or retrofit, costs could be higher.* *Through the implementation of this measure, industry would however reduce the risk of oil spills, and therefore avoid economic losses related to the quantity of oil spilled, as well as avoid cost for remediation.*	*Response preparedness contingency plans can also be developed by oil industry stakeholders, and this can require an investment, though this is likely minimal.* *Through the implementation of this measure, industry would however mitigate the impact of oil spills, and therefore reduce the economic losses related to the quantity of oil spilled, as well as potentially reduce the cost for remediation.*	*Those responsible for the pollution (e.g. industry, in case of malfunctioning or non-compliance with safety measures) should pay for clean-up and restoration, which are substantial (estimated at 16,000 USD for each tonne of oil spilled)[1291].*
Other	**/**	**(+ to ++)** *Potential benefits for shipyards and technology developers for implementing the necessary technological changes onboard ships and platforms. Benefits would be at the same level as the costs for the shipping industry.*	**/**	**/**
Analysis				

[1291] Vanem et al (2007) Cost-effectiveness criteria for marine oil spill preventive measures.

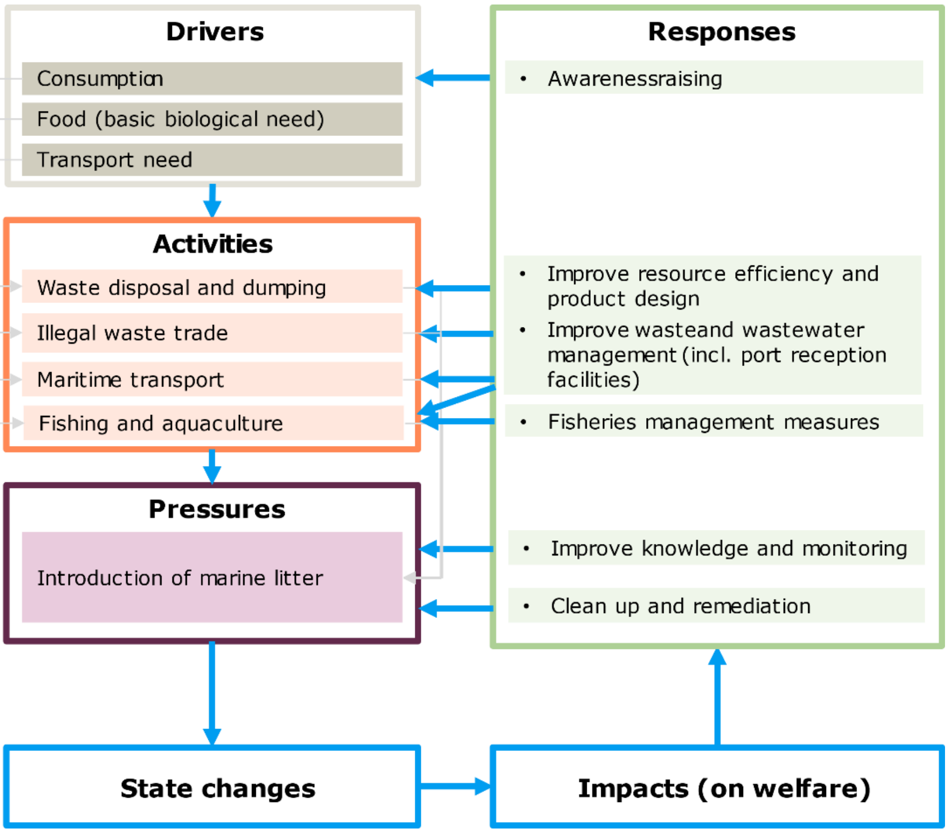
	Oil phase out	Oil spill prevention	Response preparedness	Clean up and remediation
Geographical distribution of costs and benefits	*Costs of oil phase out would be borne by oil producing countries (i.e. in terms of avoided income from oil supply), as well as by any country relying on oil as a fuel, as they would have to invest in developing and implementing alternative fuels to satisfy their energy demand. Developing countries are also likely to be negatively impacted by this.*	*Costs are likely to be borne by oil producing (and shipping) countries e.g United States, Russia, Saudi Arabia, Canada, China and Iraq, among others.*	*Costs are likely to be borne by oil producing (and shipping) countries e.g United States, Russia, Saudi Arabia, Canada, China and Iraq, among others.*	*Costs are borne by countries interested by the oil spill (or oil industry thereof).*
Assessment of cost-effectiveness	**+ to unknown (transformative change)** *Oil phase out would constitute a transformative change, it can be expected that this would be effective in reducing and stopping oil spills, as well as contributing to substantially reduce anthropogenic GHG emissions. However, since this would include a paradigm shift with many uncertainties on social and economic impacts, cost-effectiveness cannot be assessed.*	**++** *Considering the virtually irreversible negative impacts of oil spills, investing in response preparedness is considered to be the most cost-effective way of reducing the likelihood that oil spills take place and produce impacts.*	**+** *Considering the virtually irreversible negative impacts of oil spills, investing in response preparedness is considered too be a cost-effective way of reducing the impacts of oil spills - once these have occurred.*	**-- to ---** *Clean up and remediation are very costly and due to their limited effectiveness in removing the oil from the marine ecosystem, this is not considered a cost-effective option.*

/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

Introduction of marine litter

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure. As a general consideration, in relations to all proposed policy responses listed below, it can be said that managing marine litter requires both a local and transboundary approach and the collaboration of a broad variety of stakeholders involved in the whole value chain leading to the leakage of litter into the oceans. Multilateral cooperation is particularly needed because marine litter travels across regions.

Figure Flowchart for the pressure including responses



Source: Own illustration

Awareness raising

The leaking of marine litter and microplastics is also linked to unstainable patterns of consumption and production. Awareness raising campaigns, implemented at different levels, could have a beneficial effect[1292] in that they would foster the reduction in plastics demand (and the demand of other items that generate marine litter), and therefore a reduction in the potential waste generation. The education, awareness-raising and involvement of stakeholders across sectors is considered crucial to reduce the leakage of sea-based marine litter as well[1293].

[1292] UNEP, WRI (2020) Tackling plastic pollution: Legislative Guide for the Regulation of Single-Use Plastic Products

[1293] GESAMP (2021) Sea-Based sources of marine litter.

Public awareness of plastic pollution is growing, and the issue of plastic pollution is ranked among the top three environmental concerns globally. Not only, but plastic is now viewed as "the most negative material used for consumer goods items, with 65% of global consumers associating it with ocean pollution and 57% deeming it harmful"[1294]. Consumers in many communities are now trying to reduce their "plastic footprint", and the COVID-19 pandemic reportedly reinforced these intentions[1295].

Beyond awareness raising campaigns, market signals can be effective in promoting a shift in consumer behaviour. As consumers are increasingly willing to pay more for eco-friendly products (e.g. 72% of global consumers are willing to pay up to 10% more for eco-friendly packaging)[1296], these economic incentives could prove effective in fostering more sustainable forms of consumption.

Improve resource efficiency and product design

Despite the growing attention that marine litter is gaining in the public eye, in general, plastics manufacturers, and manufacturers of products that incorporate plastics have little incentives for designing products with end-of-life management in mind. They rather focus on product performance, and in fact the number of polymer types and structures continue to grow. Also, the recyclability of plastics is sometimes hindered by factors such as the widespread use of chemical additives and the growing complexity of many plastic-containing products[1297].

The improvement of resource efficiency through the plastics (and other wastes) lifecycle, including through improved product design is considered key to reduce the among of marine litter that ends up in the oceans. This involves limiting the use of plastics to applications where there are few environmentally preferable alternatives, by ensuring that the plastics that are produced remain in use for as long as possible, and by recovering a greater share of plastics at their end of life – including following circular economy principles[1298]. For sea-based sources of litter, this could mean designing fishing gear to reduce partial loss or producing them with bio-degradable materials, as well as designing vessels in a way that reduces discarding of gear or other marine litter[1299].

Policymakers can foster resource efficiency and improved product design in various ways. Similar to marine litter, a broad range of measures can be taken to stimulate improved product design, including binding ecodesign and resource efficiency requirements, labelling, standardisation and certification measures, product sourcing requirements, extended producer responsibility schemes, market-based instruments and bans on the use of specific products[1300]. A comprehensive overview of possible measures is provided in UNEP, WRI (2020)[1301]. The EU for instance, has adopted the Directive on Single Use Plastics and fishing gear, which includes a ban on selected single-use products made of plastic for which alternatives exist on the market, extended Producer Responsibility schemes covering the cost to clean-up litter, applied to

[1294] WWF (2020) The business case for a UN treaty on plastic pollution.

