TECHNICAL ASSESSMENT FOR PEATLAND PROTECTION

SECTOR: LAND USE

AGENCY LEVEL: GOVERNMENT

KEYWORDS: AVOIDED DEFORESTATION, BIOSEQUESTRATION, ECOSYSTEM PROTECTION

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EXECUTIVE SUMMARY

This solution protects carbon-rich peatlands, leading to reduced degradation rates and the safeguarding of carbon sinks. This solution replaces the destruction of non-degraded peatlands for numerous uses.

Peatlands are a hugely important stock of soil organic carbon. Despite covering less than 3 percent of the global land area, they hold 30 percent of all soil carbon, amounting to at least 500 gigatons – twice the carbon stock of all forest biomass. Unlike most terrestrial ecosystems, peatlands continue sequestering carbon in soil organic matter for centuries or millennia.

Peatlands are currently being degraded for agricultural, horticultural, forest, fuel, and infrastructural needs. An estimated 15 percent of the world's peatlands have been degraded so far, and nearly 50 percent of that degradation is for agricultural land use.

Peatland degradation for various land uses is leading to enormous carbon emissions. Currently, peatlands are degrading at the annual rate of 0.4 million hectares per year. Moreover, global peat volume is decreasing at an annual rate of 20 cubic kilometers per year. Peatland degradation results in nearly 3 gigatons of carbon dioxide-equivalent emissions per year, equivalent to more than 10 percent of global fossil fuel emissions. The rate is expected to increase in the future unless land management practices and peatland development plans are changed and reconsidered.

It is extremely important to prevent any further degradation of peatlands as well as to develop sustainable management plans for already degraded peatlands. The *peatlands* solution projects adoption of protection of non-degraded peatlands.

In the *Plausible* Scenario, 236.78 million hectares come under protection. Climate impact is 13.94 gigatons of carbon dioxide equivalent. Total carbon stock protected is 1692.59 gigatons of carbon dioxide equivalent with the prevention of 22.19 million of non-degraded peatland from future degradation.

In the *Drawdown* Scenario, 399.76 million hectares come under protection. Climate impact is 25.14 gigatons of carbon dioxide equivalent. Total carbon stock protected is 2857.70 gigatons of carbon dioxide equivalent with the prevention of 39.35 million of non-degraded peatland from future degradation.

In the *Optimum* Scenario, 390.90 million hectares come under protection. Climate impact is 28.29 gigatons of carbon dioxide equivalent. Total carbon stock protected is 2794.33 gigatons of carbon dioxide equivalent with the prevention of 42.59 million of non-degraded peatland from future degradation.

Financials are not modeled.

1. Literature Review

1.1. State of the Practice

Introduction

Rising levels of atmospheric CO2 have been considered as a major area of focus in climate change research and studies. However, little emphasis has been given to soil carbon resources which represent the 'hidden half' of the global carbon balance (Lal, 2003). Moreover, the role of soil as a source of carbon or a sink depends largely on soil management. In recent times, soils have been exploited to a greater extent for meeting anthropogenic needs, resulting in the imbalance of the rate of carbon deposition in the soil and release to the atmosphere. One of such land type is peatland. Peatland is primarily found in freshwater wetlands having an organic soil layer of at least 30 cm, which may extend to 15-20 m depth (Biancalani, Avagyan, & others, 2014; Clymo, Turunen, & Tolonen, 1998; Gorham, 1991; Hans Joosten & Clarke, 2002; Kaat & Silvius, 2006; Strack, 2008; M Strack & Zuback, 2013; Turunen, Tomppo, Tolonen, & Reinikainen, 2002). The rich carbon content of native peatland is attributed to the high rate of plant production and peat accumulation compared to the rate of organic matter decomposition, which is slowed due to anaerobic conditions (Dise et al; 2009).

Peatlands cover about 4.23 $\times 10^6$ km^2 area representing 2.84% of the global land area (Xu et al., 2018). Despite representing less than 3% of the global land area, peatlands contain at least 550 Gt of carbon (Barthelmes et a., 2015). This is equivalent to 30% of all global soil carbon, 75% of all atmospheric carbon, equal to all terrestrial biomass, and twice the carbon stock in the forest biomass of the world (Biancalani et al., 2014; Strack, 2008; Turunen et al., 2002). The geological studies show growth of peatland during the current postglacial period (Strack, 2008).

The majority of the peatlands are found in temperate-cold climates in the northern hemisphere, with 64% concentrated in Russia, Canada and the USA, followed by 11.5% in South America and 10.5 % in the rest of Asia (Xu et al., 2018). However, it should be noted that "Peat layers in tropical regions are typically thicker than those in temperate and boreal peatlands explaining the relatively large SOC stocks in tropical peatlands despite relatively low areal extent (Page et al. 2011)." (Lorenz and Lal, 2018). Gumbricht et al. (2017) model estimates "unprecedented extents and volumes of peatland in the tropics (1.7 Mkm2 and 7,268 (6,076–7,368) km3), which more than threefold current estimates" with South America leading the contribution to tropical peatland area and volume with 44% followed by Asia with 38%. Further research in mapping peatlands is highlighted as a priority “for both reducing our reported uncertainty and for their conservation and restoration” (Griscom et al. 2017).

Degradation

Peatland drainage for agricultural, horticultural and timber use, extraction for fuel demands and forest fires are the major causes of global peatland degradation. Large areas of tropical peatlands have been cleared and drained for food crops and cash crops, such as oil palm and other plantations in recent years (A Hooijer et al., 2012), (Miettinen et al., 2012). Large-scale drainage of peatlands for agricultural use has led to major problems of subsidence, fire, flooding, and deterioration in soil quality (Strack, 2008). The root cause of peatland degradation varies from region to region. In northern and Eastern Europe and Southeast Asia, forest plantations are leading to peatland degradation. In North America and Asia peatlands have been degraded for timber extraction. However, in Europe and South America, peat from peatlands has been extracted for fuel, both for domestic as well as industrial use. Peat extraction to produce growing substrates and gardening is a multi-million-dollar industry in North America and Europe. For instance, the Netherlands import 150 million Euros worth of peat every year as a substrate for horticulture (Szajdak & Simakina, 2008).

