**Technical assessment for**

**SEAFLOOR PROTECTION**

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# Executive Summary

Project Drawdown defines *seafloor protection* as: the legal protection of high in organic carbon seafloor sediments from disturbance by bottom trawling fishery leading to reduced CO2 emissions from disturbed sediments.

Marine protected areas (MPAs) are recognized as one of most effective tools in adaptation and mitigation of climate change impacts. The majority of attention regarding blue carbon has been given to coastal ecosystems such as seagrasses, mangroves and salt marshes. Within these ecosystems, the MPAs mitigation potential to prevent loss of those ecosystems is well established. Despite the fact, that they sequester a large amount of global carbon (46.7 percent), they only cover 2 percent of the global ocean. The vast majority of the ocean floor is represented by the off-shore sediments that together cover an area greater than all other habitats on Earth. It is important to recognize the potential of those sediments to prevent, mitigate and enhance the impacts of climate warming especially in regard to seafloor disturbances cause by bottom trawling practices that disturbs sediments together with stored carbon.

The Total Ocean Area is defined as million hectares of seafloor oxic sediments disturbed by bottom trawling gear and amount 490 in 2014. Current adoption is set as 0 because the area protected from bottom trawling by 2018 has been subtracted from the TOA. Five scenarios has been build following the predicted growth of marine protected areas expansion or bottom trawling bans. These scenarios were combined to produce *Plausible* (average of all),  *Ambitious* (high of all), and *Maximum* (highest single scenario) scenarios.

Total adoption in the *Plausible Scenario*is 283 million hectares in 2050, representing 58% percent of the total addressable market. Total adoption in the *Ambitious Scenario* is 384 million hectares in 2050, representing 78 percent of the total addressable market. Total adoption in the *Maximum Scenario* is 441 million hectares in 2050, representing 90 percent of the total addressable market. Climate impact is 3.80, 5.14, and 5.91 gigatons of carbon-dioxide equivalent in the *Plausible, Ambitious* and*Maximum*scenarios respectively.

# Literature Review

Ocean protection has gained increasing interests within national and international authorities to avoid further degradation of natural ecosystems and fish populations and to achieve sustainable ocean resources for future generations (Early et al., 2020; Hoegh-Guldberg O. et al., 2019). It has been also recently underlined that ocean has a great potential in mitigating the climate warming thus nations, non-federal governments, and non-governmental organizations are creating ocean-climate leadership coalition to successfully preserve the ocean (Anne Merwin et al., 2020). There are different mechanisms of ocean protection - one of the most effective being establishment of no-take zones Marine Protected Areas (MPAs) or marine reserves where no commercial activity is allowed (Lester & Halpern, 2008). Moreover, protection of ocean areas from certain activities such as bottom trawling by bans or closures is often implemented. One of the important aspects of ocean protection is to carefully design protection mechanisms that are most appropriate for specific ecosystems or ocean zones. The negative effects of human activity touch both the benthic and pelagic ocean zones. This literature review only focuses on ocean protection of benthic ecosystems and its ability to preserve long-term sequestered carbon.

## State of practice

The ocean is an important carbon sink and it plays an enormous role in regulating the global climate. So far the ocean absorbed around one-third of all human-generated CO2 emissions (Avelar et al., 2017). Three major mechanisms drive carbon cycling in the ocean:

* solubility pump – a physiochemical mechanism of carbon solubility in the seawater and deposition in the seafloor by thermohaline circulation,
* biological pump – mechanisms involving photosynthetic fixation of carbon in the ocean interior, seafloor deposition and remineralization, and long-term sequestration in the sediments,
* marine carbonate pump – mechanisms involving calcification of microorganisms at the ocean surface and transport of that material to the seafloor where it can be remineralized or buried.

The active transportation of organic carbon to the ocean seafloor is also carried out by zooplankton, fish, cephalopods and vertebrates via producing faeces and dead organic matter (Lavery et al., 2010). Once organic carbon is deposited in the sediments and remains undisturbed, it is stored for centuries (Legge et al., 2020). Because of this, marine ecosystems have been often recognized for their ability to act as blue carbon sinks by sequestering carbon for long-term time scales and helping to regulate the global climate crisis (Solan et al., 2020).

Marine protected areas (MPAs) are recognized as one of most effective tools in adaptation and mitigation of climate change impacts (Simard, F. et al., 2016). The majority of attention regarding blue carbon has been given to coastal ecosystems such as seagrasses, mangroves and salt marshes. Within these ecosystems, the MPAs mitigation potential to prevent loss of those ecosystems is well established (Anne Merwin et al., 2020). Despite the fact, that they sequester a large amount of global carbon (46.7 percent), they only cover 2 percent of the global ocean (Duarte et al., 2013). The vast majority of the ocean floor is represented by the off-shore sediments that together cover an area greater than all other habitats on Earth (Snelgrove, 1999). It is important to recognize the potential of those benthic environments to prevent, mitigate and enhance the impacts of climate warming (Solan et al., 2020).

The recent global estimates show that the ocean is currently storing around 3117 (3006-3209) Pg carbon in the top 1 meter of sediment and that a large amount (75 percent) of this carbon stock is found in global ocean abyssal sediment (Atwood et al., 2020). The same study provides evidence of similar sediment carbon stock within EEZs and the High-Seas jurisdiction (1606 vs 1512 Pg carbon in the top 1 meter of sediment)(Atwood et al., 2020). Another study estimates that the upper 5 centimetres of global seafloor sediment stores 87 Gt of organic carbon (Lee et al., 2019) corresponding to 10 percent of total carbon sequestered from the atmosphere (867 Gt C, assuming ~410 ppm CO2). It has been indicated that marine sediment carbon stocks in maritime nations can be similar in magnitude to those of soils and should be considered in national GHG inventories (Avelar et al., 2017). According to Atwood et al. 2020, within the global sediment carbon stock, 4 percent is protected by MPAs and only 2 percent by highly protected, no-take MPAs (Atwood et al., 2020). It means that a vast amount of organic carbon stored in the seafloor remains unprotected and occurs in Exclusive Economic Zones (EEZs) areas that are subjected to high exploitation. The degradation of the seafloor includes bottom trawling, the infrastructure of undersea cables and renewable energy constructions, waste disposal, oil rigs and mining activities (Kroger et al., 2018). Within those activities, the one that degrades ocean floor continuously on a large scale is bottom trawling (Fig. 1). Bottom trawling has been recognised as important driver shaping the physical basis of entire continental margin benthic habitats, with an ability to transform seascapes comparable to that of the destructive agriculture or deforestation on land (Martín, Puig, Palanques, & Giamportone, 2014).



Figure 1.1 Bottom trawling effects on the seafloor after Kroger et al. 2018

Majority of trawling activity takes place within the EEZs and the estimation of the global active swept area covered by trawling based on vessel monitoring systems (VMSs) data is of about 0.5 million km2/year (Amoroso et al., 2018). However this global figure has been updated by the most recent estimation using automatic identification system (AIS) that covers more countries including most South-East Asian countries and the new estimation is on average 4.8 million km2/year (Sala et al., 2021). On the European shelf, which is subjected to one of the highest trawling intensity on earth, the bottom trawling footprint (seabed area trawled at least once in a specific region and time) on the seafloor may exceed 50% (Amoroso et al., 2018). The main effects of trawling on the seafloor include damages to benthic habitats that are often composed of sessile long-lived organisms such as corals and sponges with slow recovery rate (some cold-water corals are assumed to never recover), affecting the structure of sediments, and correspondingly release of long-stored organic carbon as well as nutrients (Kaiser et al., 2002; Rijnsdorp et al., 2020). The impact of trawling on the seafloor depends on fishing gears surface and sub-surface footprint, on the weight and speed with which the heavy parts of the gear are towed over the seafloor and on the extent and intensity spectrum of bottom trawling (Rijnsdorp et al., 2016). It has been also identified that natural dynamics (currents, waves), depth, temperature, season and sediment properties may impact the mechanism of sediment resuspension and carbon remineralization (Luisetti et al., 2019; Martín, Puig, Palanques, & Ribó, 2014; Puig et al., 2012). The perturbations generated by trawling on sediment organic carbon can vary in cohesive (i.e., muddy sediment with high clay content) and non-cohesive (i.e., sandy seafloor) sediment (Paradis et al., 2019). In general, seabed areas that are naturally disturbed by currents and waves are less sensitive to trawling disturbances (Puig et al., 2012). Decrease of organic carbon content in surface sediments of trawled compared to untrawled grounds has been already observed (Bhagirathan et al., 2010; Paradis et al., 2019; Pusceddu et al., 2014). However, the opposite trend has been also recorded for the upper 5 cm of the sediment that might be caused by redistribution of organic carbon deposited in the deeper sediment layers to the top by sediment column mixing or decrease of organic matter consumption due to increased macrofauna mortality (Polymenakou et al., 2005; Pusceddu et al., 2005). Moreover, there are contrasting responses of benthic communities with some opportunistic, mobile macrofauna increasing its abundance right after trawling disturbances as they feed on the dead tissue of degraded biota (Simon Jennings et al., 2001) and long-lived taxa significantly decreasing in biomass and areal extent (Heifetz et al., 2009; Moran & Stephenson, 2000; van Denderen et al., 2020; Wassenberg et al., 2002). When organic matter is released from the seafloor sediments, it may be partly deposited back at the seafloor, dissolve in the water column and be remineralized and that processed depends on its origin and quality but also on physical features such as temperature and oxygen concentrations that shape the microbial processes (Lønborg et al., 2020). The most dynamic form of organic matter is labile organic matter (Zhongqi & Fengchang, 2015) with turnover rate from hours to days (Lønborg et al., 2020).

