TECHNICAL ASSESSMENT FOR FOREST PROTECTION

SECTOR: LAND USE
AGENCY LEVEL: GOVERNMENT
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*Note: For some of the technical reports, the result section is not yet updated. Kindly refer to the model for the latest results.

CONTENTS

List of Figures 4

List of Tables....4

Acronyms and Symbols Used 5

Executive Summary....6

Literature Review 7

1.1. State of Forest Protection....7

1.2. Adoption Path....12

1.2.1 Current Adoption 12

1.2.2 Trends to Accelerate Adoption 12

1.2.3 Barriers to Adoption....14

1.2.4 Adoption Potential 14

1.3 Advantages and disadvantages of Forest Protection....15

1.3.1 Similar Solutions....15

1.3.2Arguments for Adoption 15

1.3.3Additional Benefits and Burdens....16

2.0 Methodology 18

2.1 Introduction 18

2.2 Data Sources....18

2.3 Total Available Land 18

2.4 Adoption Scenarios....19

2.4.1 Reference Case / Current Adoption 22

2.4.2 Project Drawdown Scenarios....22

2.5 Inputs....22

2.5.1 Climate Inputs....22

2.5.2 Financial Inputs 24

2.5.3 Other Inputs 24
2.6 Assumptions 24
2.7 Integration 26
2.8 Limitations/Further Development 27
3. Results 28
3.1 Adoption 28
3.2 Climate Impacts 29
1.4 Financial Impacts 31
3.1 Other Impacts 31
4.0 Discussion 32
4.1 Limitations 32
4.2 Benchmarks 32
5. References 34
Glossary 45

LIST OF FIGURES

Figure 3.1 World Annual Adoption 2020-2050 [Mha] 29
Figure 3.2 World Annual Greenhouse Gas Emissions Reduction 30

LIST OF TABLES

Table 1.1: Protected forest area evolution (from Morales- Hidalgo et al. (2015) 7
Table 1.2: Deforestation area and rate 13
Table 1.3: Land Use Solutions Comparison: Economic Impacts 16
Table 1.4 Land Use Solutions Comparison: Social and Climate Impacts 17
Table 3.1 World Adoption of the Solution 29
Table 3.2 Climate Impacts 30
Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq 31
Table 3.4: Carbon stock and reduced land degradation 31
Table 4.1 Benchmarks 33

ACRONYMS AND SYMBOLS USED

EXECUTIVE SUMMARY

Project Drawdown defines *forest protection* as: the legal protection of forest lands, leading to reduced deforestation rates and the safeguarding of carbon sinks. This solution replaces non-protected forest land. It is assumed that *forest protection* primarily happens at the government and non-governmental organization (NGO) level. Mature, healthy forests have spent decades or centuries accumulating carbon through photosynthesis. They represent massive storehouses of carbon in soils and biomass. Yet, forests are being cleared and degraded at a rapid rate, causing carbon loss as well as negative impacts on ecosystem services like habitat, erosion control, soil-building, water regulation, water supply, and air pollution removal. *Forest protection* reduces these emissions from deforestation. Emissions from tropical deforestation and forest degradation alone are estimated at 5.1-8.4 gigatons of carbon dioxide-equivalent per year. This accounts for 14-21 percent of anthropogenic emissions. Future deforestation and forest degradation, although difficult to estimate due to uncertainties in population growth, enforcement of existing laws, scaling up of bioenergy, and other factors, are likely to contribute significantly to greenhouse gas emissions over the 21st century.

Out of a total land area available for the solution of 1,060 million hectares, the current solution adoption is 651 million hectares. Starting from this adoption value and based on a historical evolution of protected forest area and two different degradation rates, ten custom PDS adoption scenarios were developed for this solution which were combined to produce the *Plausible*, *Drawdown* and *Optimum* scenarios.

In the *Plausible* Scenario, 961.87 million hectares come under protection totaling 91% of total land area in 2050. Climate impact is 5.26 gigatons of carbon dioxide equivalent. Total carbon stock protected is 638.7 gigatons of carbon dioxide equivalent with the prevention of 14.73 million of non-degraded forest from future degradation.

In the *Drawdown* Scenario, 1,047.90 million hectares come under protection totaling 99.14 % of total land area in 2050. Climate impact is 6.79 gigatons of carbon dioxide equivalent. Total carbon stock protected is 696.9 gigatons of carbon dioxide equivalent with the prevention of 19.24 million of non-degraded forest from future degradation.

In the *Optimum* Scenario, 1,054.46 million hectares come under protection totaling 99.76 % of total land area in 2050. Climate impact is 7.56 gigatons of carbon dioxide equivalent. Total carbon stock protected is 700.2 gigatons of carbon dioxide equivalent with the prevention of 21 million of non-degraded forest from future degradation.

Financials are not modeled.

1. LITERATURE REVIEW

1.1. STATE OF FOREST PROTECTION

Project Drawdown defines *forest protection* as the legal protection of forest lands, leading to reduced deforestation rates and the safeguarding of carbon sinks. The solution excludes peatlands and mangrove forests as these are modeled as separate solutions. This solution does not address avoided deforestation via reduction of food demand or intensification of agricultural production, as these are modeled elsewhere (see *plant-rich diet, reduced food waste, educating girls, family planning, smallholder intensification,* and other agricultural solutions).

Morales-Hidalgo et al. (2015) include an evolution of protected forest area for 1990-2015 by climatic domain based on FAO's Global Forest Assessment Report (2016):

Table 1.1: Protected forest area evolution (from Morales- Hidalgo et al. (2015)

	Protected forest area [Mill. Ha.]				
Climatic domain	**1990**	**2000**	**2005**	**2010**	**2015**
Subtropical	4	8	9	10	11
Boreal	38	46	46	48	48
Temperate	39	54	68	78	79
Tropical	236	299	344	367	379
TOTAL	**317**	**407**	**467**	**503**	**517**

It should be noted that the evolution on the table includes countries which consistently reported for the 25 -year period, which represent around 80% of global forest for each year (as a reference, the total protected forest area in 2015 was 651 Mha) (Morales-Hidalgo et al., 2015). The average yearly increase in protected forest area was quite considerable for the first 20 years of analysis: 2,5% and 2,1% for 1990-2000 and 2000-2010 respectively, whilst it declined to 0,6% for the 2010- 2015 period.

Deforestation is a common phenomenon that involves clearing of forests for other land uses. There has always been a tradeoff between one land use to another. As a reference, the forest area totaled 4823 Mha in 1850 (Houghton and Nassikas, 2017). However, to support the food, fodder, and other demands of the human population, the rate of deforestation has increased significantly in the last two centuries. As per the latest statistics, the forest area has decreased from 4128 million hectares (Mha) in 1990 to 3999 Mha in 2015 (FAO, 2016). This resulted in a loss of 129 Mha area, equivalent to the size of South Africa, in a span of 25 years (FAO 2016). The estimated net annual loss was found to be 0.13%.

Spatially, deforestation has shifted toward the tropics. Deforestation in the pre-1700 period was high in the temperate region. However, in the 19^{th} century, the clearing of forest for various other land uses accelerated in the tropical region. Deforestation acceleratedparticularly in South America, Africa, and Asian regions (FAO, 2016).

The causes and magnitude of deforestation are difficult to quantify and can vary significantly on an annual basis and from location to location. Agriculture has been identified as the prime cause of deforestation, reaching around 80% globally, with commercial agriculture being the key driver of deforestation in two-thirds of the deforested area in Latin America and one-third of the deforested area in Africa and subtropical Asia (Kissinger et al., 2012). On the other hand, mining, infrastructure, and urban expansion are also responsible for deforestation but their percentage is much smaller in comparison with agriculture (Kissinger et al., 2012).

Curtis et al. (2018)'s 'forest loss classification model'- based on satellite imagery- found that "Globally, 27 ± 5% of all forest disturbance between 2001 and 2015 was associated with commodity-driven deforestation" whilst "forestry represented 26 ± 4% of total forest disturbance (Table 1), followed by shifting agriculture (24 ± 3%) and wildfire (23 ± 4%). An additional 0.6 ± 0.3% of forest loss was attributed to the intensification and expansion of urban centers."

Emissions from Deforestation

Carbon emissions from deforestation and other recent land-use change activities were recently estimated to be 1.3± 0.7 GtC (4.8 ± 2.6 GtCO2) or 11.6% of global emissions in 2016 (Le Quére et al., 2017). In tropical forests, recent studies have estimated annual gross loss emissions ranging from 0.8 GtC (0.6-1.2 GtC) (Harris et al., 2012), 0.9 GtC (0.6-1.2 GtC) (Achard et al., 2014) to 1.3 GtC (1.2- 1.4 GtC) (Tyukavina et al., 2015).These values for tropical forests correspond to estimates of aboveground carbon (AGC) and belowground carbon (BGC).