According to studies conducted by Immirzi, Maltby, & Clymo (1992) and Hans Joosten & Clarke (2002), peatlands are degrading at the annual rate of 4,000 km^2 per year. Moreover, global peat volume is decreasing at an annual rate of 20 km^3 per year. Key drivers of peatland degradation are shown in figure 3. According to the latest estimates (H Joosten, 2009; HANS Joosten, 2004; Hans Joosten & Clarke, 2002), nearly 15% of the peatlands have been already degraded and remaining 85% are under the threat of continuous annual drainage of peatland for agriculture, forest, mining and infrastructural land use.

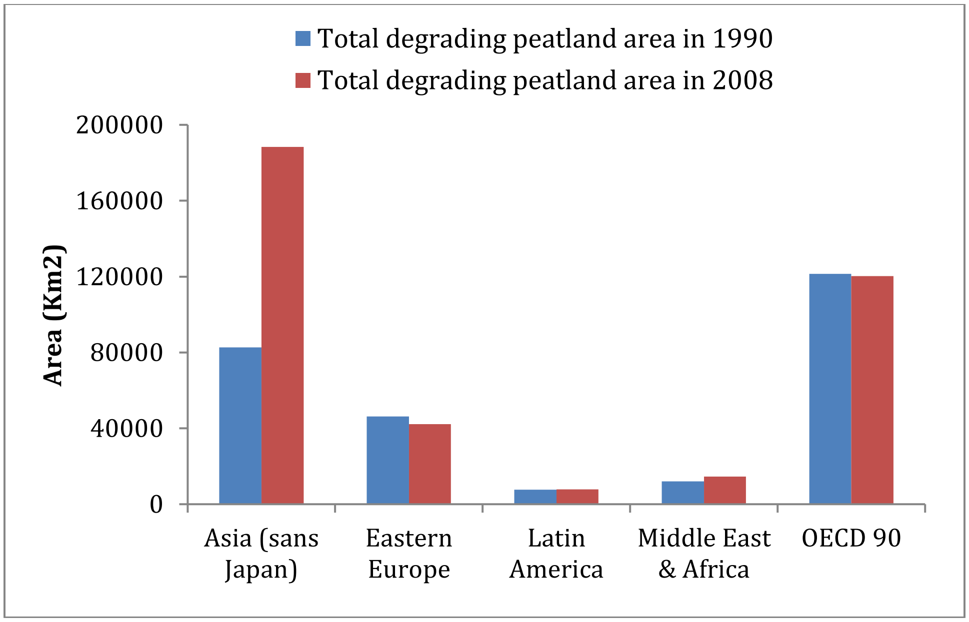

Figure 1.1 Degraded Peatland Area

The regional temporal change in degraded peatland area is shown in figure 1. The increase was observed maximum in the Asian region, despite representing only 19% of the total global peatland area. In recent times, peatland degradation has been identified as a major and growing source of anthropogenic greenhouse gas emissions.

Emissions

Although peatlands are a "long- term net carbon sink", "largely originated since the onset of the Holocene and have continued to accumulate since then (MacDonald et al., 2006), many peatlands may be close to the tipping point between carbon source or sink" (Barthelmes et al., 2015) though "disturbed peatlands may become net annual carbon sink after restoration by rewetting" (Lorenz and Lal, 2018).Carbon dioxide emissions from peatland drainage, fires and exploitation are estimated to be equivalent to at least 3,000 million tonnes per annum or equivalent to more than 10% of the global fossil fuel emissions (FAO, 2014). The regional CO2 emissions from degraded peatland areas in the years 1990 and 2008 are shown in figure 5. Despite representing a small amount of total land area, the 15% of peatland area drained represents nearly 5% all global anthropogenic greenhouse gas emissions (Joosten, 2015; Crump et al., 2017) with peatland fires being the leading source.

CO2 emissions from the degraded peatlands are higher in the Asian region followed by OECD90 and Eastern Europe regions. However, carbon emissions have doubled in 2008 in the Asian region, while it has gone down marginally in OECD90 and Eastern Europe regions. Forest fires are one of the key reasons for increased CO2 emissions from degraded peatland in the Asian regions. Forest and peatland fires were widespread during late 1990s across the Southeast Asian region. This resulted in burning of nearly 24,000 km^2 of Peatland areas that has released estimated emissions of 0.81-0.95 giga tonnes of CO2 (Page, 2008). Annual CO2 emissions for a 5 years drained peatland in the Asian region was found in the range of 355-855 tonnes; equivalent to 1.3-3.1 percent of current global CO2 emissions from the combustion of fossil fuel in 2006 (A Hooijer et al., 2012; Aljosja Hooijer et al., 2010). These regional emissions are predicted to rapidly increase until 2020 (Miettinen et al., 2012) unless successful policy enforcement – such as those resulting from the 2015 peatland fires in Indonesia- occurs. The emissions in the Asian regions have further accentuated with an increased clearance of peatlands for large scale industrial, palm oil and pulpwood plantations. Moreover, tropical climatic conditions of the Asian region also intensify the rate of biological decomposition, thus accelerating CO2 emissions (Hirano et al., 2012; Hirano, Jauhiainen, Inoue, & Takahashi, 2009; Jauhiainen, Hooijer, Page, & others, 2012).

The large forest and peatland fires the past September/ October 2015 in Southeast Asia – Indonesia in particular- released 11.3 Tg CO2 per day, almost 30% above the "fossil fuel CO2 release rate of the European Union (EU28) (8.9 Tg CO2 per day)" (Huijnen et al., 2016). The issue with peatlands fires, asides from damages and the health hazards associated with them, is that they can continue to "smolder below ground, lasting several months even following days of rain and under snow cover, and spread over long distances (Abel et al., 2011; Betha et al., 2012; Davies et al., 2013; Marlier et al., 2015b" (Crump et al., 2017).

Miettinen et al. (2017) analysis on the 2015 peatlands fires in peninsular Malaysia, Sumatra and Borneo indicates that "fire occurrence in the peatland areas was highly dependent on land cover type", with deforested undeveloped peatlands have much greater fire incidence than pristine swamp forests (831–915 vs. 30 fire detections per 1000 km2). Page and Hoojier (2016) further demonstrate "a strong interdependence between depth of burn and both distance from nearest drainage canal (as a proxy for peat moisture conditions) and fire frequency".