The different effects of bottom trawling on the benthic habitats make the quantification of its impact on carbon sequestration highly uncertain (Kroger et al., 2018; Legge et al., 2020). Nevertheless, it has been often underlined that chronic and intensive bottom trawling significantly changes the seafloor structure and alter sediment resuspension (Oberle et al., 2016; Paradis et al., 2019). A large scale regional assessment of total carbon released by bottom trawling activity has been done in the UK shelf (Luisetti et al., 2019) and showed a considerable loss of carbon stocks of 6 Mt per decade under Business as Usual and an additional 7.2 Mt under Continuous Growth and Climate Changes scenario. A global assessment of trawling effect on the carbon emission presents estimated 1.47 Pg of aqueous CO2 caused by increased carbon metabolism in the sediment (Sala et al., 2021). Those emissions stabilize after 9 years of continuous bottom trawling so the average emissions amount 0.58 Pg of aqueous CO2 (Sala et al., 2021). A global analysis of seabed biota depletion after bottom trawling disturbance shows that as much as 41% of biota can be removed after bottom trawling activity (Hiddink et al., 2017). Thus, there is a high potential that protection of seafloor subjected to bottom trawling activities, could bring a significant reduction of organic carbon release.

## Adoption Path

### Current Adoption

Currently, as presented by the UNEP-WCMC and IUCN website, the global MPA reaches 7.45%. Out of that the MPAs extend in the EEZs reaches 17.3% however, less than 3% are highly protected (including no-take zones) (*Marine Protected Areas Atlas*, 2020). As already mentioned, the majority of bottom trawling activity takes place within EEZs. The solution Total Ocean Area represents the most recent global estimate of actively swept seabed by bottom trawling gear, thus ocean seabed unprotected from bottom trawling (Sala et al., 2021) (Fig. 1.2). Therefore the Current Adoption is set as 0.



Figure 1.2 Global heat map presenting risk of carbon remineralization due to bottom trawling activities - yellow color represent the areas with high bottom trawling activity.

### Trends to Accelerate Adoption

The importance of the expansion of ocean protection has been already widely recognized. The global ocean protection accelerated in 2002 when the participants of Johannesburg World Summit on Sustainable Development (WSSD) agreed to establish representative networks of MPAs by 2012. At that time, the global ocean coverage of MPAs exceeded around 1%. Two years later, the Convention on Biodiversity (CBD) set a new target of 10% MPAs coverage by 2012. However, in 2010, the protected ocean area was only 2.5%. Therefore, the Convention on Biological Diversity in 2010 elongated the targeted adoption year with a plan called Aichi Target 11, which called for 10% of coastal and marine areas conservation by 2020 through effectively managed, ecologically representative and well-connected systems of protected areas (*Protected Planet*, 2020). Later, many countries have established their national targets (Fig 2).

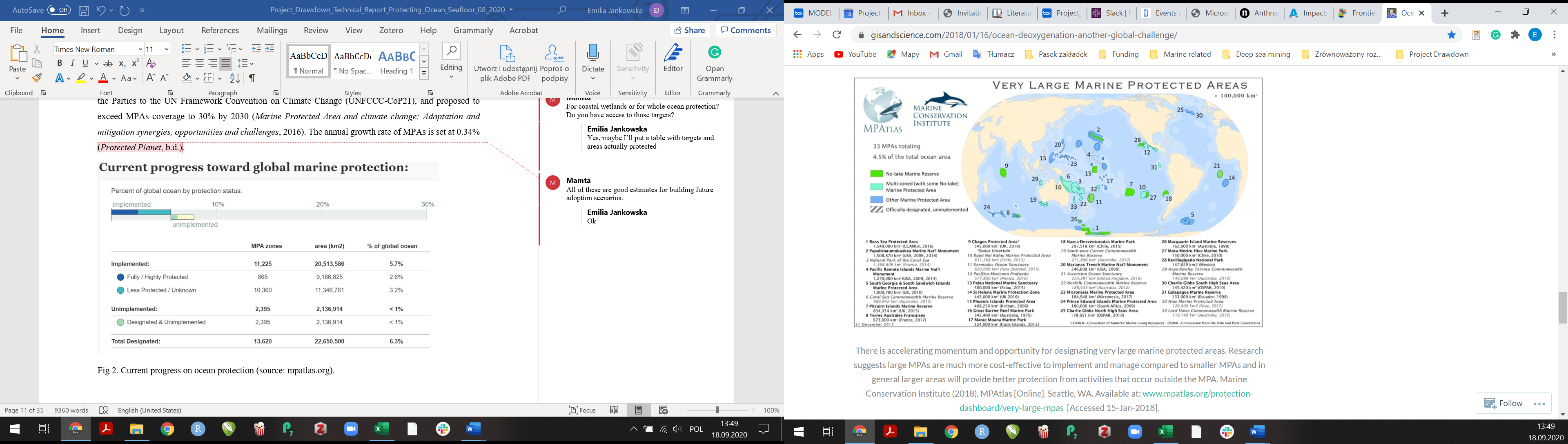


Figure 1.3 Global distribution of MPAs on national waters (Marine Conservation Institute, 2018).

At 2016 International Union for Conservation of Nature published a recommendation based on the outcomes of Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC-CoP21), and proposed to exceed MPAs coverage to 30% by 2030 (Simard, F. et al., 2016). The annual growth rate of MPAs is set at 0.34% (*Protected Planet*, 2020). In 2020 as a part of High-Level Panel for Sustainable Ocean, 14 countries has put forward an agenda to sustainable manage 100 percent of their national water and establish 30 percent of MPAs. This single commitment account on around 30 percent of global EEZs. The recent conservation planning framework to prioritize highly protected MPAs in places that would result in multiple benefits today and in the future shows that we need to protect 45% of the ocean to obtain significant benefits for fishery, biodiversity and carbon conservation (Sala et al., 2021).

When regarding specifically bottom trawling activity, some countries have applied bans or limitations proving that bottom trawling has been considered as an unsustainable. The banned regions include Indonesia, few regions of USA such as North California Current, Hawaii, Chile, Australia, Bering Sea and Arctic Sea, New Zealand seamounts and hydrothermal vents, islands of Azores, Madeira and Canaries, some parts of Mediterranean and North-East Atlantic area of NEAFC (Table 1).

Table 1.1 Regions with bottom trawling activity bans.

|  |  |  |
| --- | --- | --- |
| **Exclusive Economic Zone** | **EEZ banned to bottom trawling** | **Source** |
| Arctic Sea | 100% | (United Nations, 2006) |
| Azores | 100% | (United Nations, 2006) |
| Balearic Islands | 100815 ha | (Oceana, 2020b) |
| Bering Sea | 100% | (United Nations, 2006) |
| Brazil | 80% | (United Nations, 2006) |
| Canada | 7.8% | (DeGeorge, 2018) |
| Canary Islands | 100% | (United Nations, 2006) |
| Chile | 98% | (Oceana, 2020c) |
| China (Hong-Kong) | 170000 ha | (Tao et al., 2018) |
| Costa Rica (Pacific) | 12% | (Sullivan, 2013) |
| Denmark | 6% | (United Nations, 2006) |
| France (Mediterranean) | 3% | (The European Parliament, 2019) |
| Greenland | 6% | (United Nations, 2006) |
| Hawaii | 100% | (United Nations, 2006) |
| Indonesia | 6% | (Panggabean et al., 2016) |
| Iran | 100% | (*Iran Bans Trawling in Persian Gulf*, 2020) |
| Israel | 2% | (The European Parliament, 2006) |
| Japan | 100% | (United Nations, 2006) |
| Kiribati | 40825000 ha | (*Marine Protected Areas Atlas*, 2020) |
| Latvia | 30% | (United Nations, 2006) |
| Madagascar | 430000 ha | (Blue Ventures, 2020) |
| Madeira | 100% | (United Nations, 2006) |
| Malaysia | 3% | (*Malaysia*, 2020) |
| Mauritius | 100% | (United Nations, 2006) |
| Mexico | 30% | (United Nations, 2006) |
| Namibia | 6% | (*Government Gazette of the Repoblic of Namibia No.2657*, 2001) |
| NEAFC North-East Atlantic | ban on depths up to 800m | (The European Parliament, 2016) |
| Palau | 80% | (United Nations, 2006) |
| Philippines | 27600000 ha | (Oceana, 2020a) |
| Poland | 6% | (United Nations, 2006) |
| Saudi Arabia | 100% | (United Nations, 2006) |
| Saudi Arabia | 100% | (United Nations, 2006) |
| South Georgia & Sandwich Isl. (UK) | 2043100 ha | (Marine Conservation Institute, 2019) |
| Southern California | 90% | (Cranor, 2018) |
| Sri Lanca | 100% | (*SRI LANKA Government Ban on Trawling Nets, a Victory for Small Fishermen*, 2020) |
| Sweden | 6% | (United Nations, 2006) |
| Venezuela | 100% | (*Venezuela Outlaws Bottom Trawling in All Its Waters*, 2020) |