[1295] Idem

[1296] Idem

[1297] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

[1298] Idem

[1299] GESAMP (2021) Sea-Based sources of marine litter.

[1300] https://ec.europa.eu/environment/topics/plastics/microplastics_it

[1301] UNEP, WRI (2020) Tackling plastic pollution: Legislative Guide for the Regulation of Single-Use Plastic Products

products such as tobacco filters and fishing gear, as well as specific waste collection and product design requirements for plastic bottles[1302].

Box 5.4 Extended producer responsibility schemes

Extended Producer Responsibility (EPR) schemes also have a role to play. By making plastic and product manufacturers at least partially responsible for the cost of managing their products at the end of life, EPR can incentivise better design practices, while also creating an additional source of funding for waste management activities[1303]. There is empirical evidence that EPR schemes, combined with the use of collection/recycling targets, lead to an increase in separate collection and recycling of waste, reducing both landfilling and littering[1304]

Over the last 5 years, the number of international initiatives to fight plastic pollution has more than doubled[1305]. Worldwide, around 137 countries have put in place regulations on single use plastic or are planning to do so[1306]. The level of ambition of these initiatives, as well as their timely implementation matter. In fact, a recent publication [1307] has estimated that the plastic waste entering the oceans could reach 22 million tons and possibly as much as 58 million tons a year, in the next ten years - already considering the thousands of commitments made by the government and the industry to reduce plastic pollution. NGOs signal that "most existing policies are misaligned with major problem drivers" of plastic pollution[1308], in that they cover only a limited number of waste items (e.g. 60% the countries which have some form of plastic-related legislation, regulations only address single-use plastic bags), or that only a limited number of the countries responsible for the largest amounts of plastic leakage have put in place legislation that covers more than half of the waste found in the oceans.

Moreover, NGOs have highlighted that delays in the adoption of initiatives aimed at reducing plastics pollution have a significant impact in terms of yearly emissions of waste[1309].

Fisheries management measures

Given the diversity of sources of sea-based marine litter, as well as the nature and scale of the problem, addressing this issue demands a wide array of approaches, besides resource efficiency and product design improvements. For instance, measures aimed at regulating the way fishing and shipping activities can be implemented. For fishing gear, these measures can include: reductions in fishing effort and capacity control in specific areas, as "the less gear that is being used, the less gear there is to lose"; spatial and temporal fisheries management measures e.g. gear use limits in; fishing gear marking and tracking requirements, linked to gear loss reporting system to increase accountability, as well as to improve recording and reporting of gear loss; rewards for gear stewardship e.g. financial incentives for returning end-of-life gear[1310].

[1302] https://ec.europa.eu/environment/marine/good-environmental-status/descriptor-10/index_en.htm

[1303] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

[1304] ETC-WMGE (2019) Plastics waste trade and the environment.

[1305] WWF (2020) The business case for a treaty on plastics pollution.

[1306] Idem

[1307] https://www.science.org/doi/10.1126/science.aba3656

[1308] WWF (2020) The business case for a treaty on plastics pollution.

[1309] https://eeb.org/delay-in-proposed-microplastics-restriction-leading-to-irreversible-pollution/

[1310] GESAMP (2021) Sea-Based sources of marine litter.

Enforcement, including community-supported enforcement can be critical for the success of these kinds of measures.

Improve waste management (incl. port reception facilities)

To date, plastics recycling continues to be an "economically marginal activity". Recycling rates are thought to be 14–18% at the global level, with some regional variations[1311]. This is substantially lower than those for other widely used materials such as steel, aluminium copper, whose recycling rate is thought to be around 50%. The remainder of plastic waste is either incinerated (24%) or disposed of in landfills or the natural environment (58–62%). In light of this, the development of better waste management systems could significantly reduce the amount of (plastic) waste that leaks into the oceans[1312].

Reportedly, there are insufficient infrastructures and policies for recycling, or for wastewater and solid waste management to date[1313].

Essential measures include those aimed at securing landfills, developing port waste management, promoting best practices for the fishing industry and improving maritime transport to limit container losses or primary microplastics spills[1314].

The improvement of port reception facilities could help reduce marine litter from different sources. Ports should provide accessible and low-cost litter disposal facilities, and that integrate recycling initiatives.

Improve knowledge and monitoring

The World Ocean Assessment II highlighted that in many countries, the lack of national and regional monitoring of marine litter is a major bottleneck for addressing the issue and for assessing the effectiveness of measures already taken[1315]. This concern is reflected in other publications by NGOs[1316], which recall that there is no global system in place to provide independent and scientifically-based effectiveness evaluations of the numerous initiatives out there – thereby increasing uncertainty with regards to their effectiveness.

The World Ocean Assessment II indicated that, in general, there is a lack of standardisation of methods for collection and analysis of data on the quantities and impact of marine litter, as well as a lack of evidence concerning the natural environmental variability related to marine litter. The report informs that the "challenge now is to better understand how plastic is cycled through marine ecosystems, where it goes and how it degrades"[1317]. Concerning sea-based sources of

[1311] Recycling rates in low to middle-income countries are largely unknown, but may be significant in situations where there is a well-established and effective informal sector. Data from Wilson et al. indicates that plastics recycling rates may be approaching 20 – 40% in some developing-country cities. From OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

[1312] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

[1313] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1314] Idem

[1315] Idem

[1316] WWF (2020) The business case for a UN treaty on plastic pollution.

[1317] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

marine litter, further research into “causes, quantities, impacts, and solutions” has been called for, to inform management and policy change recommendations at all scales[1318].

The management of marine litter pollution is considered “exceptionally complex”. As such, it requires an integrated approach encompassing a number of actions, including reducing knowledge gaps and improving monitoring[1319], so that this knowledge can allow the development of adequate and efficient regulations[1320].

Clean up and remediation

Clean up and remediation activities include beach clean ups and the use of technology to collect plastics from oceans. Clean up and remediation activities vary in scale, going from community-led beach litter collections to larger ocean cleaning systems (e.g. The Ocean Cleanup project). These aim to remove plastics already in the natural environment, and “can be a potentially important way of addressing the legacy plastics that are already in the ocean”, though their cost effectiveness and applicability to certain types of plastics remain uncertain[1321]. Data and information about existing clean up technologies already on the market or in the process of being marketed is very limited, including concerning their impact on litter reduction.

[1318] GESAMP (2021) Sea-Based sources of marine litter.

[1319] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1320] Pinto da Costa et al (2020) The Role of Legislation, Regulatory Initiatives and Guidelines on the Control of Plastic Pollution.

[1321] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

Comparison of Responses

	Awareness raising	Improve resource efficiency and product design	Improve waste (and wastewater) management	Improve knowledge and monitoring	Clean up and remediation
Costs and benefits					
General society[1322]	/	*/ to (-)* *This might result in higher prices for products, but it remains unclear. It might be that more resource-efficient products, or products that use recycled or alternative material are actually less expensive in the long run.*	- *Waste and wastewater management are expensive, both in terms of CAPEX and OPEX and it is important that locally adapted systems are selected, considering aspects such as cost-effectiveness, long-term sustainability, and availability of space.*	/	/ *Community-led coastal clean-ups are undertaken by civil society organisations and coastal communities.*
National public authorities	- *Limited costs for developing and rolling out awareness raising campaigns*	**(- to - -) (measure-dependent)** *Public authorities might incur costs to adopt and enforce legislation and incentives to stimulate resource efficiency and improved product design. The costs will depend on the type of measure and scale of implementation. Monitoring enforcement and product compliance*	***/ to –*** *As already mentioned in section 8.3.1, in cases where user charges for new and/or updated infrastructure would create affordability issues, public authorities can support, either by subsidising the operations themselves*[1323] *or by subsidising affordable*	***- to --*** *Public authorities and the international community are the ones who would bear most of the costs for additional research and monitoring of marine litter. Given the complexity of the topic, as well as the complexity of monitoring the pressure at sea, these*	***(- to --)*** *Clean up and remediation activities are mostly undertaken by public authorities. The costs of recuperating marine litter at sea can be significant.*

[1322] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1323] Which is, however, not fully aligned with the polluter pays principle.