Peatland extractions for fuel, horticulture and timber production are the major cause of CO2 emission from degraded peatlands in the temperate region. Over 10 million ha of peatlands in Norway, Sweden, Finland, Russia have been drained for forestry purpose. On the other hand, forestry in un-drained peatlands is being practiced in Canada, USA, and Indonesia (Biancalani et al., 2014; Strack, 2008). Usage of peat for domestic energy purposes by local communities is a very common and age old traditional practice. However, peat consumption for energy fuel was commercially developed in the 20th Century in some of the European countries and the Soviet Union. Today, European countries account for almost 90% of the world's production and consumption of peat energy. Peat is also used in horticulture, as a growing medium, but the volume used annually is only about half of that of the fuel peat. Germany and Canada account for over half of horticultural peat extraction (Strack, 2008). Indonesia has been identified as the top emitter of GHG emissions from the degraded land followed by USA.

An annual CO2 emission of 630 million tons per year was estimated from drained peatlands in year 2005 (Strack, 2008). The rate is expected to increase in the future unless land management practices and peatland development plans are changed and reconsidered. Thus, it is extremely important to prevent any further degradation of peatlands as well as to develop sustainable management plans for already degraded peatlands.

In the current study, a global level assessment of current peatland degradation and associated GHG emissions was conducted. Estimation of future GHG emissions under business as usual (BAU) and a range of Project Drawdown scenarios, where measures for peatland protection will be taken, were estimated.

1.2. Adoption Path

1.2.1 Current Adoption[1]

The data availability of peatland protected area is very limited. The Protected Planet reports are published by the United Nations Environment Programme- World Conservation Monitoring Centre (UNEP- WCMC). The UNEP- WCMC was contacted to enquire about the availability of a historical evolution of the protected peatlands area (building up on the published value in the 2014 report). The team stated that they do not have that information. In addition, the Greifswald Mire Centre – which hosts the Global Peatland database- was contacted for the same purpose with the same outcome.

1.2.2 Trends to Accelerate Adoption

The importance of peatland protection has now been realized, however, its implementation has not yet been initiated. This is currently under policy framework; various countries are in the process of making long-term plans for protecting their native peatland reserves.

Several global agreements, conventions and directives have realized the importance of peatland protection and restoration. Some of the key conventions on peatland protection and restoration are:

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[1] Current adoption is defined as the amount of land area adopted by the solution in 2018. This study uses 2014 as the base year due to the availability of global adoption data for all Project Drawdown solutions evaluated.

- *Ramsar Convention:* This is concerned with the conservation and wise use of the world's wetlands. The convention came into action in 1975. This is one of the key bodies putting significant efforts on peatland issues.
- *Convention on Biological Diversity (CBD):* CBD commits contracting parties to maintaining and enhancing the natural biodiversity of their territories through a series of specific actions. The convention came into action in 1992. However, they introduced peatland in their agenda only in 2004.
- *UNESCO World Heritage Convention:* a Memorandum of Understanding between Ramsar Sites and World Heritage Convention signed back in 1999, which had the objective of promoting wetland areas nominations under both conventions, resulted in several areas being designated with both Conventions. (Barthelmes et al., 2015).
- *Food and Agricultural Organization of the United Nations (FAO):* Since the launch of the Mitigation of Climate Change and Agriculture (MICCA) framework, FAO has started paying more attention to peatlands and producing several reports promoting their sustainable use given that despite "agriculture and forestry are the main drivers of peatland drainage worldwide, but that peatland drainage – through huge GHG emissions and subsidence associated land loss – is in turn frustrating the aims of a sustainable provision of food, fodder, fiber and fuel". (Barthelmes et al., 2015).
- *UN Framework Convention on Climate Change (UNFCCC):* Peatlands were not initially included in the global negotiations of GHG emissions in the Kyoto Protocol. This has resulted in little to no attention on peatland degradation especially in context of Clean Development Mechanisms (CDM) in the initial year of its establishment. However, considering their huge importance in the global carbon cycle and GHG mitigation, the Ramsar Convention was later added to the overall framework to combat GHG emissions. The results of COP[2] 21 Durban Negotiations are listed below.
    - Incentives for emission reductions by rehabilitating drained peatlands in developed countries: From 2013, developed countries can choose to achieve their emission reduction targets by rehabilitating drained peatlands and account for it under the Kyoto Protocol.
    - Inclusion of organic soil emissions in REDD+[3] reporting: Under the guidelines for submissions of information on reference levels for REDD+, participating countries are required to provide information including all significant pools, gases and activities - thus also organic soil

[2] COP: The Conference of the Parties is the governing body of the United Nations Framework Convention on Climate Change (UNFCCC), and advances implementation of the Convention through the decisions it takes at its periodic meetings.

[3] REDD: Reducing emissions from deforestation and forest degradation (REDD) is a mechanism that has been under negotiation by the United Nations Framework Convention on Climate Change (UNFCCC) since 2005, with the objective of mitigating climate change through reducing net emissions of greenhouse gases through enhanced forest management.

emissions - in their forest reference emission levels. These reference levels will be used to assess their respective emission reductions. This clause creates incentives for bilateral and multilateral investments in peatland conservation, restoration and sustainable use in countries with significant peatlands.

- *Wetland International Initiatives*:
    - In Russia: Provided scientific and technical advice for the restoration and rewetting of 40,000 ha of degraded peatlands in former agricultural and peat mining areas. This results in prevention of peat fires (such as the ones that occurred in 2010) and reduces GHG emissions. This five-year programme integrates peatland rehabilitation with paludiculture and biodiversity conservation.
    - In Indonesia: Piloted the partial rewetting of 60,000 ha of drained and degraded peatlands in the Ex-Mega Rice Project area in Central Kalimantan (Borneo), Indonesia. This has avoided annual peat decomposition emissions of about 2.5 million tonnes of CO_2 by reducing the fire risk and improving the firefighting operations in 25 villages.

At the same time, a range of national and regional activities are also going on to develop payment for ecosystem service schemes (Bonn et al., 2014; Matzdorf et al., 2014) for peatland restoration through agri-environment schemes (Reed et al., 2014) and compliance and voluntary markets (Barthelmes et al., 2015).

Two other recent relevant initiatives are the Brazzaville Convention and the Global Peatlands initiative. The Brazzaville Declaration, signed in early 2018 between the Democratic Republic of Congo, the Republic of Congo and Indonesia, "aims to implement coordination and cooperation between different government sectors to protect the benefits provided by peatland ecosystems" (UNEP, 2018). The Congo Basin is home to one of the largest peatland areas in the world, the Cuvette Centrale, which stores 30.6 PgC belowground and was scientifically mapped for the first time in 2017 (Dargie et al., 2017). At COP22, in a joint effort by UNEP, the government of Indonesia and other partners, the Global Peatlands Initiative was established with the aim "to increase the conservation, restoration and sustainable management of peatlands in countries with significant peatlands." (Minasny et al., 2017).