Many studies prove a destructive impact of bottom trawling both at the benthic habitat, communities and fish. And yet the landings from deep-sea fisheries are minor, contributing less than 0.5% to global fisheries landings (Victorero et al., 2018). One long-term study of reported and unreported bottom trawling catches shows that as much as 42% of global bottom trawling landings were overall under-reported contributing to the removal of an estimated 25 million tons of deep-sea fish (Victorero et al., 2018). Globally, the voices calling for banning bottom trawling due to its destructive nature are being stronger (e.g. Oceana, Deep Sea Coalition) and every year new areas closed for bottom trawling are established. Moreover, it has been recently noticed that more attention should be given to offshore and deep ocean benthic communities in the climate change mitigation agenda (Solan et al., 2020). As closing areas for bottom trawling has already taken place in several regions of the world, it proves that there are existing policies that can enable the banning/regulation of the bottom trawling.

### Barriers to Adoption

To achieve successful implementation of ocean seafloor protection by closing area subjected to bottom trawling, it is important to properly design those protected areas. This should be carefully considered and planned with the use of most advanced and recent spatial, habitat maps and bottom trawling footprint data coming from vessels satellite monitoring systems as well as with social conscious. Five key characteristics were assigned specifically to MPAs (no-take, well-enforced, well-established (≥10 y old), large (≥100 km2), and isolated) and have been shown to produce the greatest conservation benefits, and the effectiveness in supporting climate change mitigation and adaptation will be contingent, in part, on these factors (Solan et al., 2020). However, very large marine reserves or bottom trawling closures will not be appropriate in all instances, for example near coasts populated by those who rely on fishing for subsistence. Resolving the challenge between biological and socio‐economic objectives remains one of the major challenges of fishery management (McConnaughey et al., 2020). To scale up ocean protection effects to achieve regional and global impacts, such approaches need encouragement and support from governments and development agencies, using appropriate legal, financial, and social incentives, and should be considered part of national and international commitments regarding climate change adaptation and mitigation. Potential shortcomings of marine reserves or bottom trawling closures include, prominently, lack of staff, equipment and funding, inadequate consultation with and support from local communities, concerns about managing displaced fishing effort, if such occurs and insufficiencies in management scope (Roberts et al., 2017). Safeguards are required to ensure that, for example, restoration projects do not prevent local communities from accessing marine resources (McDermott et al. 2012). Increasing investment in conservation and restoration of blue carbon ecosystems through innovative finance (insurance, debt swaps, taxes, and credits) and public-private partnerships are, therefore, needed (Hoegh-Guldberg O. et al., 2019). Moreover, banning bottom trawling on areas that are currently disturbed has to come together with reducing fishing effort and legal protection of the remaining EEZs areas to ensure bottom trawling activity is not directed to areas previously untrawled. This means, that bottom trawling should be considered to be significantly reduced or completely banned, what is unlikely to happen as some countries highly rely on this type of fishery.

### Adoption Potential

There is high potential with high technological readiness, to protect marine habitats and ecosystems through spatial measures including marine protected areas, marine reserves or closing areas to certain activities (Gattuso et al., 2018). With the adoption of the Convention on Biological Diversity (CBD) and the Fish Stocks Agreement), and the subsequent development of ecosystem-based fisheries management (EBFM), sustainability has become an overarching principle across marine policy, both at the national and international levels by numerous organizations (Food and Agricultural Organization, International Council for the Exploration of the Sea, CBD, Arctic Council). There are also calls for including blue carbon solutions in nationally determined contributions (NDCs) and other relevant climate policies for mitigation and adaptation (Herr and Landis 2016). Conservation and restoration of seabed can be also linked to achieving the UN Sustainable Development Goals. As already mentioned, the negative effect of bottom trawling on seafloor and fish population degradation has been widely recognized, and several countries closed all or significant amount of their EEZs waters to bottom trawling. EEZs has been also proved to be effective spatial measures for monitoring fishing activity, detecting illegal fishing, and are respected by unauthorized resource users (Englander, 2019). Therefore, extending spatial protection measures such as marine reserves or area closures to bottom trawling within EEZs have high potential to be well managed and recognized by the fishing industry.

Nowadays, there is also increasing number of advances in access to data, that according to the High-Level Panel for a Sustainable Ocean, provides the enormous potential for policymakers, NGOs, businesses and investors to implement more informed protection mechanisms. Some of those financial and technological advances that help in the proper development and enforcement of marine protection measures include (Early et al., 2020):

* Ocean Observatories Initiative funded by America’s National Science Foundation gathering physical, chemical, geological and biological properties of marine ecosystems,
* Global Fishing Watch a collaboration of Google, Oceana and SkyTruth that visualizes tracks of fishing fleets and makes freely available data on fishing activity in near real-time,
* UN Decade of Ocean Science that will begin in 2021 and aims to ensure that science can fully support the effort by countries to achieve a sustainable healthy ocean,
* A growing number of companies (e.g. Marine Databank) that use machine learning, artificial intelligence, advanced moorings and other types of measuring equipment, and satellite images to inform and promote sustainable fisheries, ocean health and coastal community resilience.

## Advantages and disadvantages of seafloor protection

### Similar Solutions

There are two more ocean solutions that use protection mechanisms - Coastal wetlands protection, Macroalgae protection and their climate impact is defined as additional CO2 sequestered (by protecting existing habitats) or avoiding CO2 emissions (when the coastal wetlands gets degraded, the stored CO2 in sediments belowground will be emitted). Current solution assumes protecting seafloor sediments from bottom trawling degradation thus avoiding CO2 emissions. It assumes protecting seafloor from areas different than the ones covered by coastal wetlands or macroalgae’s. Therefore, there is no overlap between climate impact of those three ocean protection solutions.

### Arguments for Adoption

Implementing seafloor ocean protection has many more benefits to the natural environment than the preservation of long-term stored organic carbon. It will also lead to the protection and restoration of vulnerable benthic habitats such as cold-water corals, sponges, gorgonians, bivalves and epifauna to name a few (van Denderen et al., 2020). Those ecosystems play an important function in sustaining fish populations many of which are commercially exploited. Therefore, protection of the seafloor by trawling closures would play the role of ocean reserves where invertebrates and fish biomass grow and expand to the neighboring areas which still can be commercially exploited (Howarth et al., 2018). Smart planning of protection areas together with local communities would, therefore, support small scale artisanal fishery that is highly promoted as is being more sustainable (FOLU, 2019; Sala et al., 2018). Currently, the majority of global bottom trawling fishing activity is largely subsidized by governmental agencies. Without government subsidies, bottom trawling would not be profitable with maximum annual losses of $230 million before subsidies (Sala et al., 2018). Therefore, protecting the seafloor from bottom trawling will serve an important role in repairing capture fisheries that are currently reaching their maximum sustainable yields (McDermott et al., 2019).

### Additional Benefits and Burdens[[1]](#footnote-1)

Here this solution is compared with other solutions in the ocean sector in terms of ecosystem, social and climate impact. Seaweed farming represents the highest climate impact within all ocean solutions with high adoption potential and intermediate environmental and social benefits.

Table 1.2 Ocean Solutions Comparison.