In addition to loss of aboveground biomass carbon, significant losses of below ground carbon from soil and emissions of nitrous oxide (N_2O), methane (CH_4), and black carbon (BC) soot can also accompany deforestation processes, particularly when fire is employed as the land clearing technique, and in peatland areas where there are extremely dense underground soil carbon stocks. Conversion of forest to agricultural fields or pasture, for example, has been estimated to result in a 20 to 40 percent decrease in soil carbon (Guo and Gifford, 2002). Nepstad et al. (2009) estimated that ~80% of deforestation in the Amazon rainforest (~19,500 km2 cleared annually from 1996-2005) is the result of the cattle production industry in Brazil. Slash-and-burn (otherwise known as shifting cultivation) probably accounts for the majority of biomass burning in the tropics resulting in significant emissions of not only CO2, but also methane, nitrogen oxides, and black carbon soot (Kindermann 2008, Sohngen and Beach 2006).

Uncertainties in Emissions Reduction from Reducing Deforestation

While the uncertainty in estimating emissions remains large, future emissions due to deforestation of tropical forests have been estimated to be 87 to 130 GtC by between 2000 and 2100 (Houghton et al., 2005; Gullison et al. 2007). On the other hand, “stopping deforestation and allowing secondary forests to grow would yield cumulative negative emissions between 2016 and 2100 of about 120 PgC, globally” (Houghton and Nassikas, 2018).

There exist many uncertainties in preserving or increasing the terrestrial carbon sink including CO2 fertilization, enhanced decomposition, and large-scale or catastrophic release of carbon from terrestrial carbon sinks including forests and soils.

CO2 fertilization is used to “denote increased plant growth due to a higher carbon dioxide concentration” (UNFCCC, 2018). It has been hypothesized to increase the efficiency of photosynthesis and water use thereby leading to net increases in primary productivity. Recent studies, however, suggest that the benefits may be marginal and could be canceled or reversed by other trends of climate change (Long et al., 2006; Schmidhuber and Tubiello, 2007; Brown and Funk, 2008; Lobell et al., 2011).

Enhanced decomposition of biomass may decrease inputs of forest biomass into soil systems and enhance microbial decomposition rates. Additionally, climate change may increase the vulnerability of forests with increased frequency and intensity of droughts, heatwaves, fires, pests, and disease (Flannigan, 2000; Kurz, 2009; Allen, 2010). Many of these can have interacting effects that could decrease the net primary productivity of forest ecosystems. The die-back of boreal pine forests in Canada and the northwest United States due to rising heat levels and bark beetle are one example of this. Warming temperatures allow the bark beetle to increase growth rates and reproductive cycles. Heat stress decreases the ability of the forests to cope with infestations. As forests die, carbon dioxide trapped in forest biomass and soils is released. Recent studies have documented a statistical uptick in forest mortality (Allen et al., 2010). Even normally wet forests are experiencing dieback as the result of drought.

Recently, researchers have become concerned about the growing likelihood of “mega-fires,” anomalously large and catastrophic fires. Mega-fires could result in the emergence of new, less resilient ecosystems capable of storing far less carbon. Malhi et al. (2009) analyze the likelihood of a “die-back” of the Amazonian rainforest and its transition into “fire-dominated, low biomass forests” as a result of climate-change intensified droughts and the resulting increase in fire vulnerability. However, they stress that this “tipping point” can be avoided through a combination of mechanisms which includes expanding protected forest areas (Malhi et al., 2009). These uncertainties constrain our ability to accurately determine exactly how much carbon could be stored or the long-term security of this carbon.

A recent analysis of global forest area disturbance (based on FAO’s latest Global Forest Resources Assessment Report) identified a variable -- yet decreasing -- trend in global forest area burned for the 2003-2012 period under analysis with an average of 50 Mha burned per year, while insect pests and severe weather were the other most significant disturbance agents affecting 85 Mha and 38 Mha on the period of analysis respectively (van Lierop et al., 2015).

A recent review on the effect of climate change on forest disturbance suggests that disturbances from insects, pathogens, droughts, fire, and wind are likely to increase globally whereas disturbances from snow and ice are likely to decrease (Seidl et al., 2017).For the sake of analysis, these potential scenarios (CO_2 fertilization, enhanced decomposition, and forest dieback) are explicitly recognized but are not included in the model owing to large uncertainties.

Forest Protection Strategies

Strategies to avoid deforestation include protection of indigenous lands and conservation reserves (Ricketts et al., 2010), enforcement of existing anti-logging laws by governments (Tacconi, 2009), community-owned forestry cooperatives (Klooster and Masera, 2000), sustainable timber harvesting methods (Putz et al., 2008), alternatives to slash-and-burn (Palm et al., 2005), and payment of ecosystem services and carbon sequestration to landowners.

Wunder (2005) coined the definition of Payment for Ecosystem Services (PES) based on 5 criteria, “a voluntary transaction where a well-defined ES (or a land-use likely to secure that service) is being ‘bought’ by a (minimum one) ES buyer from a (minimum one) ES provider if and only if the ES provider secures ES provision (conditionality).” (page 3). PES are used “as a mechanism to translate external, non-market values of the environment into real financial incentives for local actors to provide such services” (Engel et al., 2008, page 664). Most of the schemes include carbon sequestration and storage, biodiversity protection, watershed protection, and protection of landscape beauty.

A recent review on the global trends and status of PES schemes has identified “over 550 active programmes around the globe and an estimated US$ 36–42 billion in annual transactions”, with 387 PES (US$ 24.7 Billion in 2015) on watershed services, 120 PES (US$ 2.5- 8.4 Billion in global transactions per year) on biodiversity and habitat, and “48 forest and land-use carbon PES programmes: 31 government-financed and 17 compliance” in over 67 countries with a spending of US$ 2.8 billion since 2009 (Salzman et al., 2018).

The UN Programme on Reducing Emissions from Deforestation and Forest Degradation (REDD+) is a key policy initiative that was established a decade ago. Despite the optimistic take on the program's progress (Brockhaus et al., 2017), other studies determined that is has not met expectations (Creed and van Noordwijk, 2018; Minang and van Noordwijk, 2013; Matthews et al., 2014; Matthews and van Noordwijk, 2014). In addition, "evidence suggests that REDD+ is failing to promote forest governance and tenure as a focus for action in the forest sector, which must be corrected (Angelsen et al., 2017; Fletcher et al., 2016; Sunderlin et al., 2018)" (Dooley et al., 2017).

Alternatives to slash-and-burn are central to reducing deforestation and lowering global carbon emissions. Pervading economic and social conditions present formidable challenges particularly for smallholders and subsistence agriculturalists to have the necessary means for implementing alternatives, however (Palm et al., 2005). The total amount of carbon emissions that can be avoided is highly dependent on adopted policies (particulary REDD+), enforcement of existing laws restricting deforestation, the price of carbon as an incentive for forest conservation, and changes to agricultural practices which could either increase or decrease the demand for arable land clearing and thus deforestation.

Following Project Drawdown´s definition of forest protection as the legal protection of forest lands, the role of the government agency level for this solution is crucial. Governments not only have the power to implement legal structures to protect forest areas, but also have the authority to enforce them.

Challenges for Forest Protection

Challenges to ensuring successful forest protection are monitoring, reporting, and verifying that forests aren't being deforested, as well as assuring that conserving forests in one place does not lead to deforestation elsewhere-- a phenomenon known as "leakage". Monitoring ecosystem performance benefits from tools such as remote sensing of vegetative cover, canopy thinning, fire extent, hydrologic functioning, temperature, and soil exposure, coupled with limited in-situ observations and data collection such as species counts and indexes (particularly with regards to "indicator species"), leaf area index measurements, streamflow measurements, and so forth (Stickler et al., 2009). The World Resource Institute (WRI) and Google recently partnered to create Global Forest Watch (globalforestwatch.org) which provides customizable and near real-time monitoring of deforestation around the world.

