**Technical assessment for**

**Coastal Wetlands Restoration**

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# Acronyms and Symbols Used

* EEZ – Exclusive Economic Zone
* GAEZ – Global Agro-Ecological Zones
* GHG – greenhouse gasses
* MCI – Marine Conservation Institute
* MPA – Marine Protected Area
* RSIS – Ramsar Sites Information Service
* UNEP-WCMC – United Nations Environment Programme- World Conservation Monitoring Centre

# Executive Summary

Project Drawdown defines *coastal wetlands restoration* as: “any process that aims to return a system to a pre-existing condition (whether or not this was pristine) (sensu Lewis, 1990c)” including both “natural restoration” or anthropogenic- led recovery (Lewis, 2005) of carbon-rich mangroves, seagrasses, and saltmarshes. This solution recovers coastal wetlands ecosystems capacity as carbon sinks.

Coastal wetlands significantly impact global carbon cycles and, unlike most terrestrial ecosystems, continue sequestering carbon for centuries without becoming saturated. As a result, they have accumulated vast stores of carbon, making their global significance high despite their small area. Coastal wetlands also provide important ecosystem services including coastal protection, erosion control, raw materials and food, water purification, maintenance and fisheries, tourism and carbon sequestration (Pendleton et al., 2012; Barbier et al., 2011).

These ecosystems are being replaced for other uses, including coastal development and agriculture, releasing their stored carbon and preventing future sequestration. The *coastal wetlands restoration* solution results in mitigation impacts via biosequestration.

In the *Plausible* Scenario, 6.07 million hectares are restored. Climate impact is 0.761 gigatons of carbon dioxide equivalent.

In the *Drawdown* Scenario, 7.21 million hectares come under protection. Climate impact is 1.005 gigatons of carbon dioxide equivalent.

In the *Optimum* Scenario, 7.32 million hectares come under protection. Climate impact is 1.129 gigatons of carbon dioxide equivalent.

Financials are not modeled.

# Literature Review

## State of the Practice

Coastal wetlands comprise three ecosystems: mangroves, saltmarshes and seagrasses. These ecosystems cover an area of around 50 Mha and provide a wide range of ecosystem services including coastal protection, erosion control, raw materials and food, water purification, maintenance and fisheries, tourism and carbon sequestration (Pendleton et al., 2012; Barbier et al., 2011).

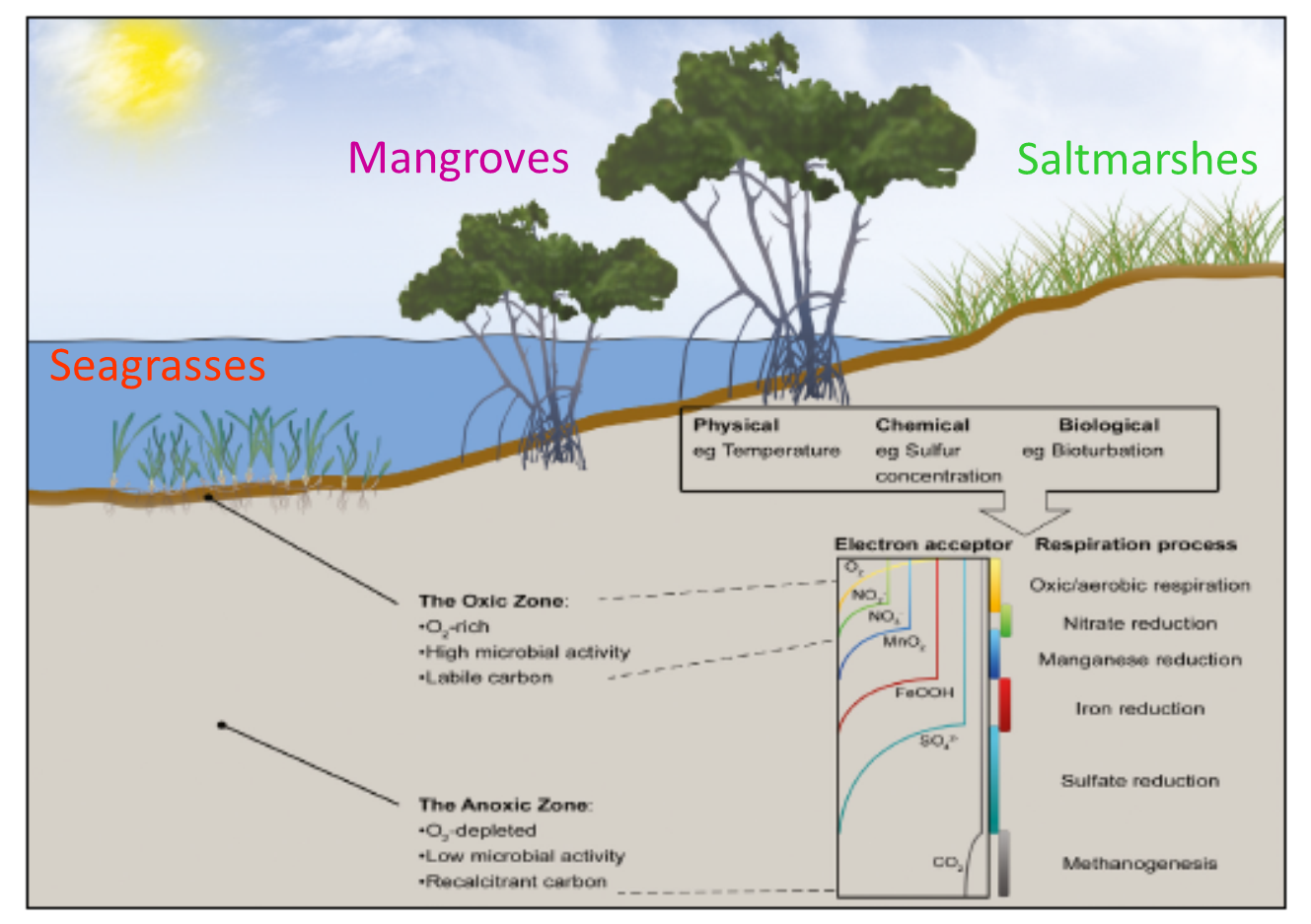


Figure 1‑1 Key factors in coastal wetlands sequestration.