**Ecosystem Services** is subjective based on impacts on biodiversity, habitat restoration, protection from extreme weather events etc. **Social Justice Benefits:** If solution is causing positive impact on local societies. **Climate Impact:** GHG reduction potentialin GT CO2 eq, 2020-2050:low >1, middle between 1 and3, high <3. **Global Adoption Potential:** TOA in Mha: low > 100, middle between 100 and 400, high < 400; TAM is applicable for only two solutions Improve Fishery and Improve Aquacultures therefore direct comparison with other ocean solutions is not possible, however, both solutions represents high total adoption potential. n/a – not applicable.

|  | **Ecosystem Services** | **Social Justice Benefits** | **Climate Impact** | **Global Adoption Potential** |
| --- | --- | --- | --- | --- |
| Conventional fishery | Low | Low | n/a | n/a |
| Conventional aquacultures | n/a | Medium | n/a | n/a |
| Conventional seaweed farming | Medium | Medium | Low | n/a |
| Improve Fishery | High | High | Middle | High (TAM 94 million tons landings) |
| Improve Aquacultures | n/a | Medium | Middle | High (TAM 126 million tons live weight) |
| Seaweed Farming | Medium | Medium | High | High |
| Macroalgae Forests Protection | High | High | Middle | Middle |
| Macroalgae Forests Restoration | High | High | Middle | Middle |
| Coastal Wetlands Protection | High | High | Middle | Low |
| Coastal Wetlands Restoration | High | High | Middle | Low |
| **Seafloor Protection** | **High** | **Medium** | **High** | **High** |

# Methodology

## Introduction

Project Drawdown’s models are developed in Microsoft Excel using standard templates that allow easier integration with each other since integration is critical to the bottom-up approach used. The template used for this solution was the Ocean model which accounts for sequestration of carbon dioxide from the atmosphere into plant biomass and soil, and reduction of emissions for a solution relative to conventional practice. These practices are assumed to use the ocean of a specific type that may be shared across several solutions. The actual and maximum possible adoptions are therefore defined in terms of ocean area (million hectares). The adoptions of both conventional and solution were projected for each of several Drawdown scenarios from 2019 to 2060 (from the base year of 2018) and the comparison of these scenarios with a reference (for the 2020-2050 segment[[2]](#footnote-2)) is what constituted the results.

*Agency Level*

Government is selected as the agency level for this solution. Though certainly other agents can, do, and should play an important role in this solution, government is the most critical player in implementation.

## Data Sources

The main data sources used in this analysis is Amoroso et al 2018, SeaAroundUs database, Atwood et al. 2020, Sala et al., 2021, Luisetti et al 2019, Martin et al 2014, Pusceddu et al. 2014, Paradis et al. 2019, Polymenakou et al. 2005, Pusceddu et al. 2005, Bhagirathan et al. 2010. The TOA is taken from Sala et al. 2021, confronted with own calculations using Amoroso et al. 2018 and SeaAroundUs database, the carbon stock in 1 meter of sediment column is taken from global metanalysis Atwood et al 2020, while organic carbon release from the disturbed seafloor is calculated using Luisetti et al 2019, Martin et al 2014, Pusceddu et al. 2014, Paradis et al. 2019, Polymenakou et al. 2005, Pusceddu et al. 2005, Bhagirathan et al. 2010.

## Total Ocean Area

The Drawdown Ocean model defines the Total Ocean Area as the ocean area (in million hectares) suitable for a given solution. For the protecting ocean seafloor solution, the TOA represents the total seafloor of oxic sediments swept by bottom trawling gear on an annual basis. This is often called a bottom trawling footprint or swept area (Amoroso et al., 2018). The majority of bottom trawling is taking place on Exclusive Economic Zones (Pauly et al., 2020) therefore, the TOA only represent ocean area within EEZs boundaries. The bottom trawling disturbances have different effects on different sediment types but the oxic sediments has higher potential for carbon remineralization as mixing of the sediments and resuspension increases the amount of time the disturbed carbon is in contact with oxygen (Sala et al., 2021). For the purpose fn current analysis, we are using Sala et al. 2021 assumption and considering only oxic sediments.

Thanks to the introduction of vessel monitoring systems (VMSs) or authomatic identification system (AIS) which provide high-resolution data on locations of fishing vessels, it is possible to monitor and analyze fishing activity (Deng et al., 2005). VMSs has been already proven useful in supporting marine spatial planning (Campbell et al., 2014), providing advice on MPAs placement and their effectiveness (Watson & Haynie, 2016). The World Resources Institute estimated a globally trawled surface area of at least 22 million square kilometres, with 40% of the world trawling grounds located at depths beyond the continental shelf-break (Martín, Puig, Palanques, & Giamportone, 2014). Another study based on high-resolution satellite vessel monitoring system (VMS) provided a conservative estimate of world trawling grounds on continental slopes of 4.4 million square kilometres worldwide (Puig et al., 2012). The more recent large scale assessment of bottom trawling footprint on 30 regions also based on VMS data provides even more conservative estimate of global swept seafloor of 0.5 million square kilometres (Amoroso et al., 2018). However, the most recent global estimation based on AIS data coming from Global Fishing Watch shows that 4.9 million square kilometers gets actively disturbed by trawling gear (Sala et al., 2021). To calculate TOA, we used (Sala et al., 2021) database that we consider the most conservative source (490 Mha). We however, did some comparison using (Amoroso et al., 2018) database and Sea Around Us database (Pauly et al., 2020) to check if Sala et al 2021 study includes all countries that report bottom trawling catch.

Amoroso et al. 2018 study provides a total area that is permitted to bottom trawling in 30 analyzed regions (so exclude areas that has trawling bans or where marine reserves occur) (Amoroso et al., 2018). Data for 24 regions account for more than 70 percent of all known trawling activity over 2 to 6 years and data for the remaining 6 regions account for less than 70 percent of known trawling activity. The trawling footprint has been also presented in ICES Advice 2019 report (ICES Advice, 2019) for four additional regions (the North Sea, Bay of Biscay and Iberian Coast, Celtic Sea, Baltic Sea). ICES Advice 2019 report provide and demonstrate the application of estimates of the spatial extent of physical loss and disturbances per subdivision and habitat type (following EUNIS classification (*The European Nature Information System*, 2020)) in the European Union Member States (ICES Advice, 2019). In the ICES Advice 2019 report, the bottom trawling pressure on the seafloor is called abrasion and deposition.

Because the (Amoroso et al., 2018) dataset only provides data on 30 mentioned regions, not on all regions that are bottom trawled, their database has been complemented using Sea Around Us data. Sea Around Us database (Pauly et al., 2020), gathers wild fishery catchment records on a jurisdiction and gear type basis. Based on that database filtered by EEZ and gear type (included beam trawl, bottom trawl, dredge gear, dredge, otter trawl, shrimp trawl) additional 138 countries perform (excluding the ones analyzed in (Amoroso et al., 2018). The EEZs of those 138 countries were extracted from the Sea Around Us database with a total area of 7 568 million hectares. An additional literature search was conducted to see if any spatial protections eliminate bottom trawling on those EEZs, such as marine reserves, bottom trawling closures and bans. The literature search was supplemented by personal communication with experts from Oceana (*Oceana, About Us*, 2020) that established a long-term portfolio of tracking bottom trawling activities all over the world. Different sources provided a different kind of data on protection from bottom trawling – an area of marine reserves, an area designated to closure (in square km or hectares), percentage of their EEZ closed to bottom trawling, miles extend from the coast prohibited to bottom trawling and trawling allowed only after certain depths. In the case of the last type of data, the area closed to bottom trawling has been calculated using GIS analysis (QGIS.org, 2020). Based on the literature search, 35 countries have some protection within their EEZs by 2020 (Table 1.1) that in the total amount of 1 032 million hectares. Therefore, the additional 138 countries EEZ area allow to bottom trawling is 6 535 million hectares. Afterwards, the average 20 percentage of bottom trawling footprint coming from (Amoroso et al., 2018) and (ICES Advice, 2019) has been applied to the 6 535 million hectares, as well as low estimate of 5%. As a result, the final check value for TOA coming from (Amoroso et al., 2018) and Sea around Us extrapolations amount of 1 445 million hectares if we use average estimates and 465 million hectares if we use low estimates. The low estimates figure is in the same range as Sala et al. 2021 direct measurement and estimation.

## Adoption Scenarios

Two different types of adoption scenarios were developed:

A Reference (REF) Case which was considered the baseline, where not much changes in the world, and a set of Project Drawdown Scenarios (PDS) with varying levels of ambitious adoption of the solution. Published results show the comparison of one PDS to the REF, and therefore focus on the change to the world relative to a baseline.

Five custom adoption scenarios were developed for this solution using a linear growth curve. Ocean seafloor can be protected by two different mechanisms – marine reserves that prohibit any fishing activity within its boundaries and bottom trawling bans or closures of ocean areas. The protection of ocean has received increasing attention recently and International Union for Conservation of Nature published a recommendation to exceed MPAs of strict protection coverage to 30% by 2030 (Simard, F. et al., 2016). In 2020, 14 countries has put forward an new ocean action agenda as a part of High-Level Panel for Sustainable Oceans and committed to establish MPAs on 30 percent of their national waters. The bottom trawling bans and closures has its beginning before 1980 when Indonesia implemented a ban in the Malacca Strait and Northern Coast of Java (United Nations, 2006). Also, under European Community regulations, trawling has been prohibited above seagrass meadows in the Mediterranean since 1994. There is an increasing number of national bans implemented in the past three years (see Table 1.1.1) and they were used in developing some of custom adoption scenarios.