Assessing the financial costs and benefits of avoided deforestation is challenging because it often involves a policy intervention to generate the desired outcome, as opposed to other strategies which may be economically advantageous without any policy intervention required. Fundamentally, payments toward landowners, forest dwellers, and other groups to make conserving forests more economically advantageous than clearing them (Jackson and Baker, 2010). Economic benefits of avoided deforestation do exist, but largely in the form of flows that are difficult to quantify, for example, non-timber forest products, ecosystem services, and cultural and aesthetic benefits. Other less obvious economic benefits could accrue. For example, greater than 50% of timber exported from the Central African Basin, South East Asia, the Amazon, and Russia is illegally harvested and leads to losses of $10-15 billion per year (World Bank). Generally, the total carbon sequestration potential of avoided deforestation is quantified by specifying a price for conservation in terms of tons of CO_2-eq avoided. Kindermann et al. (2008) found that a 10% reduction in deforestation would cost 0.4 to 1.7 billion USD per year from 2005 to 2030 with a total emissions reduction of 300 to 600 $MtCO_2$-eq per year. Boucher (2008) found that reducing deforestation by 20%, 50%, and 65% would cost approximately $5, $20, and $50 billion per year.

1.2. Adoption Path

1.2.1 Current Adoption

Current adoption of *forest protection* is 651.0 million hectares (FAO, 2016). Heino et al. (2015) provide an alternative adoption value of 785 Mha in 2012 which, using the yearly average rate based on the 12-year forest loss from the paper, results in 779 Mha of protected forest in 2015. Given that the difference between both adoption values for 2015 is quite significant coupled with the fact that FAO (2016) is widely cited, the Heino et al. (2015) data point has been excluded from the analysis.

1.2.2 Trends to Accelerate Adoption

Globally, a common consensus has been made to protect forests from any additional deforestation in the future. Internationally and nationally, countries are making commitments for preserving their forest area. For example, The New York Declaration on Forests -- a non-legally binding agreement signed in 2014 currently endorsed by 190 entities (including over 40 national governments) -- aims to “at least halve the rate of loss of natural forests globally by 2020 and strive to end natural forest loss by 2030” (NYDF Global Platform).

Other relevant adoption pathways include:

- The Convention on Biological Diversity (Aichi target 5) – By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced” (Aichi Biodiversity targets).
- The United Nations Global Goals (Target 6.6) – By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes", one of the several targets which refer to forests (targets 15.1, 15.2 and 15.B are also relevant). (https://www.globalgoals.org/6-clean-water-and-sanitation)

- The World Business Council for Sustainable Development's Vision 2050 – The forests of 2050 have regained much of their capacity to protect against climate change and biodiversity loss and to meet the resource needs of society. Forests cover 30% of world land area. The total stock of carbon sequestered in forests is more than 10% greater than 2010 levels. Deforestation has significantly reduced. Primary forest coverage is held intact and expanded somewhat. Primary forests are no longer used for wood, wood products, new farmland, or biomass. This practice sequesters carbon and protects biodiversity, water, and additional ecosystem services (WBCSD, 2010).

The global rate of deforestation has halved in the past 25 years: decreasing from 0.18% in 1990-2000 to 0.08 % in 2010- 2015 (Table 1.2.). However, regional and country-level rates of deforestation are still high. In our analysis, we have used Heino et al. (2015)'s country-level detail for non-protected forest area change in 2000-2012 to estimate an annual global deforestation rate of 0.47%.

Table 1.2: Deforestation area and rate

Period	Deforested Area (Mha)	Rate of Deforestation (%)
1990-2000	7.27	0.18
2000-2005	4.57	0.11
2005-2010	3.41	0.08
2010-2015	3.31	0.08

Source: FAO, 2016

The FAO 2016 report clearly stated the following points:

- Forests and forest management changed substantially over the past 25 years.
- The rate of net forest loss was cut by over 50 percent in the last 25 years.
- The period also witnessed much attention paid to sustainable forest management (SFM) initiatives.
- Thus, more land has been protected in the form of permanent forest.
- Significant efforts have been made for assessment, monitoring, reporting, planning, and stakeholder involvement towards SFM.
- There was an increase in area under international forest management certification schemes: from 14 million ha in 2000 to 438 million ha in 2014, of which 58 percent was under the Programme for the Endorsement of Forest Certification scheme and 42 percent was under the Forest Stewardship Council certification scheme.

Thus, there are promising signs that indicate that, in the future, efforts towards forest protection will continue with much stronger commitments and deadlines at the national and international level.

1.2.3 Barriers to Adoption

Avoiding deforestation could increase pressure on the existing agricultural lands for meeting the increasing demand for food production, forestry products, biofuels, and other products. The global population is expected to increase from 7.2 billion in 2014 to 9.6 billion by 2050 and 10.5 billion by 2100. The increase in population has been estimated largely for developing countries, where the vast majority of tropical forests are located (UNEP, 2013). Kothke et al. (2013) analysis on 140 countries identified an increase in population density as a driver of forest cover reduction (Kothke et al., 2013; Creed and van Noordwijk, 2018). In addition, increasing urbanization will apply more pressure on tropical deforestation (deFries et al., 2010; Creed and van Noordwijk, 2018).

Although emissions from deforestation and land-use change are already seeing declining trends, there is the possibility that deforestation will be avoided even under business-as-usual (BAU) scenarios where the mitigation of climate change is not prioritized. On the other hand, it appears likely that deforestation rates may again climb to meet the demand for food production, as projected to increase by >70% by 2050. As a result, either more food will need to be grown on existing crop and pasture land, or more forests and other ecosystems will need to be converted to food production.

Despite leading companies' commitment to achieving zero-deforestation from commodity supply-chains (Donofrio et al., 2017), Curtis et al. (2018) stress "that policies designed to achieve zero-deforestation commitments are not being adopted or implemented at the pace needed to meet 2020 goals".

Zarin et al. (2016) scenario-based analysis of the feasibility of halving deforestation by 2020 as aimed by the New York Declaration on Forests highlights the key role Brazil -- which is not a signatory of the NYDF -- should play.

1.2.4 Adoption Potential

Gullison et al. (2007) suggested that avoided deforestation in countries where 50% of the land area has been deforested and the rate of deforestation is now slowing, will prevent emissions of ~50 gigatons of carbon dioxide equivalent by 2050. Nabuurs et al. (2007) using bottom-up models suggested that the mitigation potential of forestry options could lead to emissions reductions of 0.44 to 0.74 gigatons of carbon dioxide equivalent per year at prices of 20 to 100 USD per ton of carbon dioxide equivalent, respectively, by 2030. Top-down models suggested much larger mitigation potential of 13.76 gigatons of carbon dioxide in 2030 at prices 100 USD tCO_2eq^{-1} or below (Nabuurs et al., 2007). Kindermann et al. (2008) suggest that "A program providing a 10% reduction in deforestation from 2005 to 2030 could provide 0.3–0.6 gigatons of carbon dioxide per year in emission reductions and would require \$0.4 billion to \$1.7 billion yr^{-1} for 30 years. A 50% reduction in deforestation from 2005 to 2030 could provide 1.5–2.7 gigatons of carbon dioxide per year in emission reductions and would require $17.2 billion to $28.0 billion per year." The most recent IPCC assessment finds that: "The economic potential of supply-side measures is estimated to be 7.2 to 11 gigatons of carbon dioxide per year in 2030 for mitigation efforts consistent with carbon prices up to 100 USD per ton of carbon dioxide equivalent, about a third of which can be achieved at a <20 USD per ton of carbon dioxide equivalent."

Grassi et al. (2017) analysis of the National Determined contributions stresses on the key role 'forest-based' climate mitigation could play in meeting Paris Climate Agreement's target, with a mitigation contribution from the land-use sector in 2030 "ranging from 0.8 to 3.1 GtCO2e yr-1 for unconditional (I)NDCs and from 1.5 to 3.8 GtCO2e yr-1 for conditional (I)NDCs".

1.3 Advantages and Disadvantages of Forest Protection

1.3.1 Similar Solutions

Protection Solutions

Peatlands and mangroves are types of forests with extremely high carbon stocks. These are thus distinct subtypes of forest protection and are analyzed as separate solutions. Indigenous forest management – another separate solution – 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, salt marshes, seagrass beds, ocean areas) is also important for maintaining carbon stocks.

Restoration Solutions

Ecosystem restoration efforts (for forests, coastal wetlands, etc.) restore healthy ecosystems on degraded land and then protect them.

1.3.2 Arguments for Adoption

The solution will lead to the enhancement of ecological services associated with forests which, in turn, leads to:

- Water regulation by intercepting rainfall and regulating its flow through the hydrological system;
- Improvement in soil quality by increasing the soil organic carbon content as provided by the organic matter of the forests;

- Control in soil erosion, as the soils of the forest are bound by the roots of the trees. Also, the forest provides a vegetative barrier to water flow and thus controls the flow of water resulting in a minimal amount of soil erosion;
- Enriching biodiversity components by enabling environments for micro and macro flora and fauna;
- Regulating air quality and thus providing a healthy and clean environment for human beings;
- Increasing the aesthetic value of an area

1.3.3 Additional Benefits and Burdens

Here this solution is compared with other solutions in the food production cluster for farm, ecosystem, and social impacts.