	Awareness raising	**Improve resource efficiency and product design**	**Improve waste (and wastewater) management**	**Improve knowledge and monitoring**	**Clean up and remediation**
		can impose significant costs.	*tariffs for poorer parts of the population.* *Waste management assets – collection vehicles, transfer stations, sorting plants, disposal facilities etc. – deliver a public good (the protection of people's health and the environment), and therefore tend to rely heavily on government funding for their construction and operation. In this setting, achieving long-lasting improvements in the coverage and quality of waste management systems implies significant increases in public spending.*[1324]	*are likely to be substantial. These efforts would also require international cooperation e.g. in particular in terms of standardisation of methodologies and coverage of monitoring studies.*	
International community	**/**	(-) *Some countries might need technical assistance for the implementation of resource efficiency and product design*	***- to - -*** *Given the considerable capital investments needed to establish waste and wastewater treatment infrastructure it can be expected that*	*See above.*	(/ to –) *As marine litter is ubiquitous, and all countries contribute to it, clean up and remediation activities require collaborative efforts from*

[1324] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

	Awareness raising	Improve resource efficiency and product design	Improve waste (and wastewater) management	Improve knowledge and monitoring	Clean up and remediation
		requirements. For instance, under the proposal for the legally binding instruments on plastics pollution, it is foreseen that the international community will provide technical assistance[1325]*.*	*some regions would need considerable financial support.* *For instance, under the proposal for the legally binding instruments on plastics pollution, it is foreseen that the international community will provide technical assistance*[1326]*.*		*the international community.*
Industry	/	**- - to + (time and measure dependent)** *Improvements in product design and resource efficiency will require investments on the part of industry e.g. for R&D of products. The utilisation of alternative materials might also involve additional costs.* *At the same time, resource efficiency might lower production costs in the long run.*	-- *If no emission / pollution standards are in place yet, industry would have to invest for meeting newly introduced standards.*	/	/ to – *When marine litter is derived from intentional or accidental dumping, industry stakeholders might be required to participate in the clean up and remediation activities (according to the polluter pays principle). Attribution of liability is only possible in limited cases for marine litter.*
Other	/	/	/	/	/
Analysis					

1325 https://www.unep.org/news-and-stories/press-release/historic-day-campaign-beat-plastic-pollution-nations-commit-develop

1326 https://www.unep.org/news-and-stories/press-release/historic-day-campaign-beat-plastic-pollution-nations-commit-develop

	Awareness raising	Improve resource efficiency and product design	Improve waste (and wastewater) management	Improve knowledge and monitoring	Clean up and remediation
Geographical distribution of costs and benefits	/	/	*Countries that do not have appropriate waste (and wastewater) management today will have to spend more. Capacity building and technical assistance might be needed.*		*Costs and benefits are mostly felt in areas where high concentrations of marine litter are found.* *However, as marine litter is ubiquitous, this is likely to be spread globally.*
Assessment of cost-effectiveness	*++ to +++* *Can be expected to be very cost effective due to low costs. However, this also depends on how well the respective awareness raising campaigns manage to address the drivers leading to demand (e.g. unsustainable consumption practices).*	*++ to +++ (measure dependent)* *These measures are considered to be cost-effective, as they would reduce the amount of waste generated by consumption.* *Cost-effectiveness depends on how well the measures are able to reduce litter production.*	*++* *Despite the high costs this can be considered very cost-effective, given that adequate management of waste is very effective in reducing the introduction of marine litter.*	*+++* *Despite potentially high budgets for additional research such costs are nevertheless highly cost-effective, given the threat posed by marine litter to marine ecosystems.*	*(- to --)* *These aim to remove plastics already in the natural environment, and "can be a potentially important way of addressing the legacy plastics that are already in the ocean", though their cost effectiveness and applicability to certain types of plastics remain uncertain[1327]. As much needs to be uncovered in terms of technologies, this is likely not very cost-effective.*

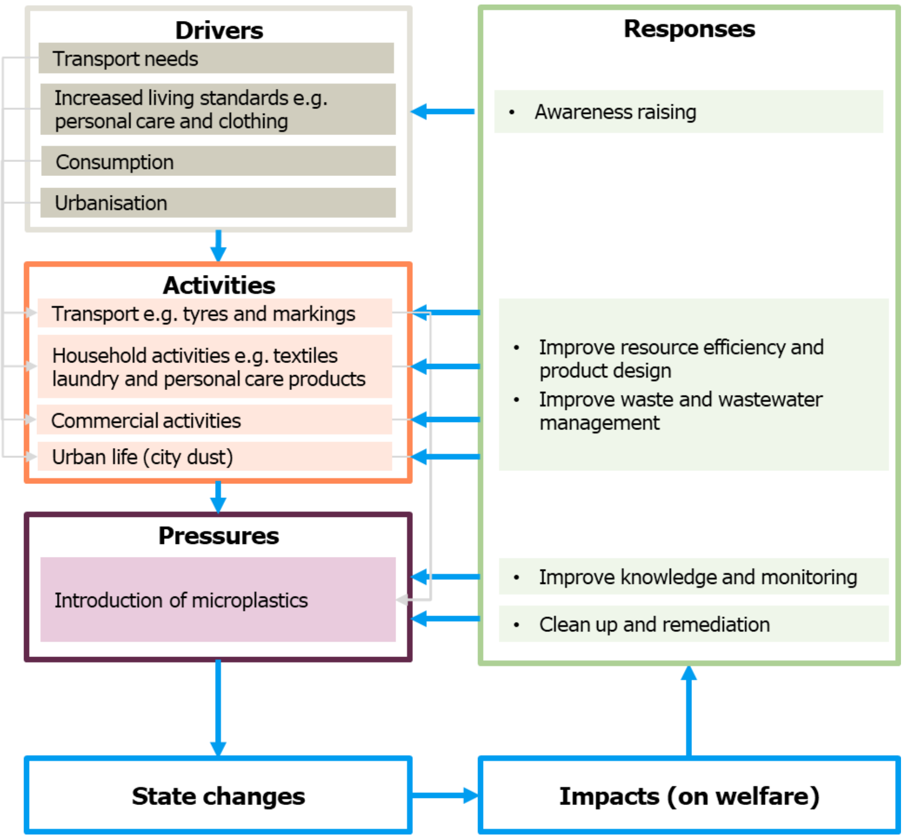
/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

[1327] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

Introduction of microplastics

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Awareness raising

As for marine litter, awareness raising can be important to help reduce microplastics leakage into the environment (see related chapter under marine litter). This should tackle specifically actions to foster sustainable consumption patterns for the main sources of microplastics, e.g. textiles, care products and tyres.

Improve resource efficiency and product design

Addressing microplastics pollution requires a life-cycle approach, aimed at reducing the quantity of plastic used for producing specific commodities, as well as the amount of plastic released during their use or maintenance[1328]. This also includes the use of alternative materials or recycled materials. The implementation of these measures will be particularly important in those

[1328] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

countries where waste management adequate, but the per-capita release of microplastics is still higher than the global average[1329].

Different solutions can be applied to improve product design of the main sources of microplastics. For instance, the following solutions could address microplastics release from textiles: designing textiles that reduce the shedding of fibres, pre-wash textiles to reduce heavy loads from first wash, install filtering devices on washing machines, using recycled fibres instead of virgin fibres. For tyres, solutions to improve ecodesign of rubber polymers and tyres to reduce abrasion as well design road pavement to reduce abrasion could be effective options[1330].

Similar to marine litter, a broad range of measures can be taken to stimulate improved product design and resource efficiency, as identified in the relative chapter under marine litter. The EU for instance, has committed to adopting an initiative to reduce the unintentional release of microplastics that will include a broad range of measures as listed above[1331].

Improve waste and wastewater management

In some regions of the world, such as India and South Asia, China and Middle East, per capita losses of microplastics are lower than global average, but a larger share of microplastics is released into the environment (compared to other areas of the world, where per capita losses are larger than global average) because they have large populations – and a low percentage of this population is connected to wastewater treatment systems e.g. 6.2% of population in India and South Asia[1332].

Improving waste management is key to preventing the release of microplastics into the environment, in particular in reasons where plastics releases are dominated by mismanaged wastes. This can involve the implementation of different technologies that detect and filter microplastics and prevent their release into the oceans. The advanced wastewater technologies more frequently used are membranes, electrodeposition, and coagulation. Membrane bioreactors, as well as biologically active filters are considered one of the most promising engineering tools to deal with microplastics in wastewater. These technologies are however more expensive than other conventional treatment methods[1333]. Anik et al (2021)[1334] provides an overview of the different mechanisms to remove microplastics from wastewater, as well as their efficiency.