1.2.3 Barriers to Adoption

Despite the crucial potential role peatlands can play in climate change mitigation, there are several barriers to successful protection of peatlands areas. These range from the need to improve the mapping of peatland areas to policy initiatives which promote sustainable peatland use. In particular:

- *Peatland area mapping and monitoring*: The exact global area of peatlands is still uncertain. For instance, the Cuvette Centrale -one of the largest tropical peatlands area- was scientifically mapped for the first time in 2017 (Dargie et al., 2017). It is extremely important to have an accurate estimate of peatland area. Along with this, there is a need to set up monitoring and evaluation plans and strategies for peatland degradation. This requires both national and international commitments and efforts.
- *Emissions checks on degraded peatlands*: Along with monitoring of degraded peatland area, a check on annual GHG emissions from degraded peatlands is very critical in estimating global GHG emissions. This will help in redefining and planning new policies and plans for peatland protection and restoration.
- *Incentives for peatland protection and restoration*: Policy level decisions are required to incentivize efforts laid in the direction of peatland protection and restoration. New opportunities for peatland protection may arise from current negotiations on financial payments for reduced emissions from avoided deforestation and forest degradation (REDD). This could put an economic value on the remaining intact peatlands and provide an incentive for their protection.
- *Wise use of peatlands*: As already discussed above, peatland protection and restoration doesn't mean total exclusion of human activities. However, there is a need to identify the wisest use of the peatlands in different locations based on local biophysical and socioeconomic conditions. Thus, it is essential that future land use of peatland incorporates the principles and practices of wise use in order to promote sustainable management, especially with respect to hydrology, water and carbon. This requires engagement between scientists, policy makers and local stakeholders.
- *Engagement of local communities*: Often conflicts between the local communities and implementation authorities have been noticed. To avoid that and for the successful implementation of peatland protection and restoration projects, it is very important to engage local communities in the overall plan.
- *CH4 emissions*: CH4 is produced in the saturated zone of peat soil and attributes to the only negative mitigation aspect of peatlands. However, the net result of peatland protection and restoration, considering the carbon sequestration potential of peatlands is mostly positive.

1.2.4 Adoption Potential

One of Griscom et al. (2017)'s Natural climate solutions (NCS)[4] is avoided peatland impacts. Some examples of activities associated with this NCS include: "protected areas establishment and improved enforcement; improved land tenure; no-net-loss mitigation regulations; re-siting of oil palm plantation permits to non-peat locations." (Griscom et al., 2017).

1.3 ADVANTAGES AND DISADVANTAGES OF PEATLAND PROTECTION

1.3.1 Similar Solutions

A number of ecosystem protection solutions are critical to safeguard carbon stocks. These include non-peat forests and mangroves. Indigenous forest management provides tenure to indigenous forest people, under whose management deforestation and degradation rates are greatly reduced. Sustainable forestry strives to maintain forest integrity while harvesting timber and other products.

Protection of non-forest ecosystems (grasslands, saltmarshes, seagrass beds, ocean areas) is also important for maintaining carbon stocks.

1.3.2 Arguments for Adoption

The large amount of carbon stored in peatland areas in a world under increasing greenhouse gases emissions is probably the main argument stressing the crucial role of protecting these precious ecosystems. The recent report by the Global Peatlands Initiative stresses that: "peatlands must be treated as lands with a high climate mitigation potential that also offer strong opportunities for climate adaptation, biodiversity conservation and contribute significantly to sustainable development. (Wetlands International, 2015)" Crump et al. (2017).

[4] "20 conservation, restoration, and improved land management actions that increase carbon storage and/or avoid greenhouse gas emissions across global forests, wetlands, grasslands, and agricultural lands"

1.3.3 Additional Benefits and Burdens

Here this solution is compared with other solutions in the ecosystem management cluster for farm, ecosystem, and social impacts. Peatland protection is of a cluster that reduce timber and biomass production, but a standout for climate and ecosystem service impacts.

Table 1.1: Land Use Solutions Comparison: Economic Impacts

First Cost: Free is $0**,** Low is $1-100, Medium is $100-500, Expensive is $500+. **Net Profit Margin:** Low is $0-100/ha, Medium is $100-500, High is $500+. **Value of Ecosystem Services:** Set values for very high, high, medium, low. **Timber and Biomass Production:** Decrease indicates restriction of logging where it currently occurs; Increase indicates new commercial biomass production where it does not currently occur.

	First Cost $/ha	Net Profit $/ha	Value of Ecosystem Services	Timber and Biomass Production
Afforestation	Expensive	Medium	High	Increase
Bamboo	Expensive	Medium	High	Increase
Forest Protection	Not calculated	Not calculated	Very high	Decrease
Indigenous People's Forest Management	Not calculated	Not calculated	Very high	Decrease
Peatland Protection	Not calculated	Not calculated	Very high	Decrease
Perennial Biomass	Expensive	Medium	Medium	Increase
Temperate Forest Restoration	Not calculated	Not calculated	High	n/a
Tropical Forest Restoration	Not calculated	Not calculated	High	n/a

Table 1.2: Land Use Solutions Comparison: Social and Climate Impacts

Carbon Stock Protected: Low 0-500 Gt CO2-eq, Medium is 500-1000 Gt CO2-eq, high is 1000+ Gt CO2-eq.

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 11.1-18.0 tCO2-eq/yr (3-5 tC), Very High 18.1 tCO2-eq/yr (5tC+). **Global Adoption Potential:** Low 0-100Mha, Medium 101-500 Mha, High 500+ Mha

	Carbon Stock Protected	Social Justice Benefits	Climate Impact/ha	Global Adoption Potential
Afforestation	Medium to High	Relevant	High	Medium
Bamboo	Medium	Relevant	High	Medium
Forest Protection	High	Relevant	Very High	Medium
Indigenous People's Forest Management	High	Targeted	Very High	Medium to High
Peatland Protection	n/a	Relevant	Very High	High
Perennial Biomass	n/a	Relevant	Low	Medium
Temperate Forest Restoration	n/a	Relevant	Medium	Low to Medium
Tropical Forest Restoration	n/a	Relevant	High	Medium

2. Methodology

2.1. 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[5]) 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.

1.2. Data Sources

Key data sources include: Wetlands International (2008) report, the 2014 Protected Planet report – which contains the first and only global estimation of protected peatland area found in the literature review- and a paper by Chaudhary et al. (2017) on sequestration rates.