Table 1.3: 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*

	First Cost $/ha	Net Profit $/ha	Value of Ecosystem Services	Timber and Biomass Production
Bamboo	Expensive	Medium	High	Increase
Forest Plantations	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 1.4 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
Bamboo	Medium	Relevant	High	Medium
Forest Plantations	Medium to High	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[1]) 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.

2.2 DATA SOURCES

Key data sources include the GAEZ database and FAO forest area data. Morales et al (2015) provided estimates of the current area of protected forest. Data from 19 peer-reviewed papers was used in the model.

2.3 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 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

[1] 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.

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.

The total land area available for the *forest protection* solution was modeled using the annual rate of forest degradation and calculations of future degraded and non-degraded areas. The projected future non-degraded, non-protected area was set as the total available area for protection. This maximum area allocated to *forest protection* is 1,060 million hectares.

2.4 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. <u>Total at risk land in the PDS</u> - 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. <u>Total undegraded land in the PDS</u> - 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. <u>Cumulative Degraded Land Under Protection in the PDS</u> - 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.

Ten custom adoption scenarios were developed for *forest protection.* All begin with current adoption of 651.0 million hectares (61 percent of the total area allocated to this solution). A total of 1,060 million hectares of non-degraded forest area was allocated to this solution.

The historical protected area evolution (1990-2015) in Morales-Hidalgo et al. (2015) was used to estimate three protected areas' yearly increase rates: 1,98%; 1,02% and 0,55% for the forest protected area increases corresponding to 1990-2015, 2005- 2015 and 2010- 2015 respectively. This, coupled with the TLA's current degradation rate of 0.47% result in scenarios 1, 2 and 3. The New York declaration on Forests is used to estimate an alternative degradation rate which starts from 0.47% and linearly decreases to half its value in 2020 and then to zero in 2030. The yearly increase rates from Morales- Hidalgo et al. (2015) plus this degradation rate result in scenarios 4, 5 and 6. Details on the ten custom adoption scenarios are given below:

- *Custom adoption scenario one "High adoption and conservative degradation rate"*: In this scenario, there is a 1.98% yearly increase in forest protected area and the unprotected forest area is affected by the conservative degradation rate of 0.47%.

- *Custom adoption scenario two "Medium adoption and conservative degradation rate"*: In this scenario, there is a 1.02% yearly increase in forest protected area and the unprotected forest area is affected by the conservative degradation rate of 0.47%.
- *Custom adoption scenario three "Low adoption and conservative degradation rate"*: In this scenario, there is a 0.55% yearly increase in forest protected area and the unprotected forest area is affected by the conservative degradation rate of 0.47%.
- *Custom adoption scenario four "High adoption and low degradation rate"*: In this scenario, there is a 1.98% yearly increase in forest protected area and the unprotected forest area is affected by the low degradation rate which decreases from 0.47% in 2014 to zero from 2030 onwards.
- *Custom adoption scenario five "Medium adoption and low degradation rate"*: In this scenario, there is a 1.02% yearly increase in forest protected area and the unprotected forest area is affected by the low degradation rate which decreases from 0.47% in 2014 to zero from 2030 onwards
- *Custom adoption scenario six "Low adoption and low degradation rate"*: In this scenario, there is a 0.55% yearly increase in forest protected area and the unprotected forest area is affected by the low degradation rate which decreases from 0.47% in 2014 to zero from 2030 onwards.
- *Custom adoption scenario seven "100% conservative degradation TLA in 2030"*: In this scenario, there is a linear increase up to 100% of TLA value in 2050 reached in 2030 (calculated with the conservative degradation rate).
- *Custom adoption scenario eight "90% conservative degradation TLA in 2030"*: In this scenario, there is a linear increase up to 90% of TLA value in 2050 reached in 2030 (calculated with the conservative degradation rate).
- *Custom adoption scenario nine "100% low degradation TLA in 2030"*: In this scenario, there is a linear increase up to 100% of TLA value in 2050 reached in 2030 (calculated with the low degradation rate).
- *Custom adoption scenario ten "90% conservative degradation TLA in 2030"*: In this scenario, there is a linear increase up to 90% of TLA value in 2050 reached in 2030 (calculated with the low degradation rate).

Impacts of increased adoption of *forest protection* 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.

2.4.1 Reference Case / Current Adoption[2]

Current adoption of *forest protection* is 651.0 million hectares (MacDicken et. al., 2015).

2.4.2 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 adopted for the plausible scenario, and future growth of the solution is estimated based on the "average of all" custom adoption scenarios as listed above.

Drawdown Scenario – For the drawdown scenario, highly ambitious approach is adopted, and future growth of the solution is estimated based on the "custom adoption scenario 4", scenario with high adoption and low degradation rate.

Optimum Scenario - For the optimum scenario, highly ambitious approach is adopted, and future growth of the solution is estimated based on the "high of all" custom adoption scenarios as listed above.

Note that even in most optimistic scenario, 100 percent protection of forest 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.

2.5 INPUTS

2.5.1 Climate Inputs

One-time emissions from deforestation (above and below- ground carbon) are set at 280.87 tons of carbon dioxide-equivalent per hectare, a low conservative estimate based on meta-analysis of 19 data points from 6 sources was considered.

[2] 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.

Table 2.1 Climate Inputs

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Avoided emissions from deforestation	*tCO2-e (one-time)*	280.87 - 578.34	280.87	19	6
Biosequestration	*tC/ha/yr*	0.70-0.97	0.84	7	2

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

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.

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[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.

2.5.2 Financial Inputs

It is assumed that any costs for *forest 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.

2.5.3 Other Inputs

The average annual forest degradation rate was calculated using the country level data on total forest area loss (excluding protected forest area) for 2000-2012 from Heino et al. (2015). The other dataset includes Global Forest Assessment Report 2015 report, having country level data on forest extent. Despite the report includes an evolution of the total forest area for 1990- 2015, the information on protected forest area is scarcer, consisting of only two values: 651 Mha for 2015 and a reference to the protected forest area having increased by 200 Mha since 1990. Moreover, Heino et al. (2015) provides information on country level disturbance rate. Thus, the current estimates on annual rate of forest degradation and disturbance at the global scale was calculated based on the Heino et al. (2015) country level data.

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Growth rate of land degradation	*% of land degraded annually*	n/a	0.47%	1	1
Disturbance rate	*% of land disturbed annually*	n/a	0.23%	1	1

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

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

Assumption 2: Countries with larger forest area and with high rate of deforestation are more at risk of future deforestation.

Assumption 3: Efforts will be laid at the national and international level to protect forest resources. Countries will make binding commitments and will protect a significant portion of their forest area.

Assumption 4: A lower rate of carbon sequestration is observed and used in the model, as it is believed that these primary forests have already reached or are near saturation of their carbon sequestration saturation level.

Assumption 5: 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 the protection of forest 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 protection model, it is assumed that the carbon benefits of protecting the forest will be realized one year later.

Assumption 6: It is assumed that the re-growth of the degraded forest area will start one year later after the forest will be brought under protection.

Assumption 7: Assumption for incorporating the delay in impact due to the time taken by the agencies to actually bring a forest under protection - It is assumed that the required agency level legalities to bring a forest under protection 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 forest area under protection. Therefore the "year of protection" is assumed to be the "year of implementation".

2.7 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.

Forest protection is part of Drawdown's Land Use sector. Within land use it is part of a cluster of solutions based on 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 of a given solution. Data on global land is acquired from 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.

Drawdown's Agro-Ecological Zone model allocates current and projected adoption of solutions to the planet's forest, grassland, rainfed cropland, and irrigated cropland areas. *Forest protection* was the fourth priority for use of non-degraded forest, following *peatlands*, mangrove protection (in the *coastal wetlands* solution), and *indigenous peoples' land management* (all of these are forms of forest protection).

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, 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, 2nd generation biofuels, building with wood, insulation, small-scale biogas,* and *district heating.* Adoption of this solution reduces biomass availability from forests.