1. ***Custom adoption scenario one:*** This scenario assumes 30% TOA protected by 2030 as the optimistic assumption following IUCN (that recommend 30% highly protected MPA coverage by 2030) after 2030 assuming linear growth.
2. ***Custom adoption scenario two:*** This scenario assumes 30% TOA protected by 2050 following the less optimistic assumption of IUCN (that recommend 30% highly protected MPA coverage by 2030).
3. ***Custom adoption scenario three:*** This scenario assumes 50% of TOA protection by 2050 (following bottom trawling bans of some countries).
4. ***Custom adoption scenario four:*** This scenario assumes 70% of TOA protection by 2050 (following bottom trawling bans of some countries).
5. ***Custom adoption scenario five:*** This scenario assumes 90% of TOA protection by 2050 (following bottom trawling bans of some countries) – highly optimistic adoption.

The degradation rate applied to the current solution is set as 100 percent because the TOA is the total area that gets disturbed by bottom trawling gear. Protecting ocean seafloor under adoption scenarios is unambiguous with complete cessation of degradation of ocean seafloor (stop of bottom trawling activities). Therefore, 100 percent of every protected hectare is regarded as an area where no degradation activity takes place. Moreover, disturbance rate is set as 0 percent, as this solution only calculate the CO2 release from disturbed sediments and not the sequestration rate of protected seafloor (there is not enough evidence that there is different sequestration rate at disturbed and undisturbed sediments).

### Reference Case / Current Adoption

Current adoption is set as 0 because the area protected from bottom trawling by 2020 has been subtracted from the TOA.

### Project Drawdown Scenarios

Three Project Drawdown scenarios (PDS) were developed for each solution, to compare the impact of increased adoption of the solution to a reference case scenario, being:

#### Plausible Scenario - This scenario is based on the average of nine custom adoption scenarios. Scenario 6 has been excluded as the most outstanding point.

#### Ambitious Scenario – This scenario is based on the ‘high of all’ estimate of nine custom adoption scenarios. Scenario 6 has been excluded as the most outstanding point.

#### Maximum Scenario – Adoption is intensified under this scenario by choosing the single highest custom scenario, scenario 10 – assuming 90% of TOA is protected by 2050.

## Inputs

### Climate Inputs

The emission of carbon from disturbed sediment by bottom trawling activity is a very uncertain process that depends on many factors. However, the recent advances in the field of global carbon stock in sediments, as well as bottom trawling footprint, allows making some approximations of the rate of CO2 emissions. Also, recent study proves that the trawling disturbances of sediment layer are associated with a sudden and temporary increase in the mineralization rate of organic matter via the introduction of a new pool of reactive organic matter (van de Velde et al., 2018). To incorporate the large uncertainty, every variable used in calculating climate input was set at a conservative rate. The main climate input for the current solution is ‘Reduced tonnes of CO2 emissions per ocean unit’. This input if coming from the following equation:

Carbon storage is taken from the global metanalysis of over 11 thousand data points from 685 sources of carbon content in the sediment cores (Atwood et al., 2020). As this study gathers global data of organic carbon content in the sediments published in the last forty years and used a different kind of extrapolations and calculations to unify collected data, the usage of raw data as inputs were not possible. Atwood et al. study provide raw data of carbon stock within 1 meter of sediment column per square kilometre, associated with geographical coordinates. Those data points were fitted to the bottom trawling areas of Sala et al. 2021 using GIS analysis (QGIS.org, 2020) and EEZs boundaries provided by (Flanders Marine Institute, 2019; QGIS.org, 2020)). Then, an average of carbon stock was calculated for every region. In total, the average carbon stock within 1 meter of sediment was obtained for 115 regions. The global average carbon stock in 1 meter of sediment is 8 379 tonnes/hectare.

The key variable in the equation is POC (particulate organic matter) disturbance by bottom trawling, that has been analysed in six studies. There is a different methodology used by the authors to calculate this variable. Some of the studies measured POC concentration in the upper sediment before and after trawling events (Bhagirathan et al., 2010; Polymenakou et al., 2005; Pusceddu et al., 2005) and the others measured POC concentration of trawled and untrawled sediments of the same location (Martín, Puig, Masqué, Palanques, et al., 2014; Paradis et al., 2019; Pusceddu et al., 2014). Four of those studies noted impoverishment of organic matter in sediments after bottom trawling in a range between 3 to 50 percent (Bhagirathan et al., 2010; Martín, Puig, Masqué, Palanques, et al., 2014; Paradis et al., 2019; Pusceddu et al., 2014) and were characterized by the sediment type of silt content with clay and a small fraction of sand. The other sources noted an increase of organic matter in sediments in a range from 2 to 76 percent (Polymenakou et al., 2005; Pusceddu et al., 2005) and did not provide the sediment type in the study area. It is also important to note that (Polymenakou et al., 2005) analysed the organic carbon concentration only in the upper 1 centimetre of the sediment layer while the other studies analyse the higher depth of sediment layer (between 10 to 50 cm). The impoverishment of organic matter content due to trawling disturbance is explained by resuspension of large amounts of sediments by the trawling gear, which exposes organic carbon stored in the sediments to oxygen as well as an increase of the penetration depth of oxygen down the sediment column thus promoting increase levels of remineralization. The latter process may also cause burial of surface sediments rich in organic matter, deeper in the sediment column where the labile form of carbon can be removed in aerobic processes (Mayer et al., 1991). While the opposite effect of carbon enhancement may be explained by the lifting of carbon accumulated in the deeper layers to the surface or increased mortality of benthic fauna that could consume organic matter (Martín, Puig, Palanques, & Giamportone, 2014). Because the bottom trawling effect on organic matter concentration is a complex issue, all six mentioned studies were used to derive with the estimation of average organic carbon resuspension. For a conservative approach, the most outstanding data points were excluded from the analysis and the average POC disturbance by bottom trawling variable finally amounts 6 percent.

The disturbance of the sediment and fraction of organic carbon resuspension will also largely depend on the gear type and type of sediments. It is generally assumed that the penetration depth of fishing gears is higher in muddy sediments but other features may also shape this variable such as gear type, its dimension and boat speed (Depestele et al., 2016, 2019; Martín, Puig, Palanques, & Giamportone, 2014). For example, the sediment penetration of otter trawl has been estimated up to even 30 centimetres in soft sediments (Jones, 1992) while typical penetration of beam trawls are in a range of 6 to 8 centimetres (Duplisea et al., 2001). However, nowadays there are technical measures that can limit the seabed contact of fishing gear such as electric pulse devices coupled to beam trawls forcing targeted species out of sediments used instead of chains (Yu et al., 2007) or disks attached to otter trawls rising sweeplines above the bottom and decreasing sediment disturbance (Rose et al., 2010). For the current analysis, the low estimate of penetration depth of 1.5 centimetres coming from 11 data points is used as a conservative assumption (Duplisea et al., 2001; Hiddink et al., 2017; Luisetti et al., 2019; Sala et al., 2021). The global study of bottom trawling impact on sediment and carbon resuspension came up with average gear penetration of 2.44 centimetres which is in higher than our estimate but we believe using conservative approach is more robust (Sala et al., 2021).

Once resuspended, the organic carbon may be dispersed on large distances together with the sediments plumes (Puig et al., 2012), be deposited back to the sediments and buried down into the sediment by burrowing organisms or be remineralized in aerobic processes (Sciberras et al., 2016). The remineralization depends on the quality of organic matter, its origin (allochthonous vs autochthonous) and lability. Labile organic matter is characterised by low molecular weight thus is easily assimilated in microbial processes and gets quickly transformed to CO2 (Zhongqi & Fengchang, 2015). In this analysis, solely labile fraction of organic matter is assumed to be remineralized following Sala et al. 2021. The lower estimate of 15 % of labile organic matter fraction derived from 28 data points has been applied in the equation as a conservative assumption (Danovaro et al., 1993; Keil et al., 1994; Sala et al., 2021)

Finally, only a small fraction of resuspended and labile organic matter will be remineralized to aquatic and atmospheric CO2. The large scale study of carbon release by bottom trawling on the United Kingdom shelf sediment, performed a 2D box model of shelf water column carbon dynamics to test what is the exchange of carbon between disturbed seafloor and surface of the ocean (Luisetti et al., 2019). The parameters that impact the exchange rate used in their model are the temperature of the surface and bottom water, season and related to it stratification of the water column as well as bloom occurrences that all are affecting the mechanism of the transformation of inorganic carbon to organic carbon during primary production. Based on their model, 100 percent of 27.6 kilograms of organic carbon per hectare gets remineralized from muddy sediments. The 27.6 kilograms of resuspended carbon per hectare estimate comes from two studies in the Mediterranean sea that measures POC flux in water above the seafloor right after trawling gear penetration, a measurement not associated with the carbon stock of disturbed sediments. It is important to notice that 100 percent remineralization assumption is in line with previous studies that however analyzed the remineralization of disturbed sediments of coastal wetlands ecosystems (Lovelock et al., 2017; Pendleton et al., 2012). The remineralization rate of organic carbon from the shelf of continental slope (where trawling occur) may be different as is happening usually at greater depths where oxygen concentration, radiation and temperatures are much lower than in the coastal wetlands habitats. Therefore, we believe that applying 100 percent of remineralization rate to our estimates would be a massive overestimation. For this analysis, an average lower estimate of 30 % is used as a conservative assumption following global study of carbon remineralized to aquatic CO2 due to bottom trawling Sala et al. 2021. We additionally assume that the aquatic CO2 will get remineralized to the atmosphere.

