***This is a micro-solution that is added on to the main solution of* Tropical Forest Restoration**

**TEMPERATE FOREST RESTORATION**

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# Literature Review

Temperate forests are found in relatively humid regions (500-2000mm rainfall/yr) between 25˚ and 55˚ both north and south of the Equator. Moving from the equator to the high latitudes, the percentage of forest carbon in soils goes up as that of biomass goes down. Temperate forests include coniferous, broad-leaved evergreen, broad-leaved deciduous, and mixed associations. The primary regions featuring temperate forests are Europe, northeast Asia, southern Chile, New Zealand, the Mediterranean, and North America. These ecosystems cover about 767 Mha globally.[[1]](#footnote-1)

Temperate forests hold roughly 10% of all terrestrial carbon, and 20% of global plant biomass.[[2]](#footnote-2) Compared to tropical forests, a greater proportion of the carbon is held in soils. [[3]](#footnote-3) Soil carbon stocks account for 60% of carbon in these ecosystems. [[4]](#footnote-4) Temperate forest soils typically contain roughly 100 t/ha of carbon. [[5]](#footnote-5) An Australian moist temperate *Eucalyptus* forest has the highest reported carbon stock in biomass, a remarkable 1,867 t/ha. [[6]](#footnote-6) See Table 1.

Table Carbon pools in temperate forest of the US.

From Lal and Lorenz 2012.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | **Carbon density (tons of carbon per hectare)** | | | | | |
| **Region** | **Trees** | **Soil** | **Forest floor** | **Understory** | **Total** | **Soil: tree ratio** |
| **Northeast** | 59.3 | 127.6 | 20.2 | 1.2 | 208.3 | 1.6 |
| **North central** | 47.3 | 123.9 | 20.5 | 1.0 | 196.1 | 1.7 |
| **Great plains** | 39.8 | 90.4 | 20.8 | 0.8 | 151.8 | 1.5 |
| **Southwest** | 85.2 | 97.6 | 42.4 | 1.7 | 226.9 | 0.75 |

This study performed meta-analysis on sequestration rates of temperate forest. The mean was 2.96. Unlike tropical studies, these figures typically include sequestration in soils as well as biomass.

As mentioned in Section 1.1 of this report, temperate forests have low albedo when compared to grassland and cropland, undesirable from a climate change mitigation perspective. This offsets their sequestration to some degree. On the other hand, temperate forests provide evaporative cooling in summer, with a more effective cooling impact than that provided by cropland.[[7]](#footnote-7)

Boreal forests, located at higher latitudes, have even more undesirable albedo impacts. This overshadows the carbon sequestration potential of boreal forest restoration.[[8]](#footnote-8) For this reason Drawdown does not model forest restoration in boreal climates.

## Adoption

Large areas of temperate forest have already been cleared for agriculture in the US, Europe, and China.[[9]](#footnote-9) Of current forest restoration commitments through the Bonn Challenge and the New York Declaration on Forests, only 7% of the area pledged is temperate (see Table 1 of Tropical Forest Restoration). This likely reflects the active current agricultural use of much of the previously forested area.

# Methodology

## Introduction

Project Drawdown’s models are developed in Microsoft Excel using standard templates that allow easier integration with each other since integration is critical to the bottom-up approach used. The template used for this solution was the Land Model which accounts for sequestration of carbon dioxide from the atmosphere into plant biomass and soil, and reduction of emissions for a solution relative to a conventional practice. These practices are assumed to use land of a specific type that may be shared across several solutions. The actual and maximum possible adoptions are therefore defined in terms of land area (million hectares). The adoptions of both conventional and solution were projected for each of several Drawdown scenarios from 2015 to 2060 (from a base year of 2014) and the comparison of these scenarios with a reference (for the 2020-2050 segment[[10]](#footnote-10)) is what constituted the results.

*Agency Level*

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

## Data Sources

Key data sources include Bonn Challenge and New York Declaration, country level data was analyzed to estimate future commitments for intact forest restoration.

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

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

Total land allocated for the *temperate forest* solution is 150 million hectares, comprising global peatlands.  Current adoption of *temperate forest* is assumed to be 0 million hectares (as detailed on section 1.2.1.).