2.8 Limitations/Further Development

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

3. Results

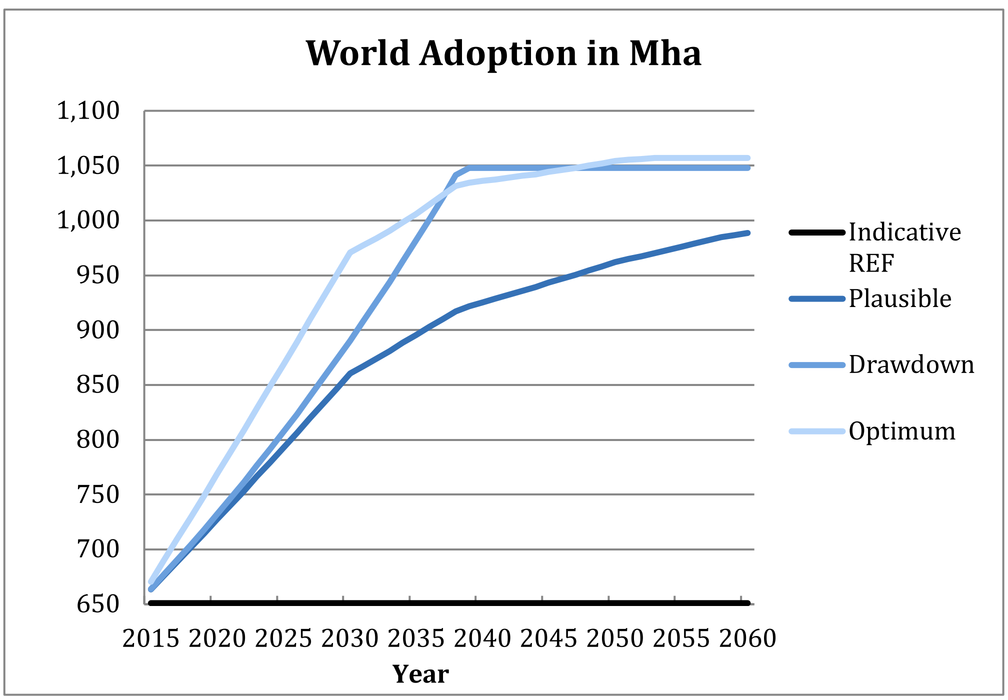
3.1 Adoption

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

Total adoption in the *Plausible* Scenario is 961.87 million hectares in 2050, representing 91 percent of the total suitable land in 2014. Of this, 310.87 million hectares are adopted from 2020-2050.

Total adoption in the *Drawdown* Scenario is 1047.90 million hectares in 2050, representing 99.14 percent of the total suitable land in 2014. Of this, 396.90 million hectares are adopted from 2020-2050.

Total adoption in the *Optimum* Scenario is 1,054.46 million hectares in 2050, representing 99.76 percent of the total suitable land. Of this, 403.46 million hectares are adopted from 2020-2050.



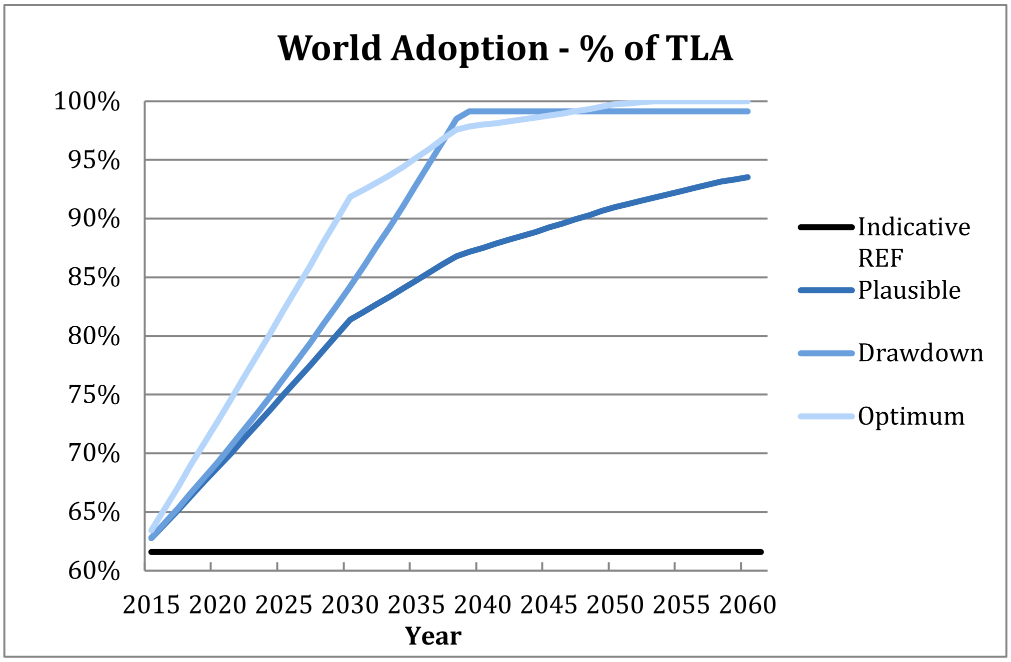


Figure 3.1 World Annual Adoption 2020-2050 [Mha]

Table 3.1 World Adoption of the Solution

Solution	Units	Base Year (2014)	New Adoption by 2050		
			Plausible	Drawdown	Optimum
Forest Protection	Mha	651	310.87	396.90	403.46
	% Total Land Available	61.6%	91.00%	99.14%	99.76%

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).

Emissions reduction impact is 5.26, 6.79 and 7.56 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	0.18	4.10	0.09	1.16	5.26	0.14	0.27
Drawdown	0.23	5.36	0.11	1.43	6.79	0.16	0.34
Optimum	0.23	5.83	0.13	1.73	7.56	0.22	0.36

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).

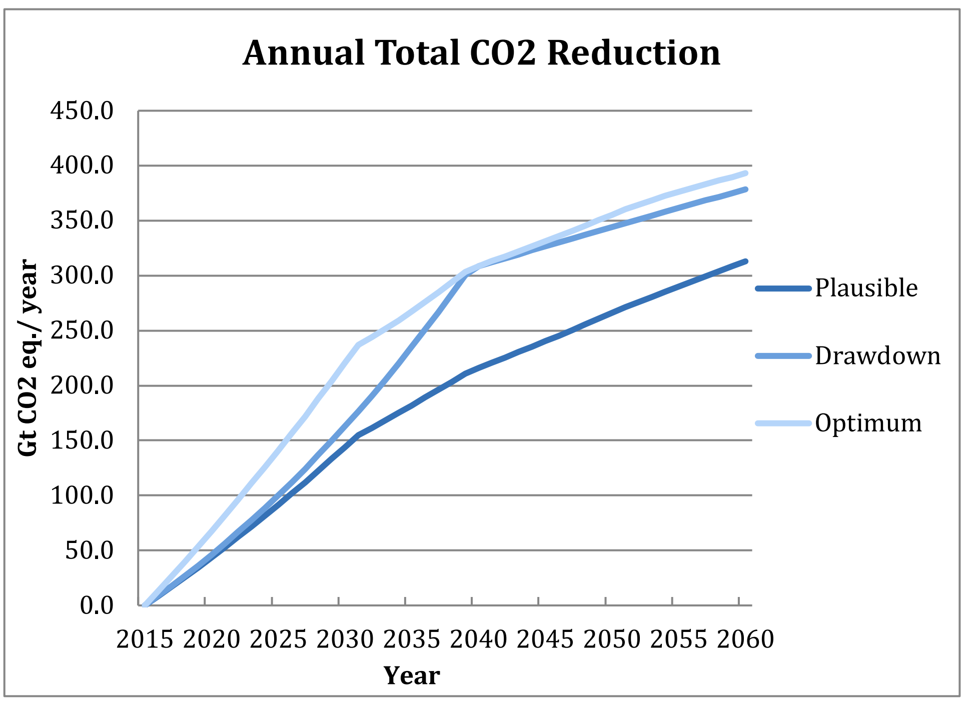


Figure 3.2 World Annual Greenhouse Gas Emissions Reduction

Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq

Scenario	GHG Concentration Change in 2050	GHG Concentration Rate of Change in 2050
	PPM CO_2-eq (2050)	*PPM CO_2-eq change from 2049-2050*
Plausible	0.437	0.020
Drawdown	0.568	0.025
Optimum	0.624	0.025

1.4 Financial Impacts

Currently financial impacts are not modeled for this solution.

3.1. Other Impacts

Protection of high carbon ecosystems, like protection of intact forests 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.