*Source: Macreadie et al. (2017)*

The carbon sequestration in vegetated coastal ecosystems – also referred to as “blue carbon”- occurs at different levels: “within their underlying sediments, within living biomass aboveground (leaves, stems, branches) and belowground (roots), and within non-living biomass (e.g. litter and dead wood)” with timeframes ranging from decades in biomass and longer (millennial) in sediments (Duarte et al. 2005; Lo Iacono et al. 2008; Mc Leod et al., 2011). Despite an area extension of one to two orders of magnitude lower than terrestrial forest types, their contribution to long- term carbon sequestration is comparable given “the higher rate of organic C sequestration in sediments” (Mc Leod et al., 2011). In addition, they account for almost half (46.7 percent) of “total carbon burial in ocean sediments” (Duarte et al., 2005; Nellemann et al., 2009; Duarte et al., 2013).

The loss of approximately half of coastal wetlands due to “anthropogenic activities, including direct impacts (such as dredging, harvesting, filling, dyking, and draining) and indirect impacts via climate change (such as sea-level rise and extreme weather events)” (Macreadie et al., 2017) has resulted in the release of “ancient carbon” (Macreadie et al. 2013, 2015; Lovelock et al., 2017). Given the state of degradation and the crucial role coastal wetlands play in climate change adaptation and mitigation, restoring these ecosystems is crucial. The following sub-sections address each ecosystem separately focusing on the state of degradation, restoration techniques and restoration success measurements.

**Mangroves**

Mangrove forests are located in saline tidal areas in tropical and sub- tropical regions, comprise 50- 75 different species and their production rates are similar to tropical forests (Barbier et al., 2011; Pendleton et al., 2012; Alongi et al., 2012).

Global mangrove area has decreased considerably in the past decades: from 19.8 Mha in 1980, to 16.4 Mha in 1990 and 14.7 Mha in 2000 down to 13.6 Mha in 2010 (FAO, 2003; Giri et al., 2011 and Bunting et al., 2018). Around 25 percent of losses have been due to anthropogenic activities, mainly due to agriculture, aquaculture and urban land conversion (Barbier and Cox, 2003; Duke et al., 2007; Friess and Webb, 2014; Spalding et al., 2010; Barbier et al., 2016). Approximately half (47 percent) of the current global mangrove extent is concentrated in five countries: Indonesia, Brazil, Australia, Mexico and Nigeria (Bunting et al., 2018).

A study on the drivers of mangrove forest change between 1996 and 2010 concluded that losses and degradation were mainly concentrated in Southeast Asia, a region with widespread aquaculture practices (Thomas et al., 2017). In addition, at the global level, 37.8perent of the tiles analyzed showed anthropogenic impact including as a result of activity prior to 1996 (Thomas et al., 2017). Mangrove restoration for coastal defense purposes has been a response to several cyclone and tsunami events in Asia since at least the 1960s (Marois and Mitsch, 2015; Balke and Friess, 2015).

We define restoration as “any process that aims to return a system to a pre-existing condition (whether or not this was pristine) (sensu Lewis, 1990c)” including both “natural restoration” or anthropogenic- led recovery (Lewis, 2005). Natural regeneration can occur over “15–30 years if: (1) the normal tidal hydrology has not been disrupted and (2) the availability of waterborne seeds or seedlings (propagules) of mangroves from adjacent stands is not limited or blocked (Lewis, 1982a; Cintron-Molero, 1992; Field, 1998).” (Lewis, 2005).

The total restorable area in our analysis results from the Mangrove Restoration Potential Map - a joint effort by The Nature Conservancy, IUCN and the University of Cambridge- which excludes land “converted to urban uses and areas that have become, through erosion or inundation, non- tidal open water” (Worthington and Spalding, 2018). The analysis is based on the area loss between 1996 and 2016 and hence could be an underestimation. Unlike Kodikara et al. (2017), it is not “irrespective of previous existence of mangroves in particular site” like planting mangroves in mudflats. The latter would be considered habitat conversion and it is outside the scope of our analysis.

According to Lewis and Marshall (1997), successful mangrove restoration entails five steps:

1. “Understand the autecology (individual species ecology) of the mangrove species at the site, in particular the patterns of reproduction, propagule distribution and successful seedling establishment.
2. Understand the normal hydrologic patterns that control the distribution and successful establishment and growth of targeted mangrove species.
3. Assess the modifications of the previous mangrove environment that occurred that currently prevents natural secondary succession.
4. Design the restoration program to initially restore the appropriate hydrology and utilize natural volunteer mangrove propagule recruitment for plant establishment.
5. Only utilize actual planting of propagules, collected seedlings or cultivated seedlings after determining through Steps 1–4 that natural recruitment will not provide the quantity of successfully established seedlings, rate of stabilization or rate of growth of saplings established as goals for the restoration project.” (Lewis, 2005).

Lewis (2005) further stresses that omitting steps 1 to 4 and jumping straight to step 5 – the “gardening approach”- explains the failure in most restoration projects. In addition, Lewis and Gilmore (2007) state that “The typical “mangrove restoration” project aimed at establishing a monospecific stand of planted Rhizophora spp. fails to restore the freshwater-marine salinity gradient and plant biodiversity characteristic of intact mangrove ecosystems.” Balke and Friess (2015) suggest coupling Lewis’s “Ecological mangrove restoration” with geomorphic knowledge to restoration planning in order to increase its success.