Assuming that trawling is happening once a year the key climate input of reduced CO2 emissions per ocean unit per year could be calculated following abovementioned equation.

Table 2.1 Climate Inputs

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| t CO2-eq (Aggregate emissions) Reduced per Ocean Unit | t CO2-eq / ha | 20.19 – 7.5 | 13.83 | 115 | Calculated; (Luisetti et al., 2019) |
| t C storage in Protected Ocean type | t C / ha | 17142 - 8379 | 8379 | 115 | (Atwood et al., 2020) – global metanalysis. |

Note: Project Drawdown data set range is defined by the low and high boundaries which are respectively 1 standard deviation below and above the mean of the collected data points[[3]](#footnote-3).

### Financial Inputs

It is assumed that any costs for *ocean seafloor protection* (e.g. carbon payments or payment for ecosystem services) are borne at a government or NGO level. Drawdown solutions only model costs that are incurred at the landowner or manager level. Therefore, costs were not included in this solution.

### Other Inputs

Other inputs were used to calculate the key climate input, the reduced CO2 emissions per ocean unit and this calculation is explained above in the 2.5.1 section.

Table 2.2 Other inputs.

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| POC disturbance by bottom trawling | % | -0.07-0.19 | 0.06 | 24 | (Bhagirathan et al., 2010; Martín, Puig, Palanques, & Ribó, 2014; Paradis et al., 2019; Polymenakou et al., 2005; Pusceddu et al., 2005, 2014) |
| Penetration depth of trawling gear | m | 0.01-0.04 | 0.03 | 11 | (Depestele et al., 2016, 2019; Duplisea et al., 2001; Hiddink et al., 2017; Luisetti et al., 2019) + Sala et al. personal communication |
| Labile organic matter fraction | % | 0.15-0.30 | 0.15 | 28 | (Danovaro et al., 1993; Keil et al., 1994) + Sala et al. personal communication |
| Remineralization rate of C to CO2 | % | - | 0.03 | 1 | (Sala et al., 2021) |
| C to Co2 conversion rate | - | - | 3.67 | - | The standard ratio of the weight of CO2 relative to that of C (that is, 3.67 tons of CO2 equal to 1 ton of C). |

## Assumptions

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions. These are that the infrastructure required for the solution is available and in-place, policies required are already in-place, no carbon price is modeled, all costs accrue at the level of agency modeled, improvements in technology are not modeled, and that first costs may change according to learning. Full details of core assumptions and methodology will be available at [www.drawdown.org](http://www.drawdown.org).

Beyond these core assumptions, there are other important assumptions made for the modelling of this specific solution. These are detailed below.

1. Assumed that seafloor is only disturbed by bottom trawling once per year (following Amoroso et al. 2018 and Sala et al. 2021).
2. Assumed that no bottom trawling is happening outside calculated TOA under both reference and PDS adoption scenarios.
3. Assumed that carbon stock is uniformly distributed in the 1 meter sediment column.
4. Assumed that protection of ocean seafloor from bottom trawling activities will reduce emissions of aquatic CO2 that gets remineralized to atmosphere.
5. Assumed that the bottom trawling incidents are happening in the spring/summer season of high productivity so the likelihood of carbon remineralization is higher than if the accidents would happen in winter season with low productivity and temperatures. This assumption is in line with main trawling seasons that in many places are happening when the production peaks.
6. Assuming that remineralization rate is the same globally despite different temperatures and seasons.
7. Assuming that mixing of the sediments and resuspension increases the amount of time the disturbed carbon is in contact with oxygen.

## Integration

The complete Project Drawdown integration documentation (will be available at [www.drawdown.org](http://www.drawdown.org)) details how all solution models in each sector are integrated, and how sectors are integrated to form a complete system. Those general notes are excluded from this document but should be referenced for a complete understanding of the integration process. Only key elements of the integration process that are needed to understand how this solution fits into the entire system are described here.

*Seafloor protection* is part of Drawdown’s new Ocean sector. Integration of this sector with the other Drawdown sectors will be developed after all the Ocean solutions are complete.

***The Ocean model***

The Drawdown Ocean model classifies the ocean into 42 possible ocean zones using three dimensions:

* + - 1. “Cover and climate” dimension: a primarily physical climate- and bathymetry- and cover- based classification of the ocean into the following regions, 4 zones for the deep ocean (biological desserts, equatorial waters, bloom waters and transition waters), 2 zones for shallow and slope waters (shallow waters and slope waters), and 1 ice-covered zone (sea ice covered waters).
      2. “Access” dimension: there are political instruments in place that can limit how large parts of the ocean are used, the most common are Exclusive Economic Zones (EEZ) and Marine Protected Areas (MPA). EEZs are broadly defined by a 200 nautical mile offset from the seacoast of a country and as such collectively represent a significant fraction of the total ocean area. EEZs also coincide with the most accessible waters because of their definition; EEZ waters are closest to shore. And while EEZs tend to be shallow waters, they are not always shallow and can cross slope waters and extend into the deep ocean. The access dimension classifies whether waters are in or out of a national jurisdiction as defined by an EEZ.
      3. “Depth” dimension: the open ocean can be broadly subdivided into three layers, the epipelagic (0 to 200 m), the mesopelagic (200 to 1000 m), and bathypelagic (1000 m to bottom). Since the bottom of the epipelagic zone corresponds to the maximum depth of the coastal or shallow waters, these two ocean zones are by definition excluded from the mesopelagic and bathypegic layers.

Table 2.3 Project Drawdown Ocean model zones.



This ocean classification has about one third the number of zones in the Drawdown Land Model in large part because the large-scale cover and climate of the oceans are not independent while cover and climate are independent on land.

## Limitations/Further Development

The right estimation of trawling footprint depends on many aspects. Both VMS and AIS data coverage of fishing fleets is high for some countries but does not include all fishing vessels activity (Amoroso et al., 2018; Sala et al., 2021). Moreover, using coarse-scale while mapping fishing activity may lead to a misleading picture of the spatial distribution of trawling since trawled areas combine with untrawled areas (S. Jennings et al., 1999). In some regions, the bottom trawling activity of small inshore vessels may not be included as they are not subjected to the same monitoring or reporting requirements as larger vessels (Amoroso et al., 2018). These aspects have a strong influence on the precision of trawling footprint estimations and calculations of the TOA. This knowledge and data gaps can be filled with better regulations and more widespread usage of recent technological advances in vessels monitoring.

There is also different respond of seafloor sediments on bottom trawling impact and it varies in cohesive and non-cohesive sediments (Paradis et al., 2019). While it is more likely and clear that bottom trawling considerably disturb oxic sediments and cause resuspension of organic carbon, the same mechanisms may not work for anoxic sediments. This may lead to underestimation of total carbon emission by bottom trawling impact.

Finally, the remineralization rate of aquatic CO2 to the atmosphere is unknown parameter that may depend on many naturally driven processes. The season (Luisetti et al., 2019), temperature (Luisetti et al., 2019), oxygen concentration (Lovelock et al., 2017), water column stratification, the activity of microbial communities (Lønborg et al., 2020), currents, wind, all parameters should be considered when estimating CO2 emissions from disturbed sediments. Further studies are needed to better understand seafloor degradation specifically in different geographical regions of the oceans.

## Sector of ocean-based solutions

Project Drawdown has investigated eight ocean-based solutions and their potential to avoid GHG emissions or sequester carbon. The ocean-based solutions form two main groups: a group of protection and restoration solutions and a group of approaches to improving fisheries and aquaculture operation.

The protection and restoration solutions focus on blue carbon sinks, and their potential to sequester carbon. They include protection and restoration of coastal wetlands and macroalgae ecosystems, as well as seafloor protection from bottom trawling activities (Fig. 2-1). The adoption of protection solutions involves the expansion of marine protected areas and other conservation tools such as bottom trawling bans. The adoption of solutions focusing on restoration additionally requires active restoration programs. The climate impact of solutions from this sector, include avoiding carbon emissions or enhanced carbon sequestration and are designated for the government agency level.

The second group of solutions explores the potential of improving fisheries, improving aquaculture and seaweed farming. The fisheries can be improved by reducing fishing effort and restoring large fish biomass. The climate impact, therefore, includes avoiding carbon emissions from fuel usage and enhanced carbon sequestration in sunken large fish biomass and the implementation of this solution involve governments. Improving aquaculture solution assumes shifting from fuel-based energy systems to hybrid systems partly based on renewables, thus includes the climate impact based on avoiding GHG emissions. The seaweed farming solution explores the potential of expanding seaweed production and its climate effect on the enhancement of carbon sequestration in the deep sea together with unharvested biomass (Fig. 2-1). The agency-level for the two last solutions involves farmers.