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	14.73	638.7	174.3
Drawdown	19.24	696.9	190.2
Optimum	21	700.2	191.1

4. Discussion

Forests are cleared for timber extraction, for firewood, and to prepare new farmland, among other reasons. Several Drawdown solutions offset the loss of these yields to some degree. *Afforestation* and *bamboo* produce timber. *Clean cookstoves* helps reduce the need for firewood through adoption of efficient stoves. And *farmland restoration* brings abandoned farmland back into production, reducing the need to clear land. *Plant-rich diet* and *reduced food waste* lower food demand and thus the need for forest clearing, as do population solutions *educating girls* and *family planning.*

Climate activists have made "keep it in the ground" a slogan in regard to fossil carbon like oil and coal. Climate mitigation requires us to keep forest carbon in the ground.

4.1 Limitations

This solution does not model avoided deforestation from agricultural intensification or reduced food demand due to diet change or food waste reduction. Inclusion of economic impacts, e.g. costs to governments and NGOs, would be a valuable addition to future updates.

4.2 Benchmarks

Griscom et al (2017)'s "Natural climate solutions" calculates an annual impact from "avoided forest conversion" of 1.82-3.60 gigatons of carbon dioxide equivalent per year in 2030. It is not clear if their figure includes avoided land use from demand reduction, or only forest protection. Note that Food sector solutions *reduced food waste* and *plant-rich diet* also incorporate substantial avoided land use change emissions not accounted for here.

Grassi et al. (2017) analysis of full- implementation of '(Intended) Nationally Determined Contributions ((I)NDCs) shows that "land use, and forests in particular, emerge as a key component of the Paris Agreement: turning globally from a net anthropogenic source during 1990‑2010 (1.3 +- 1.1 GtCO2e yr-1) to a net sink of carbon by 2030 (up to -1.1 +- 0.5 GtCO2e yr-1), and providing a quarter of emission reductions planned by countries" with a range of 0.8-3.1 GtCO2e yr-1 to 1.5- 3.8 GtCO2e yr-1 for unconditional and conditional (I)NDCs mitigation calculation respectively.

Dooley et al. (2018)'s "Missing Pathways to 1.5°C: The role of the land sector in ambitious climate action" analysis on ecosystem- based approaches "estimate the mitigation potential from avoided forest loss as equivalent to current global emissions (from both deforestation and degradation), at 4.07 Gt CO2/year" by 2050.

Table 4.1 Benchmarks

Source and Scenario	Assumptions	Mitigation Impact Gt $CO_{2\text{-}eq}$ in 2030
Grassi (2017)	Forest-based solutions	0.8-3.8
Dooley (2018)	Avoided forest loss	4.07
Griscom (2017)	Avoided forest conversion	1.82-3.60
Plausible Scenario	Forest protection and Indigenous People's forest management	0.23
Drawdown Scenario	Forest protection and Indigenous People's forest management	0.31
Optimum Scenario	Forest protection and Indigenous People's forest management	0.40

5. References

2017SupplyChange_Trackin-Committments.pdf. (n.d.). Retrieved from https://www.forest-trends.org/wp-content/uploads/2018/04/2017SupplyChange_Trackin-Committments.pdf

Achard, F., Beuchle, R., Mayaux, P., Stibig, H.-J., Bodart, C., Brink, A., … Simonetti, D. (2014). Determination of tropical deforestation rates and related carbon losses from 1990 to 2010. *Global Change Biology*, *20*(8), 2540–2554. https://doi.org/10.1111/gcb.12605

Aichi Biodiversity Targets. (n.d.). Retrieved December 30, 2018, from https://www.cbd.int/sp/targets/

Baccini, A., Goetz, S. J., Walker, W. S., Laporte, N. T., Sun, M., Sulla-Menashe, D., … Houghton, R. A. (2012a). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change*, *2*(3), 182–185. https://doi.org/10.1038/nclimate1354

Baccini, A., Goetz, S. J., Walker, W. S., Laporte, N. T., Sun, M., Sulla-Menashe, D., … Houghton, R. A. (2012b). Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps. *Nature Climate Change*, *2*(3), 182–185. https://doi.org/10.1038/nclimate1354

Bhaskar Vira, Christoph Wildburger and Stephanie Mansourian (eds.). (2015). *Forests and Food: Addressing Hunger and Nutrition Across Sustainable Landscapes*. https://doi.org/10.11647/OBP.0085

Bonn Challenge: A World of Opportunity | Global Partnership on Forest and Landscape Restoration. (2016, November 13). Retrieved November 12, 2016, from http://www.forestlandscaperestoration.org/resource/bonn-challenge-world-opportunity

Briefing-1-REDD-costs-w-endnotes.pdf. (n.d.). Retrieved from https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_energy/Briefing-1-REDD-costs-w-endnotes.pdf

Brockhaus, M., Korhonen-Kurki, K., Sehring, J., Di Gregorio, M., Assembe-Mvondo, S., Babon, A., … Zida, M. (2017). REDD+, transformational change and the promise of performance-based payments: a qualitative comparative analysis. *Climate Policy*, *17*(6), 708–730. https://doi.org/10.1080/14693062.2016.1169392

Carbon Sequestration and Plant Community Dynamics Following Reforestation of Tropical Pasture :: Tropical Native Species Reforestation Information Clearinghouse (TRIC). (2016, November 19). Retrieved November 19, 2016, from http://reforestation.elti.org/resource/95/

Chatterjee, N., Nair, P. K. Ramachandran., Chakraborty, S., & Nair, V. D. (2018a). Changes in soil carbon stocks across the Forest-Agroforest-Agriculture/Pasture continuum in various agroecological regions: A meta-analysis. *Agriculture, Ecosystems & Environment*, *266*, 55–67. https://doi.org/10.1016/j.agee.2018.07.014

Chatterjee, N., Nair, P. K. Ramachandran., Chakraborty, S., & Nair, V. D. (2018b). Changes in soil carbon stocks across the Forest-Agroforest-Agriculture/Pasture continuum in various agroecological regions: A meta-analysis. *Agriculture, Ecosystems & Environment*, *266*, 55–67. https://doi.org/10.1016/j.agee.2018.07.014

Chhatre, A., & Agrawal, A. (2009). Trade-offs and synergies between carbon storage and livelihood benefits from forest commons. *Proceedings of the National Academy of Sciences*, *106*(42), 17667–17670. https://doi.org/10.1073/pnas.0905308106

Creating an appropriate tenure foundation for REDD+: The record to date and prospects for the future - ScienceDirect. (n.d.). Retrieved December 10, 2018, from https://www.sciencedirect.com/science/article/pii/S0305750X18300202

Curtis, P. G., Slay, C. M., Harris, N. L., Tyukavina, A., & Hansen, M. C. (2018). Classifying drivers of global forest loss. *Science*, *361*(6407), 1108–1111. https://doi.org/10.1126/science.aau3445

Deforestation driven by urban population growth and agricultural trade in the twenty-first century | Nature Geoscience. (n.d.). Retrieved November 30, 2018, from https://www.nature.com/articles/ngeo756

DeFries, R. S., Rudel, T., Uriarte, M., & Hansen, M. (2010). Deforestation driven by urban population growth and agricultural trade in the twenty-first century. *Nature Geoscience*, *3*(3), 178–181. https://doi.org/10.1038/ngeo756

Design challenges for achieving reduced emissions from deforestation and forest degradation through conservation: Leveraging multiple paradigms at the tropical forest margins - ScienceDirect. (n.d.). Retrieved December 10, 2018, from https://www.sciencedirect.com/science/article/abs/pii/S0264837712000944

Dixon, R. K., Solomon, A. M., Brown, S., Houghton, R. A., Trexier, M. C., & Wisniewski, J. (1994). Carbon Pools and Flux of Global Forest Ecosystems. *Science*, *263*(5144), 185–190. https://doi.org/10.1126/science.263.5144.185

Donofrio et al. (2017), Supply Change-tracking corporate commitments to deforestation- free supply chains.pdf. (n.d.).

Dooley, K et al. (n.d.-a). *Missing Pathways to 1.5°C: The role of the land sector in ambitious climate action.* (p. 53). Climate Land Ambition and Rights Alliance.

Drivers of deforestation and forest degradation: A synthesis report for REDD+ policymakers. (n.d.). Retrieved November 29, 2018, from https://www.cifor.org/library/5167

DriversOfDeforestation.pdf. (n.d.).

Ellison, D., Morris, C. E., Locatelli, B., Sheil, D., Cohen, J., Murdiyarso, D., … Sullivan, C. A. (2017). Trees, forests and water: Cool insights for a hot world. *Global Environmental Change*, *43*, 51–61. https://doi.org/10.1016/j.gloenvcha.2017.01.002

Engel, S., Pagiola, S., & Wunder, S. (2008). Designing payments for environmental services in theory and practice: An overview of the issues. *Ecological Economics*, *65*(4), 663–674. https://doi.org/10.1016/j.ecolecon.2008.03.011

FAO (Ed.). (2018). *Forests pathways to sustainable development*. Rome: FAO.