A more recent study by Worthington and Spalding (2018) defines mangrove restoration as “strategic, fundable and achievable” and stresses that the refinement in restoration methods over the years combined with a proper application seldomly result in failure. Critical to restoration success is to “ensure that the location is restored in terms of elevation and water flows and that the social and political framework is secure against those impacts that caused their original loss, with clear ownership and regulations for the restoration locations” together with long- term monitoring and site management (Worthington and Spalding, 2018). The lack or limited monitoring often results in uncertainty regarding the restoration program’s success (Salmo III et al., 2013).

The benefits from mangrove restoration range from flooding and erosion control to carbon sequestration and sediment surface elevation enhancement (McKee, 2011; Salmo III et al., 2013; Worthington and Spalding, 2018). It should be noted that some of these benefits are not immediate; for instance: “it may take 10 years or more for the mangroves to start providing the dense protective barrier they once did.” (Worthington and Spalding, 2018).

One of the key parameters to measure restoration success is the “the rate at which the forest structure and biomass return to those of mature, natural mangroves (cf. Ellison, 2000)” (Salmo III et al., 2013). The insight from the literature review conducted on the time it takes for the restored mangroves to reach maturity is around 20- 25 years (Lugo and Snedaker 1974; Odum 1975; Colonello & Medina, 1998; Twilley et al., 1998; McKee & Faulkner, 2000; Salmo et al., 2013). The study by Salmo III et al. (2013) concluded that AGB recovery takes 10- 12 years in planted mangroves whereas soils take around 20- 25 years to reach a maturity level similar to natural forests. On the other hand, natural succession occurs “over periods of 15–30 years if hydrology has not been disrupted and supply of natural propagules is provided (Field 1998, Lewis 2005)” (Bayraktarov et al., 2016).

Worthington and Spalding (2018)’s database reports a survival rate of mangroves ranging from 60- 90 percent after a decade with much lower rates reported on larger programmes excluded from their database. They further stress on the limited availability of information regarding the success/ failure of restoration projects. The main reasons for mangrove restoration failure include: “poor planning, a desire for a rapid fix, or a lack of ecological understanding have led to restoration in the wrong locations, or planting with the wrong species” (Worthington and Spalding, 2018) together with “a lack of community involvement also led to failure of mangrove restoration efforts as people damaged restoration sites (e.g., trampling by local fishermen)” Bayraktarov et al. (2016). Luckily, the Global Mangrove Alliance provides support in research, advocacy, education and practical projects on the ground in mangroves restoration worldwide to ensure restoration efforts are optimized and customized to local conditions (Spalding & Leal, 2021).

**Saltmarshes**

Saltmarshes spread throughout the globe with a greater concentration in temperate regions. These ecosystems “are characterized by sharp zonation of plants and low species diversity, but extremely high primary and secondary production” (Barbier et al., 2011). Categorized as one of the “most productive ecosystems in the world” due to the “anoxic nature of the marsh soils (as in most wetlands), carbon sequestered by salt marsh plants during photosynthesis is often shifted from the short-term carbon cycle (10–100 years) to the long-term carbon cycle (1000 years) as buried, slowly decaying biomass in the form of peat (Mitsch and Gosselink 2008, Mayor and Hicks 2009)” (Barbier et al., 2011). Unlike freshwater wetlands, “The presence of sulfate in tidal salt marshes hinders methane production and emissions of N2O to almost negligible levels and as such, tidal wetlands have a greater net positive effect in terms of global warming potential than fresh water systems (Peteet et al., 2006; Smith and Patrick, 1983; DeLaune et al., 1990).” Artigas et al. (2014)

Global saltmarshes extension is 5.5 Mha, of which 1.9 Mha (34%) is located in the USA, 1.3 Mha (24%) in Australia, 0.7 Mha (13%) in Russia and 0.5 Mha (10%) in China (Mc Owen, 2017). Saltmarshes ecosystems have been subject to considerable degradation: “Approximately 50% of saltmarsh has been degraded or even lost worldwide [Barbier et al. (2011)] with a further 30–40% loss expected over the next 100 years [Pendleton et al. (2012)]” (Burden et al., 2019). Saltmarshes losses have been due to drainage for agriculture (Bromberg-Gedan et al. 2009; Bayrakratov et al., 2016; Burden et al., 2019), urban land conversion (French, 1997; Burden et al., 2013), coastal eutrophication (Deegan et al., 2012; Bayraktarov et al., 2016) as well as replaced by mangrove forests (Rogers et al. 2005, Saintilan et al. 2014; Bayraktarov et al. 2016). In addition, current anthropogenic threats to these ecosystems include: “biological invasions, eutrophication, climate change and sea level rise, increasing air and sea surface temperatures, increasing CO2 concentrations, altered hydrologic regimes, marsh reclamation, vegetation disturbance, and pollution (Silliman et al. 2009)” (Barbier et al., 2011).

The primary technique used for saltmarshes restoration is “managed realignment” which is defined as “the landward retreat of coastal defenses and subsequent tidal inundation of previously reclaimed agricultural land.” (Garbutt et al., 2006 Burden et al., 2019). With “relatively minimal pre-treatment and/or management of the area”, this technique “will quickly produce intertidal mudflats that are colonised by saltmarsh plants (French et al., 2000; Wolters et al., 2005)” (Burden et al., 2013).

Bayraktarov et al. (2016)’s review on saltmarshes restoration projects identified a higher survival rate for locally collected native as opposed to imported species. The also stressed that “planted saltmarsh seedlings were particularly sensitive to multiple stressors including high salinity, sediment deposition, algal smothering, and animal activity” (Bayraktarov et al., 2016). Regarding the time for restored sites to reach soil maturity similar to natural saltmarshes, studies range from 65 (Burden et al., 2013) to 100 years (Craft et al., 2003; Burden et al., 2019).