1.3. Total Available Land

Drawdown's agricultural production and land use model approach defines the Total Land Area as the area of land (in million hectares) suitable for adoption of a given solution. Data on global land is acquired from

[5] 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.

the Global Agro-Ecological Zones database, developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA). The Drawdown Land-Use Model categorizes and allocates land according to agro-ecological zones based on the following factors: thermal climate, moisture regimes, soil quality, slope, cover type, and degradation status. These characteristics influence the suitability of different practices, and solution adoption scenarios are restricted by one or more of these factors.

Determining the total available land for a solution is a two-part process. The technical potential is based on: current land cover or land use; the suitability of climate, soils, and slopes; and on degraded or non-degraded status. In the second stage, land is allocated using the Drawdown Agro-Ecological Zone model, based on priorities for each class of land. The total land allocated for each solution is capped at the solution's maximum adoption in the *Optimum* Scenario. Thus, in most cases the total available land is less than the technical potential.

Total land allocated for the *peatland* solution is 413 million hectares, comprising global peatlands. The total land area available for this solution was modeled using the annual rate of peatland degradation (e.g. from deforestation and mining): 0.51 percent. Future degraded and non-degraded areas were calculated, and the projected future non-degraded, non-protected area was set as the total available area for protection. Current adoption of *peatlands* is estimated at 6.06 million hectares (as detailed on section 1.2.1.).

1.4. 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.

The estimation of future protected and unprotected land for peatland was estimated based on the following indicators.

1. <u>Cumulative degraded land that is unprotected in the PDS</u> - This represents the total land degraded that was never protected in the PDS considering the rate of annual degradation. This rate is applied only to the land that is not covered by the solution (ie land not artificially protected) and that is not degraded.

2. Total at risk land in the PDS - This represents the total land that is neither covered by the solution nor degraded in the PDS. It's land that is potentially at risk of degradation by anthropogenic or other means. It is calculated by identifying how much land is degraded, and how much is under the solution.
3. Total undegraded land in the PDS - This represents the total land that is not degraded in any particular year of the PDS. It takes the total land area and removes the degraded land, which is the same as summing the undegraded land under the solution and at-risk land.
4. Cumulative Degraded Land Under Protection in the PDS - Even protected land suffers from degradation via disturbances (perhaps due to natural or anthropogenic means such as logging, storms, fires or human settlement). The rate of this disturbance is assumed equal both in the PDS and REF. This disturbance rate affects annually, the degradation of protected land, but is expected to be much less than the degradation rate of unprotected land.

The above four variables were also calculated for the REF case and the net area protected in the future under the PDS is estimated based on the following indicators.

5. Annual reduction in total degraded land (or annual increase in total undegraded land) (protected and unprotected) - This is the decrease in total degraded land in the PDS versus the REF in each year.
6. Net at-risk land - This is the increase in land that is neither under the solution nor degraded (ie open to nature and at risk of degradation) in the PDS versus the REF.
7. Cumulative reduction in total degraded land (or cumulative increase in undegraded land) over base year (protected and unprotected) - This is the increase in undegraded land in the PDS versus the REF (cumulatively in any year) and can be traced to the direct action of increasing solution adoption.

The future adoption of the solution was further projected based on ten custom adoption scenarios. Some of them are based on the yearly increases resulting from the historical evolution of Ramsar sites categories “forested” and “non- forested peatlands” (with management plans) combined with the degradation rate in the model and an alternative one based on the New York Declaration on Forests. Other scenarios are more aggressive in achieving higher protection trajectories. Given the small area of peatland, and the high urgency because of the degradation of unprotected peatland areas and the high mitigation efficiency of protection, several scenarios emphasized early peak adoption by 2030. The historical evolution of peatlands’ Ramsar sites with management plans is as follows:

Table 2.1: Ramsar Site with Management Plans of Forested and Non-Forested Peatlands

Year	1985	1990	2000	2005	2010	2015
Mha	3,5	8,2	14,4	17,0	20,4	21,7

Source: Ramsar Sites Information Services (www.rsis.ramsar.org)

Details on the ten custom adoption scenarios are given below:

1. ***Custom adoption scenario one***: The Peatlands Ramsar sites with management plans evolution (1985-2015) was used to estimate the yearly increase rate of 6,23% corresponding to 1985- 2015 coupled with the TLA's current degradation rate of 0.51%.
2. ***Custom adoption scenario two***: results from combining Scenario 1 with linear increase up to 70% of TLA 2050 value in 2030 and then linear increase to 100% TLA value in 2050 from then onwards.
3. ***Custom adoption scenario three***: The Peatlands Ramsar sites with management plans evolution (1985-2015) was used to estimate the yearly increase rate of 6,23% corresponding to 1985- 2015 coupled with the New York declaration on Forests (NYDF) is used to estimate an alternative degradation rate which starts from 0.51% and linearly decreases to half its value in 2020 and then to zero in 2030.
4. ***Custom adoption scenario four***: results from combining Scenario 3 with linear increase up to 70% of TLA 2050 value in 2030 and then linear increase to 100% TLA value in 2050 from then onwards.
5. ***Custom adoption scenario five***: results from a linear trend towards 100% adoption of TLA estimated with conservative degradation rate by 2050.
6. ***Custom adoption scenario six***: results from a linear increase up to 80% of TLA 2050 value in 2030 (calculated with the conservative degradation rate) and then linear increase to 100% TLA value in 2050 from then onwards.
7. ***Custom adoption scenario seven***: results from a linear trend towards 100% adoption of TLA estimated with NYDF degradation rate by 2050.
8. ***Custom adoption scenario eight***: results from a linear increase up to 80% of TLA 2050 value in 2030 (calculated with the NYDF degradation rate) and then linear increase to 100% TLA value in 2050 from then onwards.
9. ***Custom adoption scenario nine***: The Peatlands Ramsar sites with management plans evolution (1985-2015) was used to estimate the yearly increase rate of 3,94% corresponding to 1990- 2015 coupled with the TLA's current degradation rate of 0.51%.

10. ***Custom adoption scenario ten***: The Peatlands Ramsar sites with management plans evolution (1985-2015) was used to estimate the yearly increase rate of 3,94% corresponding to 1990- 2015 coupled with the TLA's NYDF degradation rate.

Impacts of increased adoption of *peatlands* from 2020-2050 were generated based on three growth scenarios, which were assessed in comparison to a *Reference* Scenario where the solution's market share was fixed at the current levels.