Federici, S., Tubiello, F. N., Salvatore, M., Jacobs, H., & Schmidhuber, J. (2015). New estimates of CO2 forest emissions and removals: 1990–2015. *Forest Ecology and Management*, *352*, 89–98. https://doi.org/10.1016/j.foreco.2015.04.022

Feldpausch, T. R., Rondon, M. A., Fernandes, E., Riha, S. J., & Wandelli, E. (2004). *Carbon and nutrient accumulation in secondary forests regenerating on pastures in central Amazonia*. Retrieved from https://ore.exeter.ac.uk/repository/handle/10871/9525

Fletcher, R., Dressler, W., Büscher, B., & Anderson, Z. R. (2016). Questioning REDD+ and the future of market-based conservation. *Conservation Biology*, *30*(3), 673–675. https://doi.org/10.1111/cobi.12680

Gilroy, J. J., Woodcock, P., Edwards, F. A., Wheeler, C., Baptiste, B. L. G., Medina Uribe, C. A., … Edwards, D. P. (2014). Cheap carbon and biodiversity co-benefits from forest regeneration in a hotspot of endemism. *Nature Climate Change*, *4*(6), 503–507. https://doi.org/10.1038/nclimate2200

Glossary. (n.d.). Retrieved December 10, 2018, from http://unfccc.int/resource/cd_roms/na1/ghg_inventories/english/8_glossary/Glossary.htm

Goal 6: Clean Water and Sanitation. (n.d.). Retrieved December 30, 2018, from The Global Goals website: https://www.globalgoals.org/6-clean-water-and-sanitation

Grassi, G., House, J., Dentener, F., Federici, S., den Elzen, M., & Penman, J. (2017). The key role of forests in meeting climate targets requires science for credible mitigation. *Nature Climate Change*, *7*(3), 220–226. https://doi.org/10.1038/nclimate3227

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., … Fargione, J. (2017a). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., … Fargione, J. (2017b). Natural climate solutions. *Proceedings of the National Academy of Sciences*, *114*(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Guariguata, M. R., & Ostertag, R. (2001). Neotropical secondary forest succession: changes in structural and functional characteristics. *Forest Ecology and Management*, *148*(1), 185–206.

Harris, N. L., Brown, S., Hagen, S. C., Saatchi, S. S., Petrova, S., Salas, W., … Lotsch, A. (2012). Baseline Map of Carbon Emissions from Deforestation in Tropical Regions. *Science*, *336*(6088), 1573–1576. https://doi.org/10.1126/science.1217962

Heino, M., Kummu, M., Makkonen, M., Mulligan, M., Verburg, P. H., Jalava, M., & Räsänen, T. A. (2015). Forest Loss in Protected Areas and Intact Forest Landscapes: A Global Analysis. *PLOS ONE*, *10*(10), e0138918. https://doi.org/10.1371/journal.pone.0138918

Houghton, R. A., & Nassikas, A. A. (2017). Global and regional fluxes of carbon from land use and land cover change 1850-2015: Carbon Emissions From Land Use. *Global Biogeochemical Cycles*, *31*(3), 456–472. https://doi.org/10.1002/2016GB005546

Houghton, Richard A. (2013). The emissions of carbon from deforestation and degradation in the tropics: past trends and future potential. *Carbon Management*, *4*(5), 539–546. https://doi.org/10.4155/cmt.13.41

Houghton, Richard A., & Nassikas, A. A. (2018). Negative emissions from stopping deforestation and forest degradation, globally. *Global Change Biology*, *24*(1), 350–359. https://doi.org/10.1111/gcb.13876

Hyvönen, R., \AAgren, G. I., Linder, S., Persson, T., Cotrufo, M. F., Ekblad, A., … others. (2007). The likely impact of elevated [CO2], nitrogen deposition, increased temperature and management on carbon sequestration in temperate and boreal forest ecosystems: a literature review. *New Phytologist*, *173*(3), 463–480.

Irena F. Creed and Meine van Noordwijk (eds.),. (n.d.). *Forest and Water on a Changing Planet: Vulnerability, Adaptation and Governance Opportunities. A Global Assessment Report.* (p. 192). Retrieved from

International Union of Forest Research Organizations (IUFRO) website: https://www.iufro.org/publications/article/2018/07/10/world-series-vol-38-forest-and-water-on-a-changing-planet-vulnerability-adaptation-and-governan/

Jacobi, J. (2016). *WOCAT Case Study - Dynamic Agroforestry in Bolivia*.

Keenan, R. J., Reams, G. A., Achard, F., de Freitas, J. V., Grainger, A., & Lindquist, E. (2015a). Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management*, *352*, 9–20. https://doi.org/10.1016/j.foreco.2015.06.014

Keenan, R. J., Reams, G. A., Achard, F., de Freitas, J. V., Grainger, A., & Lindquist, E. (2015b). Dynamics of global forest area: Results from the FAO Global Forest Resources Assessment 2015. *Forest Ecology and Management*, *352*, 9–20. https://doi.org/10.1016/j.foreco.2015.06.014

Köthke, M., Leischner, B., & Elsasser, P. (2013). Uniform global deforestation patterns — An empirical analysis. *Forest Policy and Economics*, *28*, 23–37. https://doi.org/10.1016/j.forpol.2013.01.001

Lamb, D., Erskine, P. D., & Parrotta, J. A. (2005). Restoration of Degraded Tropical Forest Landscapes. *Science*, *310*(5754), 1628–1632. https://doi.org/10.1126/science.1111773

Lambin, E. F., & Meyfroidt, P. (2011). Global land use change, economic globalization, and the looming land scarcity. *Proceedings of the National Academy of Sciences*, *108*(9), 3465–3472.

Le Quéré, C., Andrew, R. M., Friedlingstein, P., Sitch, S., Pongratz, J., Manning, A. C., … Zhu, D. (2017). Global Carbon Budget 2017. *Earth System Science Data Discussions*, 1–79. https://doi.org/10.5194/essd-2017-123

Learning from REDD+: a response to Fletcher et al. - Angelsen - 2017 - Conservation Biology - Wiley Online Library. (n.d.). Retrieved December 10, 2018, from https://onlinelibrary.wiley.com/doi/full/10.1111/cobi.12933

Lewis, S. L., Lopez-Gonzalez, G., Sonké, B., Affum-Baffoe, K., Baker, T. R., Ojo, L. O., … Wöll, H. (2009). Increasing carbon storage in intact African tropical forests. *Nature*, *457*(7232), 1003–1006. https://doi.org/10.1038/nature07771

Locatelli, B., Catterall, C. P., Imbach, P., Kumar, C., Lasco, R., Marín-Spiotta, E., … Uriarte, M. (2015). Tropical reforestation and climate change: beyond carbon: Tropical reforestation beyond carbon. *Restoration Ecology*, *23*(4), 337–343. https://doi.org/10.1111/rec.12209

Lonsdale, W. M. (1999). Global Patterns of Plant Invasions and the Concept of Invasibility. *Ecology*, *80*(5), 1522–1536. https://doi.org/10.1890/0012-9658(1999)080[1522:GPOPIA]2.0.CO;2

Luyssaert, S., Inglima, I., Jung, M., Richardson, A. D., Reichstein, M., Papale, D., … Janssens, I. A. (2007). CO2 balance of boreal, temperate, and tropical forests derived from a global database. *Global Change Biology*, *13*(12), 2509–2537. https://doi.org/10.1111/j.1365-2486.2007.01439.x

Luyssaert, Sebastiaan, Schulze, E.-D., Börner, A., Knohl, A., Hessenmöller, D., Law, B. E., … Grace, J. (2008). Old-growth forests as global carbon sinks. *Nature*, *455*(7210), 213–215. https://doi.org/10.1038/nature07276

MacDicken, K. G., Sola, P., Hall, J. E., Sabogal, C., Tadoum, M., & de Wasseige, C. (2015). Global progress toward sustainable forest management. *Forest Ecology and Management*, *352*, 47–56. https://doi.org/10.1016/j.foreco.2015.02.005

Mackey, B., DellaSala, D. A., Kormos, C., Lindenmayer, D., Kumpel, N., Zimmerman, B., … Watson, J. E. M. (2015). Policy Options for the World's Primary Forests in Multilateral Environmental Agreements. *Conservation Letters*, *8*(2), 139–147. https://doi.org/10.1111/conl.12120