## 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.

Based on the commitments of the NYDF, predictions from the WRI and current restoration commitments, nine different adoption scenarios were used to model carbon sequestration. All nine adoption scenarios (described in Table below) were calculated based on:

1. Current commitments to date.
2. Potential future commitments.
3. The proportion of committee land restored to intact forest (100% or 44.23%).
4. The year commitments are realised (2030, 2045 or 2060)

Table :Description of adoption scenarios

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Custom Scenario | Current temperate Commitments | Future Commitments | % restored to intact | Year realised | Mha restored by year realised | Adoption rate (Mha/yr) |
| 1 | 4.22 Mha a | 14.96 Mha b | 100% | 2030 | 19.18 | 1.28 |
| 2 | 4.22 Mha a | 140.46 Mha c | 100% | 2030 | 144.68 | 9.65 |
| 3 | 4.22 Mha a | 140.46 Mha c | 44.23% | 2030 | 66.35 | 4.42 |
| 4 | 4.22 Mha a | 140.46 Mha c | 44.23% | 2030 d | 66.35 | 4.42 |
| 5 | 4.22 Mha a | 140.46 Mha c | 100% | 2045 | 144.68 | 4.82 |
| 6 | 4.22 Mha a | 140.46 Mha c | 44.23% | 2045 | 66.35 | 2.21 |
| 7 | 4.22 Mha a | 140.46 Mha c | 44.23% | 2045 e | 66.35 | 2.21 |
| 8 | 4.22 Mha a | 140.46 Mha c | 100% | 2060 | 144.68 | 3.21 |
| 9 | 4.22 Mha a | 140.46 Mha c | 44.23% | 2060 | 66.35 | 1.47 |

a = 136.3 X 7% = 9.54 Mha in temperate; 9.54 X 44.23% = 4.22 Mha of intact restoration in temperate. b = (350 - 136.7)\*7% = 14.96 Mha (NYDF commitments – Current commitments in temperate region). c = (500 Mha degraded land \*39.20% for temperate forest restoration)-46 Mha of boreal restoration – 9.54 Mha)= 140.46 Mha (Area suitable for temperate forest restoration – Current tropical forest commitments). d = Continued growth post 2030. e = Continued growth post 2045.

Impacts of increased adoption of *temperate forest restoration*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.

### Reference Case / Current Adoption[[11]](#footnote-11)

Current adoption of *temperate forest restoration* is assumed to be 0 in the lack of sufficient information.

### Project Drawdown Scenarios

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

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

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

#### Optimum Scenario – This scenario represents the maximum adoption of the solution, which is represented by the “Custom adoption scenario two”.

## Inputs



### Climate Inputs

Temperate forest restoration sequestration rates are set at 2.96 tons of carbon per hectare per year, based on 18 data points from 8 sources.

Table : Climate Inputs

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Biosequestration | *tC/ha/yr* | 0.002 - 1.40 | 0.51 | 86 | 16 |

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[[12]](#footnote-12).

*Modeling Saturation*

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

The Drawdown land model takes the conservative approach that all land units currently adopted for agricultural solutions (including multistrata agroforestry) have already achieved saturation, and will not be contributing additional sequestration. New adopted land is assumed to sequester for at least 30 years before achieving saturation.

Note that there are some important exceptions to saturation. Some scientists argue that tropical forests can continue to sequester carbon at a slower rate after saturation. The addition of biochar to saturated soils may be able to overcome this constraint, as does the use of biomass from bamboo or afforestation in long-term products like buildings.

### Financial Inputs

Financial analysis was not carried out due to vast variability in data across different geography, type of restoration measures, scale of restoration etc.

## Assumptions

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions. These are that infrastructure required for the solution is available and in-place, policies required are already in-place, no carbon price is modeled, all costs accrue at the level of agency modeled, improvements in technology are not modeled, and that first costs may change according to learning. Full details of core assumptions and methodology will be available at [www.drawdown.org](http://www.drawdown.org). The Drawdown temperate forest restoration model used the same assumptions as Tropical Forest Restoration, but accounts instead for the 7% of global forest restoration that is projected to occur in temperate climates. Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below.

1. Carbon is sequestered at 2.96 tons C ha-1 yr-1 and increases linearly.
2. Adoption scenarios used for modelling used either a 15-year, 30-year or 45-year adoption.
3. Adoption scenarios used for modelling assumed either 100% or 44.23% of committed area were restored to intact forest.
4. Areas that are undergoing temperate forest restoration are naturally regenerating back to an intact forest state following disturbance.
5. The first costs of restoration are assumed to be $0, as natural regeneration does not require any financial outlay. All that is required is for land to be protected from future degrading activities.

## Integration

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

*Temperate forest restoration* is part of Drawdown’s Land Use sector. Within this sector, it is part of a cluster of solutions-based ecosystem protection.

***The Agroecological Zone model***

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

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

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

***The Yield model***

Drawdown’s yield model calculates total annual global supply of crops and livestock products based on their area of adoption in each of the three scenarios, and global yield impacts of each solution (including both gains due to increased productivity per hectare and losses due to reduction of productive area due to adoption of non-agricultural solutions, e.g., loss of grazing area due to afforestation of grasslands). Grain surpluses in the yield model were also used to set a ceiling for the amount of crops available for use as feedstock for the *bioplastic* Materials solution.