Improve knowledge and monitoring

Knowledge and monitoring of the issue of microplastics is scarce, and major gaps in knowledge still exist. According to the World Ocean Assessment II, these relate mainly to: quantification of microplastics in the marine environment, information on how plastic degrades in various components of the marine environment, presence and impact of nano plastics, roles of plastic debris as a transport vector of pathogens. Similarly to marine litter in general, the lack of

[1329] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

[1330] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

[1331] https://ec.europa.eu/environment/topics/plastics/microplastics_it

[1332] IUCN (2017) Primary Microplastics in the Oceans. See: https://portals.iucn.org/library/sites/library/files/documents/2017-002-En.pdf

[1333] https://pubs.acs.org/doi/pdf/10.1021/acsomega.9b00222

[1334] Anik et al (2021) Microplastics pollution: A comprehensive review on the sources, fates, effects, and potential remediation.

national and regional monitoring of microplastics, is a bottleneck for addressing the issue and for assessing the effectiveness of measures already taken[1335].

Clean up and remediation

Biodegradation is currently being explored as a possible remediation measure to eliminate microplastics from the oceans. This involves the use of certain types of bacteria and microbes that can degrade certain types of plastics. These microbes can be harnessed in an environmentally safe way, and they could be applied to the treatment of sewage wastewater, as well as for the remediation of contaminated environments[1336].

These solutions are however at their infancy and still experimented at the laboratory scale, therefore considerable further research and development are needed to make it suitable for large scale application[1337].

[1335] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1336] Auta et al (2017) Distribution and importance of microplastics in the marine environment: A review of the sources, fate, effects, and potential solution.

[1337] https://pubs.acs.org/doi/pdf/10.1021/acsomega.9b00222

Comparison of Responses

	Awareness raising	Improve resource efficiency and product design	Improve waste and wastewater management	Improve knowledge and monitoring	Clean up and remediation
Costs and benefits					
General society[1338]	/	*/ to (-)* *This might result in higher prices for products, but it remains unclear. Given that the most microplastics are produced by a limited number of items, this is likely to have a limited impact on household expenditure.*	- *Waste and wastewater management are expensive, both in terms of CAPEX and OPEX and it is important that locally adapted systems are selected, considering aspects such as cost-effectiveness, long-term sustainability, and availability of space.*	/	/
National public authorities	- *Limited costs for developing and rolling out awareness raising campaigns*	**(- to - -) (measure-dependent)** *Public authorities might incur costs to adopt and enforce legislation and incentives to stimulate resource efficiency and improved product design (targeting microplastics loss).*	***/ to –*** *As already mentioned in section 8.3.1, in cases where user charges for new and/or updated infrastructure would create affordability issues, public authorities can support, either by subsidising the operations themselves*[1339] *or by subsidising affordable tariffs*	***- to --*** *Public authorities and the international community are the ones who would bear most of the costs for additional research and monitoring of microplastics. Given the complexity of the topic, as well as the complexity of monitoring the*	***(-- to ---)*** *Clean up and remediation activities are mostly undertaken by public authorities. The costs of recuperating microplastics at sea can be significant, considering that solutions for microplastics clean up are still at their infancy today.*

[1338] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1339] Which is, however, not fully aligned with the polluter pays principle.

	Awareness raising	Improve resource efficiency and product design	Improve waste and wastewater management	Improve knowledge and monitoring	Clean up and remediation
		The costs will depend on the type of measure and scale of implementation. Monitoring enforcement and product compliance can impose significant costs.	*for poorer parts of the population.* *Waste management assets – collection vehicles, transfer stations, sorting plants, disposal facilities etc. – deliver a public good (the protection of people's health and the environment), and therefore tend to rely heavily on government funding for their construction and operation. In this setting, achieving long-lasting improvements in the coverage and quality of waste management systems implies significant increases in public spending.*[1340]	*pressure at sea, these are likely to be substantial. These efforts would also require international cooperation e.g. in particular in terms of standardisation of methodologies and coverage of monitoring studies.*	
International community	**/**	/	***- to - -*** *Given the considerable capital investments needed to establish waste and wastewater treatment infrastructure it can be expected that some regions would need considerable financial support.*	*See above.*	(/ to –) *As microplastics is ubiquitous, and all countries contribute to it, clean up and remediation activities require collaborative efforts from the international community.*

[1340] OECD (2019) Issue brief: Improving resource efficiency to combat marine plastic litter.

	Awareness raising	Improve resource efficiency and product design	Improve waste and wastewater management	Improve knowledge and monitoring	Clean up and remediation
			For instance, under the proposal for the legally binding instruments on plastics pollution, it is foreseen that the international community will provide technical assistance[1341].		
Industry	/	**- - to + (time and measure dependent)** *Improvements in product design and resource efficiency will require investments on the part of industry e.g. for R&D of products. The utilisation of alternative materials might also involve additional costs.* *At the same time, resource efficiency might lower production costs in the long run.*	-- *If no emission / pollution standards are in place yet, industry would have to invest for meeting newly introduced standards.*	/	/ *Unless microplastics pollution can be attributed to the accidental/deliberate dumping of plastic pellets into the sea, it would be very difficult to attribute clean up costs to industry.*
Other	/	/	/	/	/
Analysis					

[1341] https://www.unep.org/news-and-stories/press-release/historic-day-campaign-beat-plastic-pollution-nations-commit-develop

	Awareness raising	Improve resource efficiency and product design	Improve waste and wastewater management	Improve knowledge and monitoring	Clean up and remediation
Geographical distribution of costs and benefits	/	/	*Countries that do not have appropriate waste (and wastewater) management today will have to spend more. Capacity building and technical assistance might be needed.*		
Assessment of cost-effectiveness	++ to +++ *Can be expected to be very cost effective due to low costs. However, this also depends on how well the respective awareness raising campaigns manage to address the drivers leading to demand (e.g. unsustainable consumption practices).*	++ to +++ *(measure dependent)* *These measures are considered to be cost-effective, as they would reduce the amount of microplastics generated by consumption.* *Cost-effectiveness depends on how well the measures are able to reduce microplastics loss.*	*(- to +) (solution dependent)* *High costs are connected to the implementation of wastewater treatment solutions that can detect microplastics and reduce their input into the environment. Additional research is needed to assess cost-effectiveness of these measure – which is likely to be determined by the type of technique implemented.*	+++ *Despite potentially high budgets for additional research such costs are nevertheless highly cost-effective, given the threat posed by microplastics to marine ecosystems.*	***- to --*** *The implementation of clean up and remediation processes for microplastics that are already found in the oceans is still at its infancy/laboratory scale. While it is not possible to perform an assessment of cost-effectiveness due to uncertainties, it has been highlighted those substantial investments in research are needed to make these solutions suitable for application[1342].*