Malhi, Y., Baldocchi, D. D., & Jarvis, P. G. (1999). The carbon balance of tropical, temperate and boreal forests. *ResearchGate*, *22*(6), 715-740. https://doi.org/10.1046/j.1365-3040.1999.00453.x

Malhi, Yadvinder. (2012). The productivity, metabolism and carbon cycle of tropical forest vegetation. *Journal of Ecology*, *100*(1), 65–75. https://doi.org/10.1111/j.1365-2745.2011.01916.x

Martin, P. A., Newton, A. C., & Bullock, J. M. (2013). Carbon pools recover more quickly than plant biodiversity in tropical secondary forests. *Proc. R. Soc. B*, *280*(1773), 20132236. https://doi.org/10.1098/rspb.2013.2236

Martínez, L. J., & Zinck, J. A. (2004). Temporal variation of soil compaction and deterioration of soil quality in pasture areas of Colombian Amazonia. *Soil and Tillage Research*, *75*(1), 3–18. https://doi.org/10.1016/j.still.2002.12.001

Matthews, R. B., & van Noordwijk, M. (2014). From euphoria to reality on efforts to reduce emissions from deforestation and forest degradation (REDD+). *Mitigation and Adaptation Strategies for Global Change*, *19*(6), 615–620. https://doi.org/10.1007/s11027-014-9577-0

Matthews, R. B., van Noordwijk, M., Lambin, E., Meyfroidt, P., Gupta, J., Verchot, L., … Veldkamp, E. (2014). Implementing REDD+ (Reducing Emissions from Deforestation and Degradation): evidence on governance, evaluation and impacts from the REDD-ALERT project. *Mitigation and Adaptation Strategies for Global Change*, *19*(6), 907–925. https://doi.org/10.1007/s11027-014-9578-z

Miettinen, J., Hooijer, A., Shi, C., Tollenaar, D., Vernimmen, R., Liew, S. C., … Page, S. E. (2012). Extent of industrial plantations on Southeast Asian peatlands in 2010 with analysis of historical expansion and future projections. *GCB Bioenergy*, *4*(6), 908–918. https://doi.org/10.1111/j.1757-1707.2012.01172.x

Minang, P. A., & van Noordwijk, M. (2013). Design challenges for achieving reduced emissions from deforestation and forest degradation through conservation: Leveraging multiple paradigms at the tropical forest margins. *Land Use Policy*, *31*, 61–70. https://doi.org/10.1016/j.landusepol.2012.04.025

Morales-Hidalgo, D., Oswalt, S. N., & Somanathan, E. (2015). Status and trends in global primary forest, protected areas, and areas designated for conservation of biodiversity from the Global Forest Resources Assessment 2015. *Forest Ecology and Management*, *352*, 68–77. https://doi.org/10.1016/j.foreco.2015.06.011

Morton, D. C., DeFries, R. S., Shimabukuro, Y. E., Anderson, L. O., Arai, E., del Bon Espirito-Santo, F., … Morisette, J. (2006). Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon. *Proceedings of the National Academy of Sciences*, *103*(39), 14637–14641.

Moutinho, P. (2005). *Tropical deforestation and climate change.* Belém: IPAN, Washington DC-USA: Enviromental Defense.

NATIONS, F. A. A. O. O. T. U. (2016). *GLOBAL FOREST RESOURCES ASSESSMENT.* S.l.: FOOD & AGRICULTURE ORG.

nclimate3227-s1.pdf. (n.d.). Retrieved from https://media.nature.com/original/nature-assets/nclimate/journal/v7/n3/extref/nclimate3227-s1.pdf

Nepstad, D., Soares-Filho, B. S., Merry, F., Lima, A., Moutinho, P., Carter, J., … Stella, O. (2009). The End of Deforestation in the Brazilian Amazon. *Science*, *326*(5958), 1350–1351. https://doi.org/10.1126/science.1182108

NYDF Global Platform – New York Declaration on Forests. (n.d.). Retrieved December 30, 2018, from https://nydfglobalplatform.org/

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., … Hayes, D. (2011). A Large and Persistent Carbon Sink in the World's Forests. *Science*, *333*(6045), 988–993. https://doi.org/10.1126/science.1201609

Ramankutty, N., Gibbs, H. K., Achard, F., Defries, R., Foley, J. A., & Houghton, R. A. (2007). Challenges to estimating carbon emissions from tropical deforestation. *Global Change Biology*, *13*(1), 51–66. https://doi.org/10.1111/j.1365-2486.2006.01272.x

REDD+, transformational change and the promise of performance-based payments: a qualitative comparative analysis: Climate Policy: Vol 17, No 6. (n.d.). Retrieved December 10, 2018, from https://www.tandfonline.com/doi/abs/10.1080/14693062.2016.1169392

Regreening the Bare Hills - Tropical Forest Restoration in the | David Lamb | Springer. (2016). Retrieved from http://www.springer.com/la/book/9789048198696

Rey Benayas, J., Martins, A., Nicolau, J., & Schulz, J. (2007). Abandonment of agricultural land: an overview of drivers and consequences. *CAB Reviews: Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources*, *2*(057). https://doi.org/10.1079/PAVSNNR20072057

Running, S. W. (2012). A measurable planetary boundary for the biosphere. *Science*, *337*(6101), 1458–1459.

Salzman, J., Bennett, G., Carroll, N., Goldstein, A., & Jenkins, M. (2018). The global status and trends of Payments for Ecosystem Services. *Nature Sustainability*, *1*(3), 136–144. https://doi.org/10.1038/s41893-018-0033-0

Science, A. A. for the A. of. (1994). Corrections and Clarifications. *Science*, *265*(5169), 171–171. https://doi.org/10.1126/science.265.5169.171-c

Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiano, G., … Reyer, C. P. O. (2017). Forest disturbances under climate change. *Nature Climate Change*, *7*(6), 395–402. https://doi.org/10.1038/nclimate3303

Silver, W. L., Ostertag, R., & Lugo, A. E. (2000). The Potential for Carbon Sequestration Through Reforestation of Abandoned Tropical Agricultural and Pasture Lands. *Restoration Ecology*, *8*(4), 394–407. https://doi.org/10.1046/j.1526-100x.2000.80054.x

Sohngen and Beach (2006) Avoided Deforestation as a Greenhouse Gas Mitigation Tool- Economic Issues for Consideration.pdf. (n.d.).

Sohngen and Beach (2006).ris. (n.d.).

sp-44-forests-water-web.pdf. (n.d.). Retrieved from https://www.unece.org/fileadmin/DAM/timber/publications/sp-44-forests-water-web.pdf *sternreview_report_complete.pdf*. (n.d.). Retrieved from http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf

Sunderlin, W. D., Larson, A. M., Duchelle, A. E., Resosudarmo, I. A. P., Huynh, T. B., Awono, A., & Dokken, T. (2014). How are REDD+ Proponents Addressing Tenure Problems? Evidence from Brazil, Cameroon, Tanzania, Indonesia, and Vietnam. *World Development*, *55*, 37–52. https://doi.org/10.1016/j.worlddev.2013.01.013

Tyukavina, A., Baccini, A., Hansen, M. C., Potapov, P. V., Stehman, S. V., Houghton, R. A., … Goetz, S. J. (2015). Aboveground carbon loss in natural and managed tropical forests from 2000 to 2012. *Environmental Research Letters*, *10*(7), 074002. https://doi.org/10.1088/1748-9326/10/7/074002

van Lierop, P., Lindquist, E., Sathyapala, S., & Franceschini, G. (2015). Global forest area disturbance from fire, insect pests, diseases and severe weather events. *Forest Ecology and Management*, *352*, 78–88. https://doi.org/10.1016/j.foreco.2015.06.010

WBCSD Vision2050-FullReport.pdf. (n.d.).

Wunder, S. (2007). The Efficiency of Payments for Environmental Services in Tropical Conservation. *Conservation Biology*, *21*(1), 48–58. https://doi.org/10.1111/j.1523-1739.2006.00559.x

Wunder, S. (n.d.). *Payments for environmental services: some nuts and bolts*. 32.

Zarin, D. J., Harris, N. L., Baccini, A., Aksenov, D., Hansen, M. C., Azevedo-Ramos, C., … Tyukavina, A. (2016). Can carbon emissions from tropical deforestation drop by 50% in 5 years? *Global Change Biology*, *22*(4), 1336–1347. https://doi.org/10.1111/gcb.13153

(N.d.-b).

(N.d.-c).

(N.d.-d).

(N.d.-e).

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