**Seagrasses**

Seagrasses are angiosperms (flowering plants) which grow underwater to “depths where +/- 11% of surface light reaches the bottom (Duarte 1991)” (Barbier et al., 2011). These ecosystems sequester carbon dissolved in the seawater - CO2 and HCO3- -which ends up buried as sediment once the plants decay (Barbier et al., 2011).

Global seagrasses extension is 32.4 Mha - from the tropics to the polar regions - with Australia, Saudi Arabia, Indonesia, Guinea- Bissau and the Philippines being the top five countries with the greatest coverage (totaling 34 percent combined) (UNEP- WCMC and Short, 2018). Global estimation of degraded seagrasses area is very limited. Waycott et al. (2019) estimated that 29 percent of seagrasses area had been lost between 1879- 2006. However, recent reversal trend of seagrass decline has been noted in Europe and linked to improved water quality thanks to implementation of Water Framework Directive (de los Santos et al., 2019).

The decline in seagrasses includes anthropogenic drivers such as: “eutrophication, overharvesting, sediment runoff, algal blooms, commercial fisheries and aquaculture practices, vegetation disturbance, global warming, and sea level rise” (Orth et al. 2006; Waycott et al. 2009; Barbier et al. 2011). Given that “detritus burial from vegetated coastal habitats contributes about half of the total carbon burial in the ocean (Duarte et al. 2005)” and that “loss of seagrass triggers the erosion of historic carbon deposits and that revegetation effectively restores seagrass carbon sequestration capacity” (Marba et al., 2015), protecting and restoring seagrasses are valuable strategies for climate change mitigation.

The range of techniques which result in highest survival rates include: “transplantation of seagrass seedlings, sprigs, shoots, or rhizomes (57 percent of all observations on survival), transplantation of aquacultured seagrass (11 percent of all observations on survival), deployment of Hessian bags (11 percent of all observations on survival), and transplanting seagrass cores or plugs (10 percent of all observations on survival)” (Bayraktarov et al., 2016). Marba et al. (2015) estimated that the recovery rate of restored seagrasses to carbon sinks is similar to restored mangrove forests, around 20 years. In addition, there are several factors which influence restoration failure. These include site location (preferably no “high wave energy locations” or “sites with high levels of sediment movement and erosion”), type of transplant, marine contamination, poor water quality, thermal stress and trawling activities (Bayraktarov et al., 2016).

## Adoption Path

### Current Adoption

The data availability of restored coastal wetlands area is very scattered, and the literature review resulted in one global estimate for restored mangroves only. Worthington and Spalding (2018) recorded 0.2 Mha of restored mangroves based on their review of over 160 restoration initiatives in 24 countries over the last 40 years with 0.12 Mha located in South Asia (Bangladesh and Vietnam concentrate the most extensive areas). However, not all projects record exact area, nor do they include enough information to determine the success/ failure of the restoration effort. For this reason, and to ensure consistency with other restoration solutions, the current adoption for the three ecosystems was set as zero.

### Trends to Accelerate Adoption

Policy initiatives at the government level, especially those with a longer- term frame, are crucial for driving coastal wetlands restoration plans as well as increasing access to funding. As a result of the UN Framework Convention on Climate Change (UNFCCC)’s Paris Agreement, Parties need to set Nationally Determined Contributions (NDCs) outlining “post-2020 mitigation actions and targets” (Worthington and Spalding, 2018). However, quantitative restoration targets on coastal wetlands restoration are scarce. At present, the most significant ones are for mangroves (InfoFLR, 2018source):

1. Guatemala: its National Restoration Strategy aims to restore 10,000 hectares on mangroves between 2015 and 2045;
2. Madagascar: its Intended Nationally Determined Contribution includes a commitment to restore 55,000 hectares of mangroves and forests by 2030 without spreading the commitment between them.

There are other initiatives which are relevant to this solution. Despite they do not contain specific restoration targets, these could be drivers for national policies. These include:

1. UN Decade for Ecosystem Restoration (2021- 2030): declared in March 2019 by the UN General Assembly and led by UNEP and FAO, it “aims to massively scale up the restoration of degraded and destroyed ecosystems as a proven measure to fight the climate crisis and enhance food security, water supply and biodiversity” accelerating other initiatives such as the Bonn Challenge (UNEP, 2019). Building up on this, the International Organization Partners to the Ramsar Convention[[1]](#footnote-1) called for a “specific programme on Wetland Restoration” under this initiative in an Open letter.
2. The Ramsar Convention on Wetlands of International Importance especially as Waterfowl Habitat (Ramsar Convention)
3. High Level Panel for Sustainable Ocean Economy – in 2020 14 countries has put forward an agenda to sustainable manage 100 percent of their national waters and specifically focus on restoring blue carbon ecosystems
4. Sustainable Development Goals
5. Other initiatives: including Global Mangrove Alliance

Romañach et al. (2018)’s review on the global status of mangroves conservation and restoration stress that government policies need to be coupled with local commitment to ensure success. They further highlight co- management with local communities, academic institutions and NGOs as a valuable approach to coastal resource management (Romañach et al., 2018). Worthington and Spalding (2018) further stress on this, as mangrove restoration “can be greatly hampered if local land tenure is not understood and respected. Community engagement and support can ensure long-term security for restoration projects. Equitable benefit-sharing can prevent further degradation and provide an example which, in turn, leverages further restoration efforts.”

### Barriers to Adoption

Successful restoration depends both on planning and sufficient funding. Competing restoration initiatives of similar ecosystems could present a barrier to adoption. For instance, Madagascar’s Intended Nationally Determined Contribution includes a commitment to restore 55,000 hectares of mangroves and forests by 2030 without spreading the commitment between them. Depending on both alternatives’ costs, ecosystem services valuation as well as post- restoration monitored efforts required, forest restoration could outperform mangrove restoration whilst meeting Madagascar’s INDC.

Asides from a lack of community engagement in restoration efforts, other threats to successful restoration include inappropriate planning, invasive species, increase in salinity of waters, increase in human population density in coastal regions (Romañach et al., 2018).