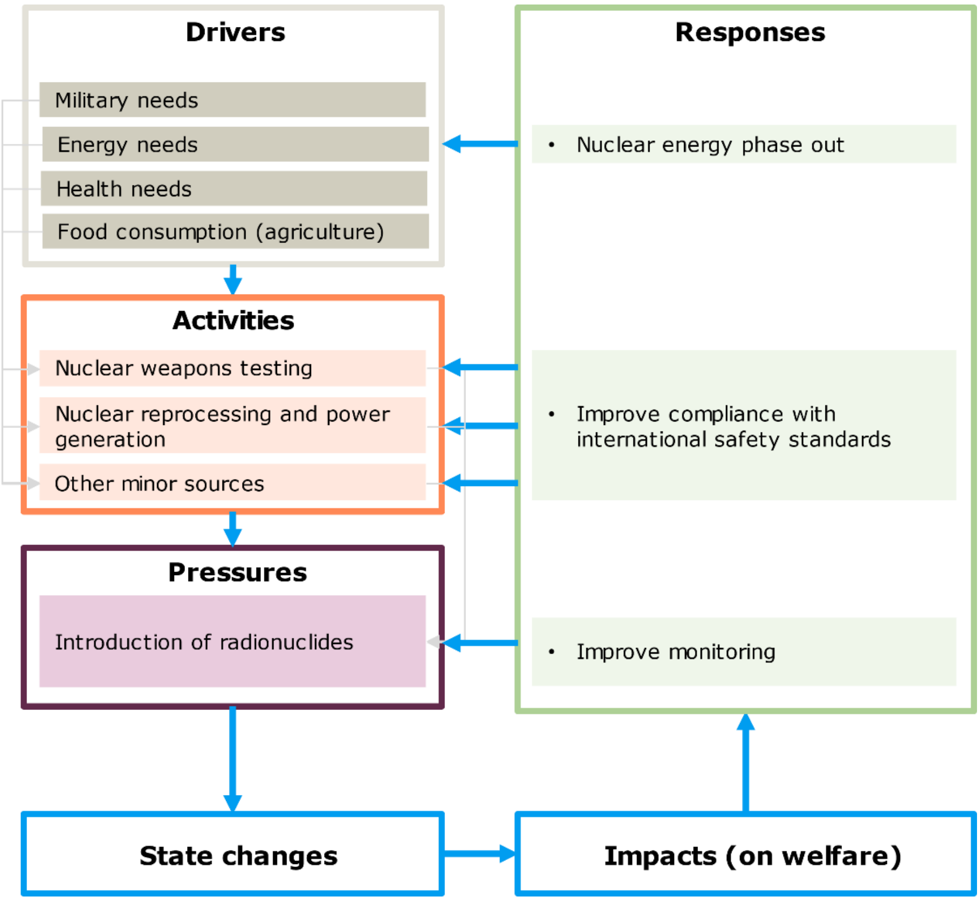
/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

[1342] https://pubs.acs.org/doi/pdf/10.1021/acsomega.9b00222

Introduction of radionuclides

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Nuclear energy phase out

Discharges from nuclear reprocessing plants as well as nuclear power plants are the main source of input of radionuclides into the environment nowadays. This includes accidental discharges due to large-scale incidents[1343]. An option to significantly reduce and virtually eliminate the risk that these discharges take place is to phase out nuclear energy.

The existing nuclear fleet of advanced economies, EU and USA, is getting old (35 years old on average). As many plants are nearing the end of their designed lifetimes, many are being shut down. It is expected that 25% of existing nuclear capacity in advanced economies will be shut down by 2025, as part of policies that aim to reduce nuclear's role in the energy. Investments required to continue nuclear activity or to build new plants are substantial, and lead times are

[1343] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

long[1344]. At the same time, other projections indicate that nuclear otal electrical generating capacity is expected to increase by about 30% by 2030, and to more than double by 2050 (compared to 2020 levels)[1345]. There are uncertainties with regards to the evolution of the nuclear energy generation, as some countries have made commitments to reduce reliance on this source, but at the same time the IEA indicates that nuclear energy will play a crucial role for the achievement of net zero targets. In fact, the IEA estimates that if no nuclear power plants are decommissioned at the end of their lifetime, and no new power plants are built, achieving the clean energy transition would require an extraordinary effort, and this could have implications for emissions, costs and energy security[1346].

Improve compliance with international safety standards

Safety standards aimed at ensuring nuclear safety and security in all activities handling radionuclides already exist, as hosted by the International Atomic Energy Agency (IAEA)[1347]. The organisations and people responsible for developing these activities have the prime responsibility for nuclear safety, and regulating safety is a national responsibility. Given that radiation risk transcends national borders, international cooperation on this matter is necessary[1348].

Existing safety standards and requirements include standards on how to safely operate nuclear power plants, research reactors, fuel cycle facilities, radioactive waste disposal facilities and transport of radioactive material[1349].

Given the virtually irreversible consequences of the discharge of radioactive material into the environment, global compliance with these standards is of the utmost importance. Compliance with the existing standards could be improved. As reported by the IAEA[1350], 81% of Member States Agency's Radiation Safety Information Management System are making good or substantial progress in strengthening their radiation safety regulatory infrastructure, but there is still a 19% of states that are making low progress and need further technical support for establishing and developing a sustainable regulatory framework for radiation safety.

Improve monitoring

The World Ocean Assessment II indicates that the available records of level of "committed effective doses to humans of radioactivity from food from the sea are less than a quarter of the IAEA recommended annual limit for the exposure of the general public to ionizing radiation", and that there is no evidence suggesting any significant change as of today. The report informs that "provided that adequate monitoring is maintained" developments in the input of radionuclides, based on current knowledge, "are not likely to be of concern"[1351].

1344 https://iea.blob.core.windows.net/assets/ad5a93ce-3a7f-461d-a441-8a05b7601887/Nuclear_Power_in_a_Clean_Energy_System.pdf

1345 https://www-pub.iaea.org/MTCD/Publications/PDF/RDS-1-41_web.pdf

1346 https://iea.blob.core.windows.net/assets/ad5a93ce-3a7f-461d-a441-8a05b7601887/Nuclear_Power_in_a_Clean_Energy_System.pdf

1347 https://www.iaea.org/resources/safety-standards

1348 https://www.iaea.org/resources/safety-standards

1349 For a complete overview of existing safety standards, please visit: http://ns-files.iaea.org/standards/safety-standards-wheel-poster.pdf

1350 https://www.iaea.org/sites/default/files/gc/gc64-inf3.pdf

1351 United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

Data of discharges of radionuclides into the marine environment is only publicly available for the North-East Atlantic, as monitored by OSPAR. Little to no data on such discharges in other areas of the world is available[1352]. Improved monitoring of discharges worldwide could be considered as an option to ensure that input of radionuclides into the marine environment is kept under control – and addressed in case it becomes an issue of concern. This could be particularly important in light of the uncertainties relating to the role that nuclear power in the future electricity generation.

[1352] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

Comparison of Responses

	Nuclear energy phase out	**Compliance with international safety standards**	**Improved monitoring**
Costs and benefits			
General society[1353]	***(- to - -)*** *General society could bear costs associated with the transition to alternative sources of energy, if these costs are transferred to consumers. There is uncertainty as regards to the specific costs, but these are likely to be substantial in the short-medium term*[1354]*. Measures to support a just transition could alleviate this negative impact.*	/	/
National public authorities	***(- to --)*** *Public authorities would bear the costs of supporting society (and industry) with the transition to alternative sources of energy. This is likely to require substantial investments e.g. in terms of R&D and infrastructure development costs, as well as welfare support for general society. It is estimated that investments in energy could go from "USD 2 trillion globally on average over the last five years to almost USD 5 trillion by 2030 and to*	**(-)** *Public authorities incur costs in establishing and enforcing regulatory frameworks for radiation safety. These are likely to be minimal.*	**(- To --)** *Monitoring discharges and reporting on them is likely to impose costs on national authorities, when monitoring is implemented at the level of the sea basin. It was not possible to assess the additional costs that this would imply.*

[1353] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1354] https://www.resolutionfoundation.org/press-releases/costs-of-net-zero-transition-for-low-and-middle-income-households-must-be-addressed-rather-than-used-to-derail-decarbonisation/

	Nuclear energy phase out	**Compliance with international safety standards**	**Improved monitoring**
	USD 4.5 trillion by 2050, if net zero emissions globally"[1355].		
International community	**/**	**/**	**/**
Industry	**-- to ---** *Nuclear energy industry would have to bear the costs of phase out and decommissioning of platforms. It is likely that these costs would be substantial, also in terms of foregone revenue from exploiting nuclear energy.*	(- to - -) *Implementing safety measures and protocols imposes costs on the different industries involved in the use of radionuclides.*	(-) *Some monitoring efforts would need to be undertaken by industries, when monitoring takes place at source.* *It is not possible to estimate costs.*
Other	**/**	/	/
Analysis			
Geographical distribution of costs and benefits	*Costs of nuclear energy phase out would be borne by countries using it as a main source of energy, as they would have to invest in developing and implementing alternative energy systems to satisfy their energy demand.*	*This affects countries where most of the nuclear energy capacity and reprocessing takes place.*	*This would require an investment in those areas of the world where nuclear power and reprocessing is significant, where monitoring is not currently available.*
Assessment of cost-effectiveness	**+ to unknown (transformative change)** *The phase out of nuclear energy would constitute a transformative change, it can be expected that this would be effective in reducing the likelihood of accidental and operational input of*	**+ *to* +++** *Safety standards and discharge limits are effective in preventing discharge and accidents. These measures are particularly cost-effective, taking into account the devastating (and*	**+ to +++** *Given the significant negative (and potentially irreversible) effects that inputs of radionuclides have on the environment, monitoring of discharges can be considered a cost-effective response. This is because monitoring*