Diagram

Description automatically generated

Figure 2.2 Schematic of all Drawdown ocean-based solutions.

# Results

## Adoption

Below are shown the world adoptions of the solution in some key years of analysis in functional units and percent for the three Project Drawdown scenarios.

Total adoption in the *Plausible* Scenario is 283 million hectares in 2050, representing 58 percent of the total suitable ocean area.

Total adoption in the *Ambitious* Scenario is 384 million hectares in 2050, representing 78 percent of the total suitable ocean area.

Total adoption in the *Maximum* Scenario is 441 million hectares in 2050, representing 90% of the total suitable ocean area.

Table 3.1 World Adoption of the Solution

| **Solution** | **Units** | **Base Year (2018)** | **World Adoption by 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Ambitious** | **Maximum** |
| Seafloor protection | *Adoption (Mha)* | 0 | 283.38 | 383.65 | 441.00 |
| % Total Ocean Area available | 0 | 57.83 | 78.30 | 90.00 |

Figure 3.1 World Annual Adoption 2020-2050.

## Climate Impacts

Below are the emissions results of the analysis for each scenario which include total emissions reduction, atmospheric concentration changes, and sequestration where relevant. For a detailed explanation of each result, please see the glossary (Section 6).

Climate impact is 3.80, 5.14, 5.91 gigatons of carbon-dioxide equivalent in the *Plausible, Ambitious,* and *Maximum* Scenarios respectively.

Table 3.2 Climate Impacts

| **Scenario** | **Maximum Annual Emissions Reduction** | **Total Emissions Reduction** | **Total Atmospheric CO2-eq Reduction** |
| --- | --- | --- | --- |
| *(Gt CO2-eq/yr.)* | *Gt CO2-eq/yr. (2020-2050)* | Gt CO2-eq (2020-2050) |
| ***Plausible*** | 0.123 | 3.80 | 3.80 |
| ***Ambitious*** | 0.166 | 5.14 | 5.14 |
| ***Maximum*** | 0.191 | 5.91 | 5.91 |

Figure 3.2 World Annual Greenhouse Gas Emissions Reduction.

Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq

| **Scenario** | **GHG Concentration Change in 2050** | **GHG Concentration Rate of Change in 2050** |
| --- | --- | --- |
| *PPM CO2-eq (2050)* | *PPM CO2-eq change from 2049-2050* |
| **Plausible** | 0.296 | 0.008 |
| **Ambitious** | 0.401 | 0.010 |
| **Maximum** | 0.461 | 0.012 |

## Other Impacts

There are no other impacts modeled.

# Discussion

It has been already emphasized that the role of offshore and deep ocean benthic communities in climate warming mitigation is under-represented (Solan et al., 2020). The global seafloor sediment stores high amount of organic carbon yet only 4 percent is protected by MPAs and only 2 percent by highly protected, no-take MPAs (Atwood et al., 2020). Recent global analysis published conservation planning framework to prioritize highly protected MPAs in places that would result in multiple benefits today and in the future including biodiversity, food provision and carbon storage in sediments benefits. It shows that MPAs has to strategically protect 21 percent of the ocean to get maximum biodiversity benefits, the MPAs protection of 28 percent of the ocean could increase food provisioning by 5.9 Mt, and eliminating 90% of the present risk of carbon disturbance due to bottom trawling would require protecting 3.6% of the ocean (mostly within EEZs) (Sala et al., 2018). Current analysis provide evidence that by expanding protection of ocean areas from bottom trawling avoid release of significant amount of carbon that is stored in the sediments. Expansions of MPAs or bottom trawling bans would have also many other benefits including restoration or preventing of degradation of benthic communities including cold water corals and sponges, rebuilding depleted fish stocks and increasing landings by the fish spillover effect with implications for food and nutritional security. Therefore, the adoption of seafloor protection falls within the UN Sustainable Development Goal 14.

The economic impacts of seafloor protection and bottom trawling closures are not modeled here but should be considered. Limiting the area of bottom trawling activity would have an implications on fisheries especially effort and employment. Considering the importance of fisheries as an employment sector, it is essential that fisheries reforms be designed in a way that mitigate these employment impacts. In particular, attention should be paid to ensure that fishery reforms and resulting job loss not disproportionately affect low-income or otherwise marginalized fishing communities. An OECD bio-economic model found that simply redirecting fisheries subsidies from capacity-enhancing to other types of subsidies (e.g., from fuel subsidies to direct income payments to fishermen) could help achieve fishing effort reduction and stock rebuilding goals while increasing total income of fishers, especially for small-scale fisheries (Martini & Innes, 2018). Significant amount of bottom trawling fisheries is relaying on harmful subsidies without which their operations would be not profitable (U. R. Sumaila et al., 2010). Therefore, redirecting harmful fishery subsidies into fishermen’s training for changing profession could be more beneficial (R. Sumaila et al., 2016).

When MPAs are well designed, they can produce conservation benefits to fish assemblages within no-take zones that will results in fishery benefits in neighboring areas through ‘spillover’ effect (Di Lorenzo et al., 2016). Global metanalysis show that, within marine reserves, fish assemblages biomass is on average 670 percent greater that in neighboring unprotected areas (Sala & Giakoumi, 2018). It has been also recently proven that 6 years after establishing marine no-take reserves that cover 35 percent of ocean area can be compensated for by a 225% increase in total catch (Lenihan et al., 2021). Even though, marine protected areas or bottom trawling bans are created for protection of natural habitats and marine resources, the positive impact of biomass rebuild goes beyond designed boarders and enhance local fisheries. It will also have a positive implication for job creation and income through ecotourism (Sala & Giakoumi, 2018).

## Limitations

Given the substantial potential economic impacts, both positive and negative, as described above, further detailed analysis of the economics of this solution would benefit future updates. It is also essential to properly design MPAs so they secure the most valuable ecosystems and have an appropriate size. Lack of habitat mapping might be a limitation in MPAs design. Very large marine reserves or bottom trawling closures will not be appropriate in all instances, for example near coasts populated by those who rely on fishing for subsistence. Resolving the challenge between biological and socio‐economic objectives remains one of the major challenges of adopting seafloor protection solution (McConnaughey et al., 2020).

## Benchmarks

The recent study estimating sedimentary carbon disturbance due to global bottom trawling served as an important source for establishing our methodology and assumptions (Sala et al., 2021). Based on their analysis the disturbance to the seafloor results in an estimated 1.47 Pg of aqueous CO2 emissions in the first year after trawling, decrease in emissions the following years of continuous trawling until they stabilize at 40 percent (0.58 Pg ) after 9 years of continuous trawling (Sala et al., 2021). When applying Sala et al. 2021 estimates to our Project Drawdown Scenarios assuming protection or banning of bottom trawling resulting in cessation of disturbance related emissions, the total emission reduction is between 6.06 and 9.56 GT CO2-eq (2020-2050) (Table 4.1). This estimate is around 60% higher than Project Drawdown total ) emission reduction that is between 3.80 and 5.91 GT CO2-eq. (2020-2050) (Table 4.1). This discrepancy between our and Sala et al. 2021 estimates is a result of a conservative approach applied by Project Drawdown that used lower estimates for the fraction of labile organic matter and sedimentary carbon disturbance due to bottom trawling. Project Drawdown has also used simplified analysis due to the model constrains and did not add into the calculations the natural sediment accumulation rates that will add more carbon to the sedimentary pool each year. And finally, Project Drawdown assumes that the fraction of emitted CO2 gets to the atmosphere whereas, Sala et al. 2021 only quantify emissions of aquatic CO2.

Table 4.1 Benchmarks

| **Source and Scenario** | **Mitigation Impact**  *(Gt CO2-eq yr. in 2030)* | **Total Emission Reductions**  *Gt CO2-eq (2020-2050)* |
| --- | --- | --- |
| Project Drawdown Plausible Scenario | 0.41 | 3.80 |
| Project Drawdown Ambitious Scenario | 0.56 | 5.15 |
| Project Drawdown Maximum Scenario | 0.64 | 5.91 |
| Sala et al. 2021 results adjusted to Project Drawdown ‘Plausible’ Scenario | 1.21 | 6.06 |
| Sala et al. 2021 results adjusted to Project Drawdown ‘Ambitious’ Scenario | 1.66 | 8.32 |
| Sala et al. 2021 results adjusted to Project Drawdown ‘Maximum’ Scenario | 1.91 | 9.56 |

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# Glossary

**Adoption Scenario** – the predicted annual adoption over the period 2015 to 2060, which is usually measured in **Functional Units**. A range of scenarios is programmed in the model, but the user may enter her own. Note that the assumption behind most scenarios is one of growth. If for instance a solution is one of reduced heating energy usage due to better insulation, then the solution adoption is translated into an increase in use of insulation. There are two types of adoption scenarios in use: **Reference (REF)** where global adoption remains mostly constant, and **Project Drawdown Scenarios (PDS)** which illustrate high growth of the solution.