For mangrove restoration in particular, “from the ecological point of view, ignorance of the major ecological drivers of mangrove health such as requirements for salinity, hydrology, and appropriate species composition were the main causes for mangrove restoration failure (Elster 2000; Primavera & Esteban 2008; Ahmad 2012)” Kodikara et al. (2017). From a governance perspective, “the lack of coordination between institutions implementing restoration projects, e.g. Forest Department and Coastal Conservation Department, was observed in our study sites and is also reportedly one of the major causes for mangrove restoration failure in Sri Lanka (Primavera & Esteban 2008; IUCN 2009; Mangora 2011).” Kodikara et al. (2017).

### Adoption Potential

Given the importance of coastal wetlands, increasing awareness and restoration efforts worldwide (Spalding & Leal, 2021), we assume that the adoption potential can reach 100% of TLA in one the Custom PDS adoption scenarios described below.

## Advantages and disadvantages of Coastal Wetlands Protection

### Similar Solutions

Some key issues include:

* There might be a potential competition for funding sources with other restoration solutions such as *Tropical forest restoration* in the case of mangroves and *peatlands* in the case of saltmarshes.
* Interconnectedness with other solutions: for instance, coastal protection from mangroves depends not only depend on the ecosystem’s characteristics but also on whether seagrasses, coral reefs and dunes are present (Alongi, 2008; Barbier et al., 2016).
* Competing land/ ocean uses with aquaculture solutions: “sustainable eco-farming aquaculture practices within mangrove forests” and shrimp farming and mangrove conservation coexistence are worth exploring (Romañach et al., 2018).

### Arguments for Adoption

The solution will lead to the enhancement/ restoration of the ecosystem services from coastal wetlands including coastal protection, erosion control, raw materials and food, water purification, maintenance and fisheries, tourism and carbon sequestration (Pendleton et al., 2012; Barbier et al., 2011). Restoration of coastal wetlands will bring back natural habitats important to many marine and terrestrial species leading to biodiversity protection and enhancement (Spalding & Leal, 2021). Therefore, the socio-economic benefits of coastal wetlands restoration are wide.

### Additional Benefits and Burdens

Here this solution is compared with other solutions in the ocean sector in terms of ecosystem, social and climate impact. *Coastal wetlands restoration* represents intermediate climate impact within all ocean solutions with high adoption potential and intermediate social benefits.

Table . Ocean Solutions Comparison.

**Ecosystem Services** is subjective based on impacts on biodiversity, habitat restoration, protection from extreme weather events etc. **Social Justice Benefits:** If a solution is causing a 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, the middle between 100 and 400, high < 400; TAM is applicable for only two solutions Improve Fishery and Improve Aquaculture therefore direct comparison with other ocean solutions is not possible, however, both solutions represent 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 aquaculture | 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 Aquaculture | 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 |

**Ecosystem Services** is subjective based on impacts on biodiversity, water quality, etc. **Social Justice Benefits:** Is solution Targeted to disadvantaged producers like smallholders and women, Relevant to them, or Not Applicable (n/a). **Climate Impacts per Hectare:** Low 0-3.7 t CO2-eq/ha/yr (0-1tC),Medium 3.8-11.0 t CO2-eq/yr (1-3 tC), High 11.1+ tCO2-eq/yr (3+tC). **Global Adoption Potential:** Low 0-100Mha, Medium 101-500 Mha, High 500+ Mha

# 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 Land 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 a conventional practice. These practices are assumed to use land of a specific type that may be shared across several solutions. The actual and maximum possible adoptions are therefore defined in terms of land area (million hectares). The adoptions of both conventional and solution were projected for each of several Drawdown scenarios from 2015 to 2060 (from a base year of 2014) 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

Key data sources include Worthington and Spalding (2018) - used for estimating the mangrove restoration TLA, Waycott et al. (2009) – used for estimating the seagrasses restoration TLA, McOwen et al. (2017), Dahl (2006; 2010) which were used to estimate saltmarshes restoration TLA.

## Total Available Land

Total land allocated for the *coastal wetlands´ restoration* solution is 7.32 million hectares: 0.81 Mha for mangroves, 5.1 Mha for seagrasses and 1.4 Mha for saltmarshes.

* Mangroves: The total restorable land area available for mangroves excludes areas converted to urban landscapes as well as “areas that have become, through erosion or inundation, non- tidal waters” (Worthington and Spalding, 2018). It should be noted that this figure is based on loss of mangroves’ area from 1996 onwards which means that this figure is a lower- bound estimate given that losses prior to 1996 could be restorable (Worthington and Spalding, 2018).
* Seagrasses: the total restorable area for seagrasses restoration results from Waycott et al. (2009)’s estimation of global seagrasses area loss between 1879 and 2006.
* Saltmarshes: The degraded saltmarshes area resulting from the literature review is quite limited and the TLA calculation is based on figures for the USA. The rationale is the following: the USA saltmarshes area is 1.88 Mha, which represents 34% of global saltmarshes area (5.5 Mha) based on McOwen et al. (2017). According to Dahl (2006), the loss of saltmarshes area in the USA totaled 13,450 ha between 1998- 2004. According to Dahl (2010), the loss of saltmarshes area in the USA totaled 45,140 ha between 2004- 2009 (4.5 years of analysis) with less than 1% resulting from conversion to urban uses. Based on this data, four TLA's were created and its average used as the TLA in the model (1.4 Mha):
* TLA 1 results from applying the yearly loss (in ha) of USA saltmarshes area from Dahl (2006) to a period of 127 years and scaling up that figure to a world level.
* TLA 2 results from applying the yearly loss (in ha) of USA saltmarshes area from Dahl (2009) to a period of 127 years and scaling up that figure to a world level.
* TLA 3 results from applying the yearly loss (in ha) of USA saltmarshes area from Dahl (2006) to a period of 30 years and scaling up that figure to a world level.
* TLA 4 results from applying the yearly loss (in ha) of USA saltmarshes area from Dahl (2009) to a period of 30 years and scaling up that figure to a world level.