[1355] https://iea.blob.core.windows.net/assets/deebef5d-0c34-4539-9d0c-10b13d840027/NetZeroby2050-ARoadmapfortheGlobalEnergySector_CORR.pdf

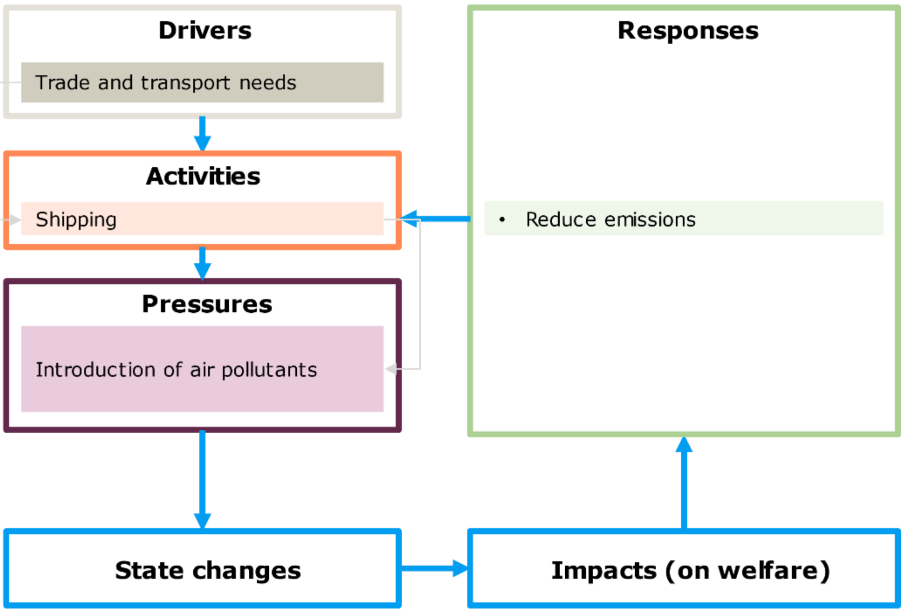
	Nuclear energy phase out	**Compliance with international safety standards**	**Improved monitoring**
	radionuclides into the environment. However, since this would include a paradigm shift with many uncertainties on social and economic impacts, cost-effectiveness cannot be assessed.	*irreversible) effects that nuclear accidents can have.*	*would allow to keep track of trends in discharges and concentration of radionuclides and would be a basis to determine whether action is needed to address the pressure – in case excesses are registered.*

/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

Introduction of air pollutants

The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

Figure Flowchart for the pressure including responses



Source: Own illustration

Reduce emissions (shipping)

The international (and national) legislative framework regulating the emissions of air pollutants from ships aim to stimulate the adoption of less environmentally damaging practices and "encourage" either investment in innovative abatement technologies or the employment of alternative fuels in the shipping industry[1356]. In particular, the international framework established by IMO, focuses on the establishment of caps for SOx, NOx and particular matter content in marine fuels, as well on the institution of minimum energy efficiency levels (in terms of grammes of CO2 per capacity mile) for different types of ships. The main pieces of legislation adopted by IMO that regulate emissions from shipping are outlined in the table below[1357]. Most of the ship-owning countries, and all of the major ship-owning economies, are part to these international agreements. As some of the key requirements of these legislations have come into force only recently, their effectiveness is largely described in terms of projections.

[1356] https://www.emerald.com/insight/content/doi/10.1108/MABR-08-2018-0030/full/pdf?title=targeting-the-reduction-of-shipping-emissions-to-air-a-global-review-and-taxonomy-of-policies-incentives-and-measures

[1357] For a comprehensive overview of other policy instruments addressing air pollution from ships, at both the global and national level, see: https://www.emerald.com/insight/content/doi/10.1108/MABR-08-2018-0030/full/pdf?title=targeting-the-reduction-of-shipping-emissions-to-air-a-global-review-and-taxonomy-of-policies-incentives-and-measures

Table Overview of international legal framework on the regulation of air pollution from ships[1358]

Name	Adoption (and entry into force)	Pollutant concerned	Provisions of relevance for air pollution from ships	Geographical scope
International Convention for the Prevention of Pollution from Ships (MARPOL) – Annex VI on the Prevention of Air Pollution from ships[1359]	1997 (2005) Revision: 2008 (2010)	• SOx • NOx • Particulate matter	• Limits the main air pollutants contained in ships exhaust gas, including sulphur oxides (SOx) and nitrous oxides (NOx); • Prohibits deliberate emissions of ozone depleting substances (ODS); • Regulates shipboard incineration; • Regulates emissions of volatile organic compounds (VOC) from tankers. The revised Annex: • Introduces a target for progressive reduction in emissions of SOx, NOx and particulate matter in marine fuels[1360]. • Introduces emission control areas (ECAs)[1361] which impose more stringent emission limits for marine fuels used in designated sea areas[1362].	International 100 states worldwide have ratified the MARPOL Convention and to Annex VI. *All largest ship-owning nations have ratified the Convention[1363].
MARPOL - Annex VI Regulations on	2011 (2013)	• CO2	• EEDI establishes minimum energy efficiency level, in terms of grammes of CO2 per capacity mile, for different ship type and size segment[1364],[1365];	International

[1358] https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx

[1359] https://www.imo.org/en/OurWork/Environment/Pages/Air-Pollution.aspx

[1360] Global SOx limit is to be reduced from current 3.50% to 0.50%, from 2020. For NOx, different limits are established based on the date of construction of ships. Ships built between 1990 – 2000 need to comply with Tier I emission limits; ships built on or after 2011 must comply with Tier II emission limits, which are more stringent.

[1361] The following ECAs have been designated so far: North American area, United States Caribbean sea area, The Baltic Sea area, The North Sea area. For more information see: https://www.imo.org/en/OurWork/Environment/Pages/Emission-Control-Areas-(ECAs)-designated-under-regulation-13-of-MARPOL-Annex-VI-(NOx-emission-control).aspx

[1362] For ECAs, the SOx limit is of 0.10% from 2015. Ships built after 2016 must comply with Tier III NOx emission limits in ECAs. Tier III emission limits are the most stringent.

[1363] Based on: http://infomaritime.eu/index.php/2021/08/22/top-15-shipowning-countries/ and https://www.isl.org/en/news/china-become-the-worlds-second-largest-ship-owning-nation

[1364] The CO2 reduction level is 10% in the first phase, and this will be tightened every 5 years. Reduction rates have been established until the period 2025 and onwards when a 30% reduction is mandated for applicable ship types calculated from a reference line representing the average efficiency for ships built between 2000 and 2010.

[1365] The index has a broad scope: ship types responsible for approximately 85% of the CO2 emissions from international shipping are incorporated under the international regulatory regime.

Name	Adoption (and entry into force)	Pollutant concerned	Provisions of relevance for air pollution from ships	Geographical scope
energy efficiency for ships **and related Energy Efficiency Design Index (EEDI) and** **Ship Energy Efficiency Plan (SEEMP)**			• SEEMP establishes a mechanism for shipowners to improve the energy efficiency of both new and existing ships using operational measures such as weather routing, trim and draught optimization, speed optimization, just-in-time arrival in ports, etc.	100 states worldwide have ratified the MARPOL Convention and to Annex VI. *All largest ship-owning nations have ratified the Convention[1366].
IMO Strategy on reduction of GHG emissions from ships[1367]	2018	• CO2	• Reduce carbon intensity of ships through the implementation of further phases of the energy efficiency design index (EEDI) for new ships; • Reduce carbon intensity per transport work, as an average across international shipping by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008; • Peak GHG emissions from international shipping as soon as possible and to reduce the total annual GHG emissions by at least 50% by 2050 compared to 2008 whilst pursuing efforts towards phasing them out.	International N/A – The strategy is not mandatory, no ratification process.
EU Sulphur in Liquid Fuel Directive Directive	2016	• SOx • NOx • Particulate matter	• Implements MARIPOL – Annex IV; • In addition, it includes provisions relating to SOx limits for passenger ships operating on regular services within the EU as well as specific limits for SOx content of fuels used in EU ports (0.1%).	EU

Source: Authors, based on IMO

[1366] Based on: http://infomaritime.eu/index.php/2021/08/22/top-15-shipowning-countries/ and https://www.isl.org/en/news/china-become-the-worlds-second-largest-ship-owning-nation

[1367] https://www.imo.org/en/OurWork/Environment/Pages/GHG-Emissions.aspx

Notably, to comply with the comply with Annex VI limits, ship operators and owners can switch to fuel oil with lower sulphur content, or they can high sulphur content by using technical means that reduce atmospheric SOx emissions to a level equivalent to the required fuel oil sulphur limit. This involves the use of "scrubbers", which clean exhaust gas of the SOx with water, and then discharge the wash water directly into the marine environment. There are three main categories of scrubbers: "(1) the open-loop scrubbers that continuously discharge their wash water effluent, (2) the closed-loop scrubbers that treat the wash water before it is discharged, and (3) the hybrid scrubbers that can switch from open to closed modes"[1368]. In addition to sulfur oxides, other substances, such as metals and organic pollutants, are also washed out of the exhausts, and "there is increasing concern that wide-scale discharge of scrubber wash water may affect the marine environment negatively"[1369].