1.3.4 Reference Case / Current Adoption

Current adoption of *peatlands* is estimated at 6.06 million hectares based on the meta-analysis of 9 data points from four sources.

The current adoption value of peatland protection is 6.06 Mha and results from the average between two values:

2. 8.84 Mha of protected peatlands according to the Protected Planet 2014 report (the category used is "Bog, Fen and Mire")
3. 3.28 Mha which is the sum of all the data points included in the previous version of the model. These data points contain protected peatland area for the UK and Eastern Europe as stated in Minaeva et al. (2008), Joosten et al. (2012) and Brag et al. (2003).

1.3.5 Project Drawdown Scenarios

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

Plausible Scenario - A conservative approach is taken for the plausible scenario, which is represented by the "average of all" custom adoption scenarios.

Drawdown Scenario – An ambitious approach is taken for the drawdown scenario, which is represented by the "high of all" custom adoption scenarios.

Optimum Scenario – This scenario represents the maximum adoption of the solution, which is represented by the scenario "Custom adoption scenario eight".

Note that even in most optimistic scenario, 100 percent protection of peatland is not possible as annual degradation continuous. Thus, to protect these important ecosystems aggressive adoption has been considered both during the drawdown and optimum scenarios.

3.2. INPUTS

2.5.1 Climate Inputs

Peatland sequestration rates are set at 0.51 tons of carbon per hectare per year, based on 86 data points from 16 sources. Emissions reductions are set at: 38.58 tons of carbon dioxide per hectare per year, 2.26 tons of nitrous oxide- carbon dioxide-equivalent per hectare per year and 3.22 tons of methane- carbon dioxide equivalent per hectare per year. The dataset includes CO2 emissions from all sources of peatland degradation, such as drainage, land use change, peat extraction for fuel, etc.

Table 2.2: Climate Inputs

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Biosequestration	*tC/ha/yr*	0.002 - 1.40	0.51	86	16
Carbon dioxide emissions reduction	*tCO2-eq/ha/yr*	0.92 - 95.35	38.58	131	42
Nitrous oxide emissions reduction	*tCO2-eq/ha/yr*	0.06 - 4.54	2.26	40	9
Methane emissions reduction	*tCO2-eq/ha/yr*	-0.12 – 11.08	3.22	24	10

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[6].

[6] 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.

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. 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.

2.5.2 Financial Inputs

It is assumed that any costs for *peatland protection* (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.

3.3. Assumptions

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions. These are that 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. Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below.

Assumption 1: The degradation will continue with the current rate of deforestation both under the solution and the conventional case.

Assumption 2: Efforts will be laid at the national and international level to protect peatland resources on an urgency basis, considering the high carbon stock in the peatland areas and their limited availability.

Assumption 3: Leakage effect which is defined as "the unanticipated decrease or increase in GHG benefits outside of the project's accounting boundary (the boundary defined for the purposes of estimating the project's net GHG impact) as a result of project activities. For example, conserving forests that otherwise would have been deforested for agricultural land may displace farmers to an area outside of the project's boundaries. There, the displaced farmers may engage in deforestation-and the resulting carbon emissions are referred to as leakage (IPCC)" is considered in the present modeling of the solution. Thus, in the present model, it is assumed that protection of peatland in the solution case will lead to some sort of leakage in the adjacent areas of the reference case. However, the leakage related degradation is a time bound phenomenon and gets stabilized after some years; which is uncertain to estimate at the global level. Therefore, to incorporate the leakage effect, in the present protect model, it is assumed that the carbon benefits of protecting the peatlands will be realized one year later.

Assumption 4: It is assumed that the re-growth of the degraded peatland area will start one year later after the peatland will be brought under protection.

Assumption 5: Assumption for incorporating the delay in impact due to the time taken by the agencies to actually bring a peatland under protection **-** It is assumed that the required agency level legalities to bring a peatland under protection will be in place by the year of adoption. Thus, there will be no delay in the climate benefits resulting from a delay in agency level efforts to bring a peatland area under protection. Therefore the "year of protection" is assumed to be the "year of implementation".

3.4. INTEGRATION

The complete Project Drawdown integration documentation (will be available at 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.

Peatland protection is part of Drawdown's Land Use sector. Within this sector, it is part of a cluster of solutions-based ecosystem protection.

The Agroecological Zone model

Drawdown's approach seeks to model integration between and within sectors, and avoid double counting. Several tools were developed to assist in this effort. The Agroecological Zone (AEZ) model categorizes the world's land by: current cover (e.g. forest, grassland, cropland), thermal climate, moisture regime, soil quality, slope, and state of degradation. Both Food (supply-side) and Land Use solutions were assigned to AEZs based on suitability. Once current solution adoption was allocated for each zone (e.g. semi-arid cropland of minimal slopes), zone priorities were generated, and available land was allocated for new adoption. Priorities were determined based on an evaluation of suitability, consideration of social and ecological co-benefits, mitigation impact, yield impact, etc. For example, *Indigenous peoples' land management* is given a higher priority than *forest protection* for AEZs with forest cover, in recognition of indigenous peoples' rights and livelihoods. *Multistrata agroforestry* is highly prioritized in tropical humid climates due to its high sequestration rate, food production, and highly limited climate constraints.

Each unit of land was allocated to a separate solution to avoid overlap between practices. The exception to this are *farmland irrigation*, *nutrient management*, and *women smallholders*, which can be implemented in addition to other practices. The constraint of limited available land meant that many solutions could not reach their technical adoption potential. The AEZ model thus prevents double-counting for adoption of agricultural and land use solutions.

Drawdown's agricultural production and land use model approach defines the Total Land Area as the area of land (in million hectares) suitable for adoption a given solution. Data on global land is acquired from Global Agro-Ecological Zones database, developed by the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis (IIASA). The Drawdown Land-Use Model categorizes and allocates land according to agro-ecological zones based on the following factors: thermal climate, moisture regimes, soil quality, slope, cover type, and degradation status. These characteristics influence the suitability of different practices, and solution adoption scenarios are restricted by one or more of these factors.

Determining the total available land for a solution is a two-part process. The technical potential is based on: current land cover or land use; the suitability of climate, soils, and slopes; and on degraded or non-degraded status. In the second stage, land is allocated using the Drawdown Agro-Ecological Zone model, based on priorities for each class of land. The total land allocated for each solution is capped at the solution's maximum adoption in the *Optimum* Scenario. Thus, in most cases the total available land is less than the technical potential.