**Approximate PPM Equivalent** – the reduction in atmospheric concentration of CO2 (in **PPM**) that is expected to result if the **PDS Scenario** occurs. This assumes a discrete avoided pulse model based on the Bern Carbon Cycle model.

**Average Abatement Cost** – the ratio of the present value of the solution (**Net** **Operating Savings** minus **Marginal First Costs**) and the **Total Emissions Reduction**. This is a single value for each solution for each **PDS Scenario**, and is used to build the characteristic “*Marginal Abatement Cost*” curves when Average Abatement Cost values for each solution are ordered and graphed.

**Average Annual Use** – the average number of functional units that a single implementation unit typically provides in one year. This is usually a weighted average for all users according to the data available. For instance, total number of passenger-km driven by a hybrid vehicle in a year depends on country and typical number of occupants. We take global weighted averages for this input. This is used to estimate the **Replacement Time**.

**Cumulative First Cost** – the total **First Cost** of solution **Implementation Units** purchased in the **PDS Scenario** in the analysis period. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Direct Emissions** – emissions caused by the operation of the solution, which are typically caused over the lifetime of the solution. They should be entered into the model normalized per functional unit.

**Discount Rate**- the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows. The discount rate in DCF analysis takes into account not just the time value of money, but also the risk or uncertainty of future cash flows; the greater the uncertainty of future cash flows, the higher the discount rate. Most importantly, the greater the discount rate, the more the future savings are devalued (which impacts the financial but not the climate impacts of the solution).

**Emissions** **Factor**– the average normalized emissions resulting from consumption of a unit of electricity across the global grid. Typical units are kg CO2e/kWh.

**First Cost**- the investment cost per **Implementation Unit** which is essentially the full cost of establishing or implementing the solution. This value, measured in 2014$US, is only accurate to the extent that the cost-based analysis is accurate. The financial model assumes that the first cost is made entirely in the first year of establishment and none thereafter (that is, no amortization is included). Thus, both the first cost and operating cost are factored in the financial model for the first year of implementation, all years thereafter simply reflect the operating cost until replacement of the solution at its end of life.

**Functional Unit** – a measurement unit that represents the value, provided to the world, of the function that the solution performs. This depends on the solution. Therefore, LED Lighting provides petalumen-hours of light, Biomass provides tera-watt-hours of electricity and high speed rail provides billions of passenger-km of mobility.

**Grid Emissions** – emissions caused by use of the electricity grid in supplying power to any operation associated with a solution. They should be in the units described below each variable entry cell. Drawdown models assume that the global electric grid, even in a Reference Scenario, is slowly getting cleaner, and that emissions factors fall over time resulting in lower grid emissions for the same electricity demand.

**Implementation Unit** – a measurement unit that represents how the solution practice or technology will be installed/setup and priced. The implementation unit depends on the solution. For instance, implementing electric vehicles (EV) is measured according to the number of actual EV’s in use, and adoption of Onshore Wind power is measured according to the total terawatts (TW) of capacity installed worldwide.

**Indirect Emissions** – emissions caused by the production or delivery or setup or establishment of the solution in a specified area. These are NOT caused by day to day operations or growth over time, but they should be entered into the model normalized on a per functional unit or per implementation unit basis.

**Learning Rate/Learning Curve** - Learning curves (sometimes called experience curves) are used to analyze a well-known and easily observed phenomenon: humans become increasingly efficient with experience. The first time a product is manufactured, or a service provided, costs are high, work is inefficient, quality is marginal, and time is wasted. As experienced is acquired, costs decline, efficiency and quality improve, and waste is reduced. The model has a tool for calculating how costs change due to learning. A 2% learning rate means that the cost of producing a *good* drops by 2% every time total production doubles.

**Lifetime Capacity** – this is the total average functional units that one implementation unit of the solution or conventional technology or practice can provide before replacement is needed. All technologies have an average lifetime usage potential, even considering regular maintenance. This is used to estimate the **Replacement Time**. and has a direct impact on the cost to install/acquire technologies/practices over time. E.g. solar panels generate, on average, a limited amount of electricity (in TWh) per installed capacity (in TW) before a new solar panel must be purchased. Electric vehicles can travel a limited number of passenger kilometers over its lifetime before needing to be replaced.

**Lifetime Operating Savings**–the operating cost in the PDS versus the REF scenarios over the lifetime of the implementation units purchased during the model period regardless of when their useful life ends.

**Lifetime Cashflow NPV**-the present value (PV) of the net cash flows (PDS versus REF) in each year of the model period (2015-2060). The net cash flows include net operating costs and first costs. There are two results in the model: Lifetime Cashflow NPV for a Single **Implementation Unit**, which refers to the installation of one **Implementation Unit**, and Lifetime Cashflow NPV of All Units, which refers to all **Implementation Units** installed in a particular scenario. These calculations are also available using profit inputs instead of operating costs.

**Marginal First Cost** – the difference between the **First Cost** of all units (solution and conventional) installed in the **PDS Scenario** and the **First Cost** of all units installed in the **REF Scenario** during the analysis period. No discounting is performed. The number of solution implementation units that are available to provide emissions reduction during the analysis period is dependent on the units installed prior to the analysis period, and hence all implementation units installed after the base year are included in the cumulative first costing (that is 2015-2050).

**Net Annual Functional Units (NAFU)** – the adoption in the PDS minus the adoption in the REF in each year of analysis. In the model, this represents the additional annual functional demand captured either by the solution in the **PDS Scenario** or the conventional in the **REF Scenario**.

**Net Annual Implementation Units (NAIU)** – the number of **Implementation Units** of the solution that are needed in the PDS to supply the **Net Annual Functional Units (NAFU).** This equals the adoption in the PDS minus the adoption in the REF in each year of analysis divided by the average annual use.

**Net Operating Savings** – The undiscounted difference between the operating cost of all units (solution and conventional) in the **PDS Scenario** minus that of all units in the **REF Scenario**.

**Operating Costs** – the average cost to ensure operation of an activity (conventional or solution) which is measured in 2014$US/**Functional Unit**. This is needed to estimate how much it would cost to achieve the adoption projected when compared to the **REF Case**. Note that this excludes **First Costs** for implementing the solution.

**Payback Period** – the number of years required to pay all the **First Costs** of the solution using **Net Operating Savings**. There are four specific metrics each with one of **Marginal First Costs** or **First Costs** of the solution only combined with either discounted or non-discounted values. All four are in the model. Additionally, the four outputs are calculated using the increased profit estimation instead of **Net Operating Savings**.

**PDS/ Project Ambitious Scenario** – this is the high growth scenario for adoption of the solution

**PPB/ Parts per Billion** – a measure of concentration for atmospheric gases. 10 million PPB = 1%.

**PPM/ Parts per Million** – a measure of concentration for atmospheric gases. 10 thousand PPM = 1%.

**REF/ Reference Scenario** – this is the low growth scenario for adoption of the solution against which all **PDS scenarios** are compared.

**Regrets solution** has a positive impact on overall carbon emissions being therefore considered in some scenarios; however, the social and environmental costs could be harmful and high.

**Replacement Time**- the length of time in years, from installation/acquisition/setup of the solution through usage until a new installation/acquisition/setup is required to replace the earlier one. This is calculated as the ratio of **Lifetime Capacity** and the **Average Annual Use**.

**TAM/ Total Addressable Market** – represents the total potential market of functional demand provided by the technologies and practices under investigation, adjusting for estimated economic and population growth. For this solutions sector, it represents world and regional total addressable markets for electricity generation technologies in which the solutions are considered.

**Total Emissions Reduction** – the sum of grid, fuel, indirect, and other direct emissions reductions over the analysis period. The emissions reduction of each of these is the difference between the emissions that would have resulted in the **REF Scenario** (from both solution and conventional) and the emissions that would result in the **PDS Scenario**. These may also be considered as “emissions avoided” as they may have occurred in the REF Scenario, but not in the PDS Scenario.

**Transition solutions** are considered till better technologies and less impactful are more cost effective and mature.

**TWh/ Terawatt-hour** – A unit of energy equal to 1 billion kilowatt-hours

1. This section should be populated once the other Ocean solutions are developed so that the comparison table can be developed. [↑](#footnote-ref-1)
2. For most results, only the differences between scenarios, summed over 2020-2050 were presented, but for the net first cost, the position was taken that to achieve the adoptions in 2020, growth must first happen from 2015 to 2020, and that growth comes at a cost which should be accounted for, hence net first cost results represent the period 2019-2050. [↑](#footnote-ref-2)
3. In some cases, the low boundary is negative for a variable that can only be positive, and in these cases the lowest collected data point is used as the “low” boundary. [↑](#footnote-ref-3)