It is expected that the implementation of the current legislative framework will lead to a reduction of SOx emissions, but that CO2 and NOx emissions could increase if no *additional* regulations are adopted[1370]. For this reason, the potential impacts of adopting enhanced emission controls is currently being assessed. The table below illustrates the different scenarios and associated impacts, as presented in an EU-level study conducted by IIASA in 2018[1371]. These scenarios are built taking into account projections of future shipping activities, reflecting current thinking on the evolution of economic growth, global trade volumes and fuel efficiency.

Table Assessment of impacts of different policy scenarios (EU seas)

Name	Scenario description	Impacts
Baseline Scenario - Current Legislation (CLE)	The Current Legislation (CLE) scenario illustrates the impacts of current policies and regulations for maritime emissions. In particular, it assumes full compliance with the IMO MARPOL Annex VI standards for fuel quality and for NOx emissions.	• SOx emissions reduced by 50-80% up to 2030; • CO_2 and NOx emissions will further increase in the absence of additional regulations. NOx emissions expected to exceed total land-based emissions in the EU-28, after 2030.
Scenario 1 - Extension of SOx Emission Control Areas and Tier III NOx emission standards	This scenario illustrates the impacts of: • Imposing a limit of 0.1 percent on the sulphur content of fuel (or equivalent emissions through scrubbers) for all vessels, as of 2025. • Extending Tier III NOx emission standards for new vessels only (corresponding to the current requirements for NECAs) or including retrofits of existing vessels as of 2025.	• SOx emissions reduced by 80-90% compared to 2015; • PM2.5 emissions reduced by 20-70% by 2050; • NOx emission reduced by 50-80% by 2050; • Avoid up to 15,000 cases of premature deaths annually

[1368] Duliere et al (2020) Potential impact of wash water effluents from scrubbers on water acidification in the southern North Sea.

[1369] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

[1370] IIASA (2018) The potential for cost-effective air emission reductions from international shipping through designation of further Emission Control Areas in EU waters with focus on the Mediterranean Sea. Available at: https://previous.iiasa.ac.at/web/home/research/researchPrograms/air/Shipping_emissions_reductions_main.pdf

[1371] IIASA (2018) The potential for cost-effective air emission reductions from international shipping through designation of further Emission Control Areas in EU waters with focus on the Mediterranean Sea. Available at: https://previous.iiasa.ac.at/web/home/research/researchPrograms/air/Shipping_emissions_reductions_main.pdf

Name	Scenario description	Impacts
Scenario 2 - Climate policy measures	This scenario illustrates the impacts of stabilising CO2 emissions by 2050, in addition to implementing the more stringent measures in Scenario 1.	• Additional reduction in SOx, NOx and PM2.5

Source: Authors, based on IIASA (2018)

As illustrated by the table, while the implementation of the current international legislative framework will achieve benefits in terms of SOx reduction in the future, this could result in the increase in CO2 and NOx emissions in the long run.

The international community could therefore discuss the tightening of the emission control measures currently in place, and in particular consider extending the SOx Emission Control Areas and the application of Tier III NOx emission standards, which the IIASA study suggests could be effective in reducing SOx and NOx emissions overtime.

Attention should however be paid to the viability of achieving these more ambitious targets, and the shift of the shipping industry towards less environmentally damaging practices and fuels should be adequately supported, including via financial incentives and support.

As anticipated in section 0 low-carbon and alternative fuels, such as ammonia, hydrogen, biofuels, methanol, LNG[1372] , have a very low penetration rate in the shipping industry to date. Reportedly[1373], biofuels are the only non-fossil fuel alternative that has been adopted to date, and they account for only 0.1% of final energy consumption. The opportunities and challenges of implementing alternative fuels are documented in different sources[1374]. In general, it is believed that substantial investments will be needed to foster the shift from HFO to more environmentally friendly fuels, including for the development of a supply chain of such fuels, but also the retrofit of engines and adaptation/creation of relevant infrastructure. A source mentions that "for any meaningful change in fueling systems across the shipping industry to bring carbon emissions within proposed IMO limits, the capital investments required have been estimated to be around 1.4–1.9 trillion U.S. dollars" (approx. 1.3 - 1.7 trillion EUR)[1375].

The impact of scrubbers as an intermediate/transitory measure to respect emission targets should also be further investigated. Concerning scrubber penetration, it was estimated that 3,628 ships (of the identified 81,297 active ships in the global fleet) had or would have had scrubbers installed by the end of 2020[1376]. Of these, open-loop scrubbers are the most common type e (85% of all scrubbers installed) and hybrids are second most popular (14%); only 1% of the scrubbers are closed loop. More than half of all scrubbers were installed in 2019 in preparation for the global marine fuel sulfur regulation that came into force at the beginning of 2020. Bulk carriers, container ships, and oil tankers represent 74% of the fleet outfitted with scrubbers, by number of ships[1377]. Ships with scrubbers are expected to discharge more than 10 gigatonnes (Gt) of washwater worldwide annually, mostly in EEZs[1378]. There is increasing

[1372] https://www.eafo.eu/shipping-transport/shipping-overview/af-for-shipping

[1373] https://www.iea.org/reports/international-shipping

[1374] Foretich et al (2021) Challenges and opportunities for alternative fuels in the maritime sector.

Union of Greek Shipowners (2021) Survey of Alternative Fuel-Technologies for Shipping.

DNV-GL (2018) Assessment of selected alternative fuels and technologies.

[1375] Foretich et al (2021) Challenges and opportunities for alternative fuels in the maritime sector.

[1376] https://theicct.org/sites/default/files/publications/scrubber-discharges-Apr2021.pdf

[1377] https://theicct.org/sites/default/files/publications/scrubber-discharges-Apr2021.pdf

[1378] https://theicct.org/sites/default/files/publications/scrubber-discharges-Apr2021.pdf concern in the scientific community that wide-scale discharge of scrubber wash water may affect the marine environment negatively[1379] – and for this reason, some ports, regions and countries have taken a precautionary approach and prohibited such discharges in their waters[1380].

[1379] Among negative environmental impacts are contribution to ocean acidification, as well as toxicity for aquatic organism. See: https://enveurope.springeropen.com/articles/10.1186/s12302-020-00380-z

[1380] United Nations (2021) World Ocean Assessment, Volume II. See: https://www.un.org/regularprocess/sites/www.un.org.regularprocess/files/2011859-e-woa-ii-vol-ii.pdf

Comparison of Responses

	Reduce emissions
Costs and benefits	
General society[1381]	++ If the costs borne to comply with emission reduction standards and targets are transferred to consumers, these are likely to experience a rise in the price of certain goods. This is likely to be minimal. Benefits of reducing emissions from ships for the general society, besides improved ecosystem services, include a reduction in mortality and morbidity. It was estimated that the timely implementation of the IMO's 0.5% low-sulphur fuel standard "will reduce ship-related premature mortality and morbidity by 34 and 54%, respectively, representing a ~ 2.6% global reduction in PM2.5 cardiovascular and lung cancer deaths and a ~3.6% global reduction in childhood asthma"[1382].
National public authorities	*(- to - -)* *Public authorities would incur costs related to the enforcement of emission reduction standards and measures.* *They could also incur costs related to the financing of public R&D project to stimulate developments in the field of alternative fuels, as well as potential infrastructure development costs for the development of infrastructure for the utilisation of these fuels.*
International community	/
Industry	**- to - - (standard dependent)** *The shipping industry would bear the costs of implementing emission reduction standards. The amount of the costs will be determined by the level of ambition of the standards, as well as the methods used to comply with them (e.g. compliance with scrubbers is allowed or not).* *It is believed that "MARPOL Annex VI regulations on sulphur in ship fuels will cause remarkable additional costs for the sea transport"[1383]. An estimate has indicated that for any meaningful change in fuelling systems across the shipping industry to bring carbon emissions within proposed IMO limits, the capital investments required have been estimated to be around 1.4–1.9 trillion U.S. dollars" (approx. 1.3 - 1.7 trillion EUR)[1384].* *By way of example, the cost of fuel switching, from HFO to MGO (marine gas oil), to comply with the MARPOL Annex VI targets in the Northern SECA has been estimated at around 4.6 billion dollars (4.1 billion EUR) in 2015. Overall compliance costs were assumed to decrease by about 35% with the installation of scrubbers on the 500 ships with the largest fuel consumption in the SECA area[1385]. The highest costs are expected to be suffered by vessels with high fuel consumption.*

[1381] Importantly, the general society is assumed to benefit from all Responses due to them contributing to healthy Oceans. This is thus not listed separately.