Peatland protection is the top priority for forested land in the AEZ model. Based, on Xu et al. (2018) an alternative TLA was added to the model using the Data interpolator based on a linear projection from 379.7 Mha in 2009 to 423.2 Mha in 2016 which resulted in 411 Mha in 2014.

The Biomass Model

Drawdown's Biomass model begins with projected global biomass demand through 2060, based on FAO historical data and other sources, in categories including sawnwood, other woody biomass, and herbaceous biomass (which includes crop residues). It determines the impact of demand reduction solutions including *clean cookstoves* and *recycled paper*, resulting in an adjusted demand projection through 2060. Biomass supply reductions are modeled as well, which result from protection of forests from *forest protection, Indigenous Peoples' forest management, mangrove protection,* and *peatland protection*, reducing biomass availability. Biomass supply increases are modeled through the increased adoption of solutions including *afforestation, bamboo, perennial biomass* and agroforestry solutions like *tree intercropping, silvopasture*, and *multistrata agroforestry*. Biomass availability from crop residues, *seaweed farming*, and dedicated biomass crops planted on cropland freed up by *sustainable intensification* is also modeled.

Surplus biomass is allocated to climate solutions that require biomass as feedstock. These include *biochar, biomass electricity, bioplastic, 2^nd^ generation biofuels, building with wood, insulation, small-scale biogas*, and *district heating.* This biomass feedstock allocation was a constraint to the adoption of this solution.

3.5. LIMITATIONS/FURTHER DEVELOPMENT

Currently, a limitation of this study is the lack of financial data.

3. Results

3.1. Adoption

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

Total adoption in the *Plausible* Scenario is 236.78 million hectares in 2050, representing 57 percent of the total suitable land. Of this, 230.72 million hectares are adopted from 2020-2050.

Total adoption in the *Drawdown* Scenario is 399.76 million hectares in 2050, representing 97 percent of the total suitable land. Of this, 393.71 million hectares are adopted from 2020-2050.

Total adoption in the *Optimum* Scenario is 390.90 million hectares in 2050, representing 95 percent of the total suitable land. Of this, 384.84 million hectares are adopted from 2020-2050.

Note that the total adoption is lower under the optimum scenario, comparing with the drawdown scenario. It is because, that the scenarios were considered based on the higher climate impact, which were observed more in the given optimum scenario even if the total adoption is slightly lower than the drawdown scenario.

Table 3.1 World Adoption of the Solution

Solution	Units	Base Year (2014)	New Adoption by 2050		
			Plausible	Drawdown	Optimum
Peatland protection	Mha	6.06	230.72	393.71	384.84
	% Total Land Available	1.5%	57%	97%	95%

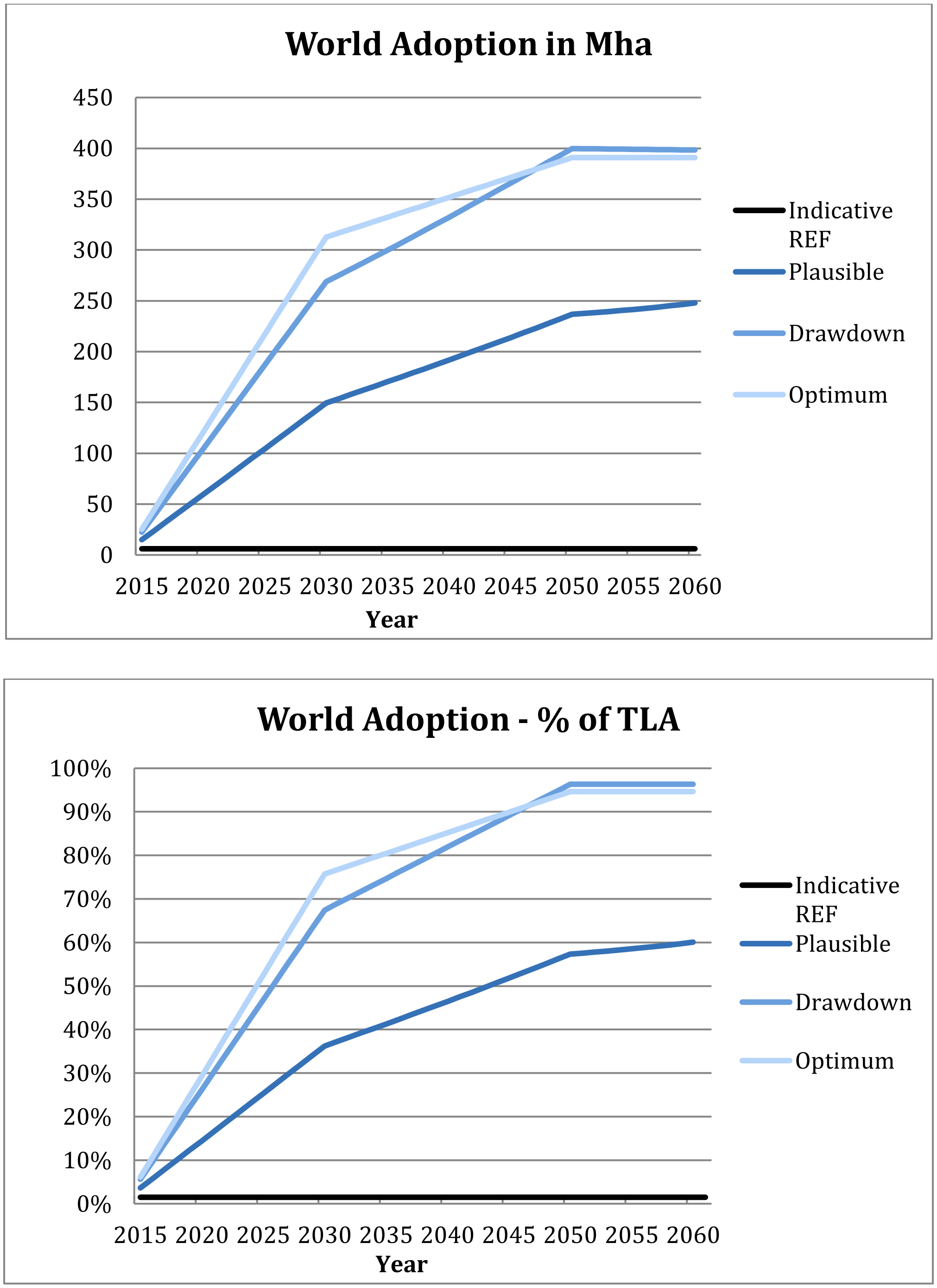

Figure 3.1: World Annual Adoption 2020-2050

3.2. 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 13.94, 25.14, and 28.29 gigatons of carbon-dioxide equivalent in the *Plausible*, *Drawdown*, and *Optimum* Scenarios respectively.