The yield model matches demand and supply as an integrated system. Both *Reference* Scenarios showed a food deficit in the high and medium population scenarios (see *family planning*and *educating girls* solutions). This would require the clearing of forest and grassland for food production, with associated emissions from land conversion.

All three Drawdown scenarios show agricultural production sufficient to meet food demand and provide a surplus that can be used in bio-based industry, for example as feedstock for *bioplastic*production*.*Due to this surplus, no land clearing is necessary, resulting in impressive emissions reduction from avoided deforestation.  Because population change (resulting from *educating girls*and *family planning*),*plant-rich diet*, and *reduced food waste* are the principal drivers of this effect, Drawdown allocates the resulting reduction in emissions from land clearing to these solutions. However, as the impacts of population on yield and food demand are highly complex, we do not include avoided land conversion emissions associated with population change in the final emissions calculations for those solutions.

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.

This solution is integrated into the yield model because it is adopted on degrad grassland and thus displaces grazing.

## 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 95.18 million hectares in 2050, representing 63 percent of the total suitable land in 2014. Of this, 95.18 million hectares are adopted from 2020-2050.

Total adoption in the *Drawdown* Scenario is 142.28 million hectares in 2050, representing 95 percent of the total suitable land in 2014. Of this, 142.28 million hectares are adopted from 2020-2050.

Total adoption in the *Optimum* Scenario is 144.39 million hectares in 2050, representing 96 percent of the total suitable land. Of this, 144.39 million hectares are adopted from 2020-2050.

Figure 3.1 World Annual Adoption 2020-2050 [Mha]

| **Solution** | **Units** | **Base Year (2014)** | **New Adoption by 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Drawdown** | **Optimum** |
| Temperate Forest Restoration | Mha | - | 95.18 | 142.28 | 144.39 |
| % Total Land Available | 0.0% | 63.45% | 94.85% | 96.26% |

Table 3. World Adoption of the Solution

## 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 22.61, 34.70, and 42.63 gigatons of carbon-dioxide equivalent in the *Plausible, Drawdown,* and *Optimum* Scenarios respectively.

| **Scenario** | **Maximum Annual Emissions Reduction** | **Total Emissions Reduction** | **Max Annual CO2 Sequestered** | **Total Additional CO2 Sequestered** | **Total Atmospheric CO2-eq Reduction** | **Emissions Reduction in 2030** | **Emissions Reduction in 2050** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| *(Gt CO2-eq/yr.)* | *Gt CO2-eq/yr. (2020-2050)* | *(Gt CO2-eq/yr.)* | *Gt CO2-eq/yr. (2020-2050)* | Gt CO2-eq (2020-2050) | (Gt CO2-eq/year) | *(Gt CO2-eq/year)* |
| ***Plausible*** | - | - | 1.03 | 22.61 | 22.61 | 0.68 | 1.03 |
| ***Drawdown*** | - | - | 1.55 | 34.70 | 34.70 | 1.10 | 1.55 |
| ***Optimum*** | - | - | 1.57 | 42.63 | 42.63 | 1.57 | 1.57 |

Table 3. Climate Impacts

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 AnnualGreenhouse Gas Emissions Reduction

| **Scenario** | **GHG Concentration Change in 2050** | **GHG Concentration Rate of Change in 2050** |
| --- | --- | --- |
| *PPM CO2-eq (2050)* | *PPM CO2-eq change from 2049-2050* |
| **Plausible** | 1.900 | 0.073 |
| **Drawdown** | 2.910 | 0.108 |
| **Optimum** | 3.531 | 0.101 |

*Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq*

## 3.6 Financial Impacts

Currently financial impacts are not modeled for this solution.

# 4 Discussion

Temperate forest restoration has high climate mitigation impact. It also of course brings many co-benefits for biodiversity, water quality, and other ecosystem services. Given the need for aggressive mitigation it is an important tool in the global toolkit.

## 4.1 Limitations

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

## Benchmarks

Griscom (2017) calculates a climate impact for temperate forest restoration of 0.20 Gt CO2-eq/yr in 2030, on 205 Mha.

| **Source and Scenario** | **Mitigation Impact**  **Gt CO2-eq in 2030** |
| --- | --- |
| Griscom et al. (2017) | 0.20 |
| *Plausible* Scenario | 0.68 |
| *Drawdown* Scenario | 1.10 |
| *Optimum* Scenario | 1.57 |

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10. For most results, only the differences between scenarios, summed over 2020-2050 were presented, but for the net first cost, the position was taken that to achieve the adoptions in 2020, growth must first happen from 2015 to 2020, and that growth comes at a cost which should be accounted for, hence net first cost results represent the period 2015-2050. [↑](#footnote-ref-10)
11. 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. [↑](#footnote-ref-11)
12. In some cases, the low boundary is negative for a variable that can only be positive, and in these cases the lowest collected data point is used as the “low” boundary. [↑](#footnote-ref-12)