NOTE: 127 years corresponds to the analysis period of degraded seagrasses area included in Waycott (2009) which was used as the model's TLA. 30 years is the analysis period of our research.

It is assumed that once the coastal wetland area is restored, it is no longer subject to further degradation which means that 100% of 2014 TLA can be achieved in 2050.

## 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.

Six custom adoption scenarios were developed for *coastal wetlands restoration*. Given the differences in climate inputs and TLAs, each ecosystem was modelled independently but the PDS scenarios are equal in all of them. However, as these are based on % commitments and applied to different TLAs, they result on different adoption areas.

The scenarios were developed based on two policies:

1. Guatemala’s National Restoration Strategy which aims to restore 10,000 hectares on mangroves between 2015 and 2045;
2. Green India Mission which included a commitment to restore 100,000 hectares of mangroves between 2010 and 2020.

The details on the six custom adoption scenarios are given below:

1. ***Custom adoption scenario one***: The National Mission for a Green India included a commitment to restore 0.1 Mha of mangroves in 10 years (up to 2020). We assume that this commitment will be replicated in the next three decades resulting in 300,000 hectares to be restored by 2050. This would represent a restoration of 87% of mangrove area in India. We apply this % to the global mangrove area.
2. ***Custom adoption scenario two***: Guatemala's NDC includes the restoration of 10,000 ha of mangroves by 2045. This would represent 38% of total mangrove area in the country. We use the average of both India (87%) and Guatemala (38 %) and apply them to the TLA (62%).
3. ***Custom adoption scenario three***: Scenario 1 assuming 100% of adoption is reached in 2030
4. ***Custom adoption scenario four***: Scenario 2 assuming 100% of adoption is reached in 2030
5. ***Custom adoption scenario five***: linear increase to 100% TLA by 2050
6. ***Custom adoption scenario six***: linear increase to 100% TLA by 2030

### Reference Case / Current Adoption

Current adoption of *coastal wetlands restoration* is estimated at zero million hectares (as detailed on section 1.2.1.). Despite several restoration projects have been on- going for several years, specific figures on complete global coastal wetlands restoration area are very scarce. In addition, this is consistent with the approach in other restoration solutions.

### Project Drawdown Scenarios

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

#### Plausible Scenario - This scenario derives the result from the "average of all" PDS custom adoption scenarios.

#### Drawdown Scenario – This scenario derives the result from the "high of all" PDS custom adoption scenarios.

#### Optimum Scenario - This scenario presents the result of the "100 TLA by 2030" PDS custom adoption scenario.

## Inputs

### Climate Inputs

The climate inputs used for this solution correspond to sequestration rates only. The studies used do not measure the emissions of the land before restoration occurred and, hence, avoided emissions could not be included.

Table . Climate Inputs

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Biosequestration from mangroves | *tC/ha/yr* |  | 6.581 | AGB+ BGC |  |
| Biosequestration from mangroves (AGB) | *tC/ha/yr* | 1.404-6.578 | 3.991 | 17 | 10 |
| Biosequestration from mangroves (BGC) | *tC/ha/yr* | 1.181- 3.998 | 2.590 | 11 | 3 |
| Biosequestration from saltmarshes | *tC/ha/yr* | 0.430- 1.427 | 0.929 | 9 | 6 |
| Biosequestration from seagrass | *tC/ha/yr* | -0.319- 2.313 | 0.997 | 12 | 4 |

Table . Climate Inputs

Note: Project Drawdown’s 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).

Note 2: The climate benefits do not include aqueous carbon potential long- term sequestration as this solution was developed using the Land Use BIOSEQ model. It might be worth conducting a literature review on new research (e.g.: Duarte and Krause- Jensen, 2017 paper on seagrasses sequestration budget) to decide whether long- term sequestration from aqueous carbon could be included into the solution and, if so, modify accordingly.

*Modeling Saturation*

Biosequestration does not have limitless potential. In most cases, there is a maximum amount of carbon that can be stored in soils and aboveground perennial biomass before they become saturated. Biosequestration continues after saturation but is offset by more or less equal emissions. In most cases soils, and biomass can return to their approximate pre-agricultural or pre-degradation levels of carbon. This takes anywhere between 10-50 years in agricultural cases, and sometimes somewhat longer in the case of ecosystems like forests. Data about saturation time is very limited.

The Drawdown land model takes the conservative approach that all land units currently adopted for agricultural solutions (including multistrata agroforestry) have already achieved saturation and will not be contributing additional sequestration. New adopted land is assumed to sequester for at least 30 years before achieving saturation. Note that there are some important exceptions to saturation. Certain ecosystems continue to sequester soil carbon for centuries, notably peatlands and coastal wetlands. Some scientists argue that tropical forests can continue to sequester carbon at a slower rate after saturation. The addition of biochar to saturated soils may be able to overcome this constraint, as does the use of biomass from bamboo or afforestation in long-term products like buildings.

Coastal wetlands are an exception to saturation because they can continue to accumulate soil and carbon as sea level rises (Laffoley & Grimsditch, 2009) and wetlands have been shown to be capable of generating exceptionally deep (10 m), carbon rich soils over hundreds of years (Brevik & Homburg, 2004; McKee et al., 2007). Furthermore, vertical carbon gradients within wetland soils are close to uniform so the older, deep soil is just as carbon-rich as the younger, shallower soil (Nahlik & Fennessy, 2016) suggesting continual sequestration potential. The Drawdown model assumes sequestration continues indefinitely for both current and future adoption areas.

### Financial Inputs

It is assumed that any costs for *coastal wetlands restoration* (e.g. carbon payments or payment for ecosystem services) are borne at a government or NGO level. Drawdown land solutions only model costs that are incurred at the landowner or manager level.