Table 3.2: Climate Impacts

Scenario	Maximum Annual Emissions Reduction	Total Emissions Reduction	Max Annual CO_2 Sequestered	Total Additional CO_2 Sequestered	Total Atmospheric CO_2-eq Reduction	Emissions Reduction in 2030	Emissions Reduction in 2050
	(Gt CO_2-eq/yr.)	*Gt CO_2-eq/yr. (2020-2050)*	*(Gt CO_2-eq/yr.)*	*Gt CO_2-eq/yr. (2020-2050)*	Gt CO_2-eq (2020-2050)	(Gt CO_2-eq/year)	*(Gt CO_2-eq/year)*
Plausible	0.98	13.41	0.04	0.53	13.94	0.24	1.02
Drawdown	1.73	24.18	0.07	0.96	25.14	0.45	1.81
Optimum	1.88	27.20	0.08	1.09	28.29	0.52	1.96

The solution was integrated with all other Project Drawdown solutions and may have different emissions 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).

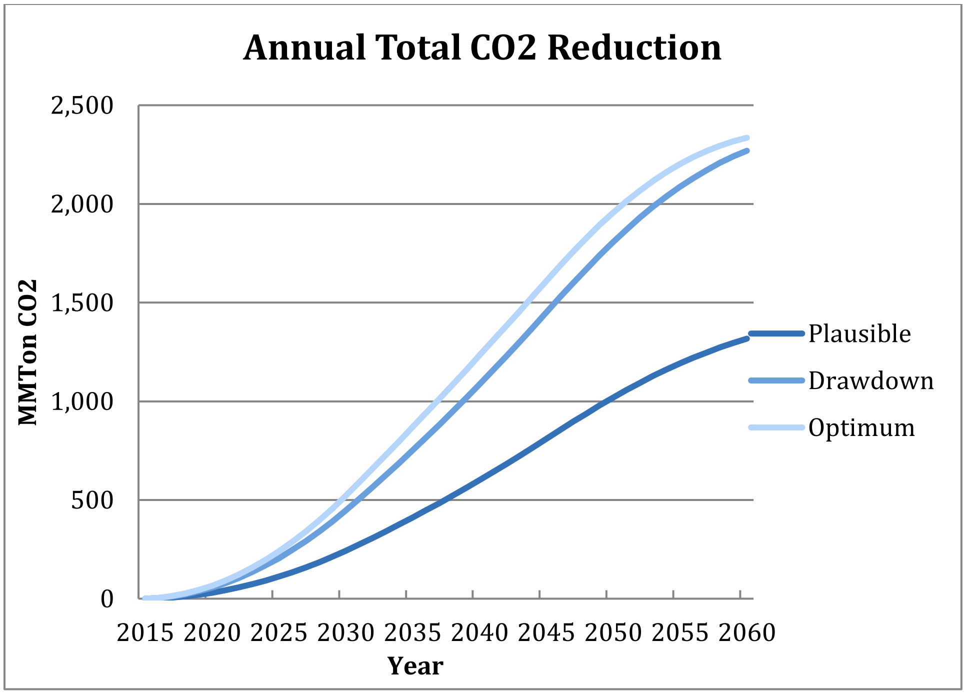

Figure 3.2: Impacts on Atmospheric Concentrations of CO2-eq

Table 3.3: World Annual Greenhouse Gas Emissions Reduction

Scenario	GHG Concentration Change in 2050	GHG Concentration Rate of Change in 2050
	PPM CO_2-eq (2050)	*PPM CO_2-eq change from 2049-2050*
Plausible	1.204	0.082
Drawdown	2.168	0.145
Optimum	2.431	0.156

3.3. Financial Impacts

Currently financial impacts are not modeled for this solution.

3.4. Other Impacts

Protection of high carbon ecosystems, like peatland also results in the increase of carbon stock in their soil and biomass as well as prevents degradation of significant amount of the intact/non-degraded ecosystems. The results for these indicators are listed below for the three drawdown scenarios.

Note that the higher carbon stock under the drawdown scenario is because of the higher adoption as stated above. However, the optimum scenario has higher climate impact in the given time frame as well as the reduced land degradation.

Table 3.4: Carbon stock and reduced land degradation

Scenario	Reduced Land Degradation	Total CO2 Under Protection by Second Year	Total Carbon Under Protection by Second Year
	Million Hectares	*Gt CO2*	*Gt Carbon*
Plausible	22.19	1692.59	461.95
Drawdown	39.35	2857.70	779.94
Optimum	42.59	2794.33	762.65

4. Discussion

The extremely high carbon stocks of peatlands, combined with their relatively tiny global extent, indicate that their protection should be an extremely high priority for climate mitigation. They also provide critical ecosystem services. Thus, aggressive efforts to protect these ecosystems are an important component of climate change mitigation efforts. This model suggests that the peatlands are an important carbon sink. Their protection (and restoration, though this was not modeled) make a modest contribution to climate change mitigation, which is rather impressive given the relatively tiny area of peatlands.

4.1. Limitations

Projecting financials at the government or non-governmental organization level is recommended.

4.2. Benchmarks

Annual emissions from degraded peatlands today are estimated at 1.0 gigatons carbon dioxide-equivalent per year (IPCC, 2014). This will surely increase as degradation is ongoing. The Drawdown model calculates emissions reduction of 0.23-0.5 gigatons carbon dioxide-equivalent per year by 2030. This study is within range of this benchmark, as the degraded area will continue to grow in business-as-usual scenarios, and emissions will continue from degraded peatlands for decades or longer given the immense size of the stocks. Griscom et al (2017)'s "Natural climate solutions" calculates 0.45-0.75 gigatons of carbon dioxide equivalent per year in 2030 with a 95% confidence interval bounds for maximum mitigation potential ranging from 0.24 to 1.2 Gt CO2 eq/ yr.

Table 4.1: Benchmarks

Source and Scenario	Mitigation Impact Gt $CO_{2\text{-}eq}$ in 2030
Griscom	0.45-0.75
Project Drawdown – Plausible Scenario (PDS1)	0.24
Project Drawdown – Drawdown Scenario (PDS2)	0.45
Project Drawdown – Optimum Scenario (PDS3)	0.52

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6. 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 CO_2 (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 CO_2e/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**.

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