[1382] https://www.nature.com/articles/s41467-017-02774-9.pdf

[1383] Jalkanen et al (2012) The price of sulphur reductions in the Baltic Sea and North Sea shipping.

[1384] Foretich et al (2021) Challenges and opportunities for alternative fuels in the maritime sector.

[1385] Jalkanen et al (2012) The price of sulphur reductions in the Baltic Sea and North Sea shipping.

	Reduce emissions
Other	/
Analysis	
Geographical distribution of costs and benefits	*Costs will be felt everywhere, as it is likely that the investments needed to reduce emissions (energy efficiency, alternative fuels, scrubbers) will be reflected into the price of goods. Countries that are importing a large part of their goods are likely to be impacted more, as well as countries that are responsible for shipping.*
Assessment of cost-effectiveness	***+ to +++ (standard dependent)*** *The benefits of further emission controls for international shipping outweigh the costs by a wide margin, reportedly "for measures across all European Seas, on average the monetized benefits exceed costs by a factor of 6 in 2030 and by a factor of 12 in 2050"[1386]. The precise scale of the cost-effectiveness depends on the level of ambition of the measure.*

/: no impact
Costs, burdens, or negative performance on indicators: signalised with between 1 and 3 minus signs, between low costs or burdens (-) and high (---)
Benefits, savings and positive performance on indicators: signalised with between 1 and 3 plus signs in the same way (+; ++; or +++)
(): brackets if costs, benefits etc. are only potentially
If there is uncertainty as to the range of costs, benefits etc. a range is indicated: e.g. ++ to +++ or – to +

Changes in water properties due to climate change

As mentioned in chapter 4, the main human activities leading to GHG emissions include energy supply (power generation), transport, buildings, industry, AFOLU[1387], and waste; however, countless other activities also emit greenhouse gases (GHGs) and thus contribute to climate change[1388].

This in turn contributes significantly to all the pressures listed in this chapter, namely:

- Large-scale changes in water temperatures
- Large-scale changes in salinity regime
- Large-scale changes in sea level
- Large-scale changes in currents
- Large-scale changes in pH

Thus, those activities are not discussed separately for all pressures.

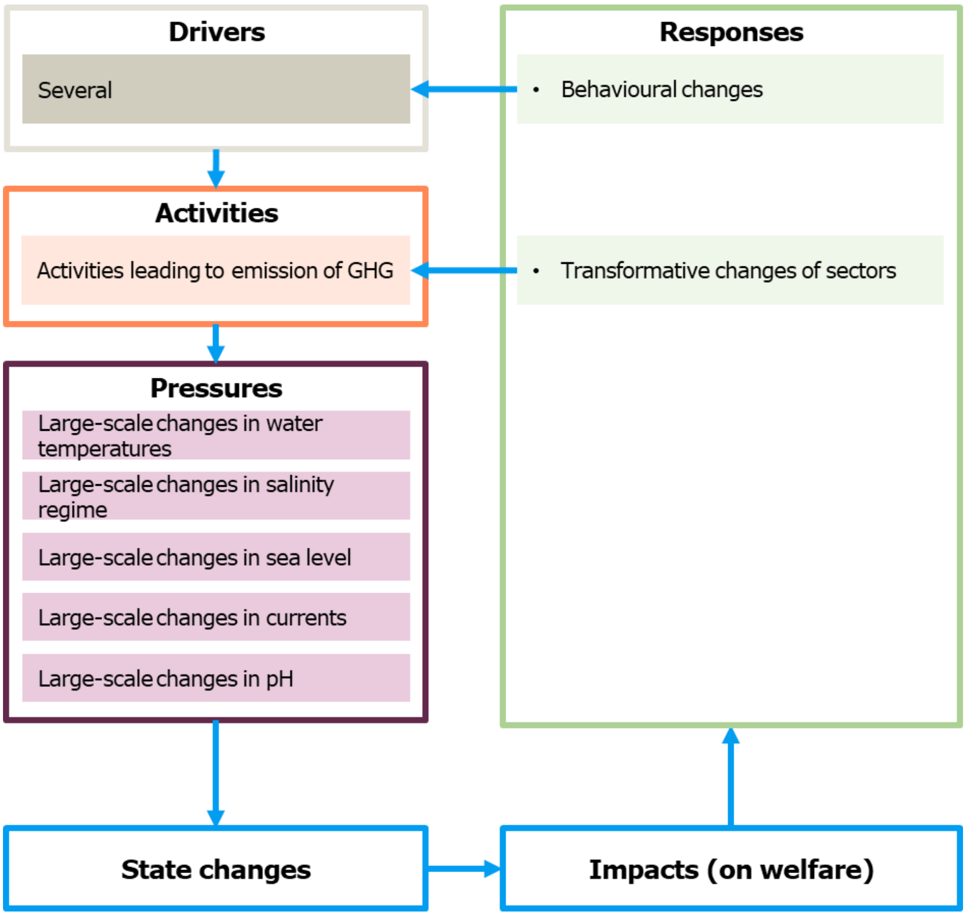
The Figure below summarises the responses that could be taken to address and manage the drivers and activities leading to the pressure.

[1386] IIASA (2018) The potential for cost-effective air emission reductions from international shipping through designation of further Emission Control Areas in EU waters with focus on the Mediterranean Sea. Available at: https://previous.iiasa.ac.at/web/home/research/researchPrograms/air/Shipping_emissions_reductions_main.pdf

[1387] Agriculture, Forestry, Other Land Use

[1388] Blanco, G., et al. (2014). Drivers, Trends and Mitigation. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. See: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_chapter5.pdf

Figure Flowchart for the pressure including responses



Source: Own illustration

As can be seen, across all those sectors, wide-reaching and transformative changes are needed to reach the limits agreed on in the Paris Agreement. Under the Paris Agreement all countries – both developed and developing – are expected to contribute towards the Agreement's ambitious goals to prevent of dangerous anthropogenic interference with the Earth's climate system. Consequently, all signatory Party countries are expected to align their long-term climate change mitigation efforts with limiting global temperature increases to within 2°C of pre-industrialisation levels, pursue efforts to limit the increase to 1.5°C, and to achieve a balance between emissions of GHGs from sources and the removal of GHGs from the atmosphere by sinks by the second half of this century. This last goal is widely referred to as 'net-zero emissions' or 'carbon neutrality'.

Those required sectorial changes are well documented and not the focus of this report and thus not discussed in detail.

The costs of such required changes are very challenging to estimate. Part of the Paris Agreement was that developed countries USD 100 billion per year in climate finance by 2020 and agreed to continue mobilising finance at this level until 2025. However, it should be noted that the 2020 goal by 2020 has not been met[1389] and also that according to the IPCC, several trillion USD would be needed in the energy sector alone for reaching the agreed targets[1390].

[1389] UN (2020). DELIVERING ON THE $100 BILLION CLIMATE FINANCE COMMITMENT AND TRANSFORMING CLIMATE FINANCE. INDEPENDENT EXPERT GROUP ON CLIMATE FINANCE. See: https://www.un.org/sites/un2.un.org/files/100_billion_climate_finance_report.pdf

[1390] Coninck, E., et al. (2018): Strengthening and Implementing the Global Response. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)]

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