Bayraktarov et al. (2016)’s review on a synthesis of 235 studies on marine coastal restoration projects concluded that “The median and average of restoration cost for all ecosystems was around US$80 000/ ha and US$1 600 000/ha, respectively” with mangrove restoration projects identified as the least expensive per hectare, coral reefs and seagrasses were the most expensive and saltmarshes the least cost- effective.

The review only included studies from developing countries for seagrass, saltmarshes and oyster reef ecosystems due to data availability constraints. This could have a considerable impact on results considering that “Total restoration costs for projects in developing countries were almost half as expensive for coral reefs and 30 times less for mangroves compared to costs in developed countries when accounting for economic conversion based on the countries’ inflation” (Bayraktarov et al., 2016).

The review highlights that “most funding for restoration was provided by government, mostly financing small-scale research projects. The next most abundant projects were financed partly by government and a non-governmental organization (NGO; Appendix S1: Table S6).” Bayraktarov et al. (2016)

## 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 are 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 modeling of this specific solution. These are detailed below. Coastal wetland degradation will continue with the current rate of degradation under the conventional case and either the current rate of degradation or a reduced rate of degradation will apply to the solution case.

1. Efforts will be made at the national and international level to restore coastal wetlands on an urgency basis, considering their role in carbon sequestration.
2. The leakage effect can be accounted for by delaying the carbon benefits of restoring coastal wetlands by one year. The leakage effect is defined as “the unanticipated decrease or increase in GHG benefits outside of the project's accounting boundary” (IPCC, 2013). For example, protecting a wetland may displace wetland disturbance activities to another location. The leakage related degradation is a time bound phenomenon and will stabilize after some time; here we assume that time scale is one year.
3. It is assumed that the re-growth of the degraded coastal wetland area will start one year after the coastal wetlands will be brought under restoration.
4. It is assumed that the required agency level legalities to bring a coastal wetland under restoration will be in place by the year of adoption. Thus, there will be no delay in the climate benefits as a result of delay in agency level efforts to bring a coastal wetland area under restoration. The "year of restoration" is assumed to be the "year of implementation".

## Integration

This is not yet developed for the ocean sector.

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.

*Improve aquaculture* 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.



Figure 2‑1 Project Drawdown Ocean model zones.

## Limitations/Further Development

Currently a limitation of this study is the lack of financial data. In addition, the models and report are based on actual data from restoration projects. The potential impacts from climate change (though acknowledged in relevant sections) are not modelled. Given the potential risk that sea level rise poses to coastal wetlands, incorporating this in the near future could be a valuable addition.

## 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. Improve 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

*Fig. 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. In Table 3.1, the percentages of the new adoption up to 2050 of the total land available are presented for each wetland type and then aggregated over all three wetland types.

Total adoption in the *Plausible* Scenario is 6.07 million hectares in 2050, representing 83% of the total land available. Of this, 5.38 million hectares are adopted from 2020-2050.

Total adoption in the *Drawdown* Scenario is 7.21 million hectares in 2050, representing 98.5% of the total suitable land. Of this, 6.17 million hectares are adopted from 2020-2050.

Total adoption in the *Optimum* Scenario is 7.32 million hectares in 2050, representing 100% of the total suitable land. Of this, 6.1 million hectares are adopted from 2020-2050.

| **Solution** | **Units** | **Base Year (2014)** | **New Adoption 2020- 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Drawdown** | **Optimum** |
| Mangrove forest restoration | Mha | 0 | 0.6 | 0.68 | 0.68 |
| % TLA | 0 | 73.5 | 84.3 | 83.3 |
| Seagrass meadow restoration | Mha | 0 | 3.75 | 4.3 | 4.25 |
| % TLA | 0 | 73.5 | 84.3 | 83.3 |
| Saltmarshes restoration | Mha | 0 | 1.03 | 1.18 | 1.17 |
| % TLA | 0 | 73.5 | 84.3 | 83.3 |
| All Coastal Wetlands’ restoration | Mha | 0 | 5.38 | 6.17 | 6.1 |
| % Total Land Available | 0 | 73.5 | 84.3 | 83.3 |

Table . World Adoption of the Solution

Figure 3‑1 World Annual Adoption 2020-2050

## Climate Impacts

Below are the emissions results of the analysis for each scenario which include biosequestration. Total impact is 0.761, 1.005, and 1.129 gigatons of carbon-dioxide equivalent in the *Plausible, Drawdown,* and *Optimum* Scenarios respectively in the period 2020-2050. Mangrove forests and seagrasses make the greatest contributions.

| **Scenario** | **Max Annual CO2 Sequestered** | **Total Additional CO2 Sequestered** | **Total Atmospheric CO2-eq Reduction** |
| --- | --- | --- | --- |
| *(Gt CO2-eq/yr.)* | *Gt CO2-eq/yr. (2020-2050)* | Gt CO2-eq (2020-2050) |
| *Plausible Mangroves* | 0.016 | 0.347 | 0.347 |
| *Plausible Seagrasses* | 0.015 | 0.330 | 0.330 |
| *Plausible Salt Marsh* | 0.004 | 0.085 | 0.085 |
| ***Plausible Total*** | **0.036** | **0.761** | **0.761** |
| *Drawdown Mangroves* | 0.019 | 0.458 | 0.458 |
| *Drawdown Seagrasses* | 0.018 | 0.435 | 0.435 |
| *Drawdown Salt Marsh* | 0.005 | 0.112 | 0.112 |
| ***Drawdown Total*** | **0.042** | **1.005** | **1.005** |
| *Optimum Mangroves* | 0.020 | 0.514 | 0.514 |
| *Optimum Seagrasses* | 0.019 | 0.489 | 0.489 |
| *Optimum Salt Marsh* | 0.005 | 0.126 | 0.126 |
| ***Optimum Total*** | **0.043** | **1.129** | **1.129** |

Table . Climate Impacts

The solution when integrated with all other Project Drawdown solutions may have different climate results from the models. This is due to adjustments caused by interactions among solutions that limit full adoption (such as by feedstock or demand limits) or that limit the full benefit of some solutions (such as reduced individual solution impact when technologies are combined).

| **Scenario** | **GHG Concentration Change in 2050** | **GHG Concentration Rate of Change in 2050** |
| --- | --- | --- |
| *PPM CO2-eq (2050)* | *PPM CO2-eq change from 2049-2050* |
| Mangroves Plausible | 0.0286 | 0.0012 |
| Seagrasses Plausible | 0.0272 | 0.0011 |
| Salt Marsh Plausible | 0.0070 | 0.0003 |
| **All Plausible** | **0.0627** | **0.0026** |
| Mangroves Drawdown | 0.0373 | 0.0013 |
| Seagrasses Drawdown | 0.0355 | 0.0013 |
| Salt Marsh Drawdown | 0.0091 | 0.0003 |
| **All Drawdown** | **0.0818** | **0.0029** |
| Mangroves Optimum | 0.0416 | 0.0013 |
| Seagrasses Optimum | 0.0396 | 0.0012 |
| Salt Marsh Optimum | 0.0102 | 0.0003 |
| **All Optimum** | **0.0914** | **0.0028** |

Table . Impacts on Atmospheric Concentrations of CO2-eq

Figure 3‑2 World AnnualBiosequestration

## Financial Impacts

At present, no financial analysis is included.

| **Scenario** | **Cumulative First Cost** | **Marginal First Cost** | **Net Operating Savings** | **Net Profit Margin** | **Lifetime Profit Margin** | **Lifetime Cashflow Savings NPV (of All Implementation Units)** |
| --- | --- | --- | --- | --- | --- | --- |
| *2015-2050 Billion USD* | *2015-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *Billion USD* |
| **Plausible** | $ | $ | $ | $ | $ | $ |
| **Drawdown** | $ | $ | $ | $ | $ | $ |
| **Optimum** | $ | $ | $ | $ | $ | $ |

Table . Financial Impacts

# Discussion

## Limitations

Inclusion of economic impacts, e.g. costs to governments and NGOs, would be a valuable addition to future updates.

## Benchmarks

Griscom et al (2017)’s “Natural climate solutions” calculates an annual impact from “coastal wetland restoration” maximum additional mitigation potential of 0.841 gigatons of carbon dioxide equivalent per year in 2030.

The main reason for the considerable difference between Griscom et al. (2017)’s annual climate mitigation impact and those resulting from our models is the restoration area included in the analysis. The average adoption area by 2030 of the three PDS adoption scenarios is 6 Mha whereas Griscom et al. (2017) is 29 Mha. Griscom et al. (2017) restored area estimates are based on older papers which included a great range of global area estimates (Pendleton et al. 2012, McLeod et al. 2011). For instance, according to Pendleton et al. (2012) and McLeod et al. (2011), saltmarshes global extent ranged from 2.2- 40. Our analysis is based on updated global figures which are considerably lower: 5.5 Mha (McOwen et al. 2017).

Replacing the restored area from our models into Griscom et al. (2017)’s calculation will result in a decrease in mitigation impact from 0.841 to 0.114 GtCO2eq per year. The other difference between Griscom et al. (2017)’s analysis is that the study includes an avoidable flux from soil carbon oxidation in degraded coastal wetlands. As mentioned previously in this report, the studies included in our analysis did not report estimates regarding the emissions from the degraded lands prior to restoration which is why it was not possible to include this dimension of analysis.

More recent estimation of coastal wetlands mitigation potential done by High-Level Panel for Sustainable Ocean range between 0.20 and 0.33 GtCO2eq per year in 2050 (Hoegh-Guldberg O. et al., 2019). Their estimates are lower than Griscom et al. (2017)’s but still higher than our results. Hoegh-Guldberg O. et al., 2019 used more aggressive scenarios and as they assumed recovery of about 40 percent of historical ecosystem cover by 2050, which is consistent with Global Mangrove Alliance goals; and a much more aggressive scenario of complete restoration of pre-1980s cover. While our TLA is only 7.32 Mha, Hoegh-Guldberg O. et al., 2019 restorable area is almost 100 Mha, thus the differences in our results are expected.

Table . Benchmarks

| **Source and Scenario** | **Coastal wetlands restoration mitigation impact**  **Gt CO2-eq yr in 2030** |
| --- | --- |
| Griscom et al. (2017) | 0.841 |
| *Plausible* Scenario | 0.025 |
| *Drawdown* Scenario | 0.037 |
| *Optimum* Scenario | 0.043 |
| **Source and Scenario** | **Coastal wetlands restoration mitigation impact**  **Gt CO2-eq yr in 2050** |
| Hoegh-Guldberg O. et al., (2019) | 0.20-0.33 |
| *Plausible* Scenario | 0.035 |
| *Drawdown* Scenario | 0.042 |
| *Optimum* Scenario | 0.043 |

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# Glossary

**Adoption Scenario** – the predicted annual adoption over the period 2015 to 2060, which is usually measured in **Functional Units**. For the coastal wetlands protection, the functional units are millions of hectares, Mha. 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 (i.e. the area of coastal wetlands protected) 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 Drawdown 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**.

**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. “The International Organization Partners of the Ramsar Convention on Wetlands are: BirdLife International, The International Water Management Institute (IWMI), The Wildfowl & Wetlands Trust, Wetlands International, WorldWide Fund for Nature (WWF), and The International Union for Conservation of Nature (IUCN)”. Available at: <https://www.iucn.org/news/water/201903/call-wetland-decade-under-un-decade-ecosystem-restoration-2021-2030> [↑](#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 2015-2050. [↑](#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)