**Technical assessment for**

**Silvopasture**

Sector: Food

Agency Level: Rancher/Pastoralist

Keywords: Biosequestration, Livestock Production, Agroforestry

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# Executive Summary

Climate mitigation literature often fails to differentiate between *silvopasture* and other "agroforestry" cropping systems such as *multistrata agroforestry* and *tree intercropping*, grouping these systems together. Project Drawdown defines *silvopasture* as a form of agroforestry practice which integrates trees, forage and livestock.

This solution has the potential to replace conventional livestock grazing on pasture and rangeland, in regions where rainfall is sufficient to permit tree growth. Research suggests that silvopasture systems can store significant amounts of carbon in both soils and tree biomass, contributing to carbon sequestration, while maintaining or increasing productivity and providing a suite of additional benefits. Traditional silvopasture systems, such as *dehesas* in Spain or forest pastures in Scotland, have existed for centuries. Under *silvopasture*, livestock production contributes to emissions of the other greenhouse gases such as methane and nitrous oxide. Nevertheless, these are offset by the significant increase in carbon sequestration through crop and tree biomass compared to conventional grazing systems - at least until soil carbon saturation is achieved. Drawdown takes the conservative assumption that emissions do not change with conversion from conventional to *managed grazing*.

In Drawdown’s Agroecological Zone model *silvopastures* are established on conventional grazing land. The current extent of silvopasture systems is estimated to be about 488 million hectares globally. Future adoption potential was modeled based on global satellite data documenting tree-coverage on agricultural land, and on current and historical regional and national proportions of grazing land under silvopasture. Further adoption is constrained principally by low recognition of the solution’s potential, leading to a lack of incentives for farmers, as well as high establishment costs and water requirement.

Under the projected *Plausible* Scenario, total adoption is 698.50 million hectares with 35.69 Gt CO2 eq. sequestered by 2050. Cumulative first cost is US$244.78 billion, with a net profit margin of US$1,655.12 billion and projected yield increases of 1.36 million tons. Under the *Drawdown* Scenario, total adoption is 738.00 million hectares with 42.87 Gt of CO2 eq. sequestered by 2050. Cumulative first cost is US$$319.96 billion, with net profit margin of US$2,055.17 billion and projected yield increases of 1.64 million tons. Under the *Optimum* Scenario, projected total adoption is 765.90 million hectares with 52.39 Gt of CO2 eq. sequestered by 2050. Cumulative first cost is US$357.08 billion, with net profit margin of US$2,578.85 billion and projected yield increases of 2.04 million tons.

# Literature Review

Silvopastures are production systems which integrate tree and livestock components; they can take varied and diverse forms and can be applied across a range of climates and at different scales. Increased recognition of their many environmental and economic benefits, particularly in the context of climate change and land degradation, coupled with improved national or regional incentive mechanisms, is likely to significantly increase future adoption rates of this solution at the farmer / pastoralist agency level.

## State of the Practice

*Silvopasture* is an agroforestry practice which integrates trees, forage and livestock (Cubbage et al., 2012; Toensmeier, 2016). While tree densities in silvopasture systems can vary widely (Cubbage et al., 2012), Drawdown defines silvopastures as managed tree-pasture-livestock systems with tree densities of 30% and higher. This definition can include a broad variety of management approaches and objectives. In traditional forms of silvopasture like *dehesa* systems in Spain and Portugal or wood-pastures in Scotland, which have existed for thousands of years, trees are integrated into livestock pastures (Montagnini et al., 2013; Mosquera-Losada et al., 2005). Establishment practices range widely: for instance, existing native trees can be thinned or coppiced and integrated with livestock grazing (Pinheiro and Nair, 2018), or alternatively trees can be introduced into already existing grazing landscapes.

In the southeastern USA or Uruguay, silvopasture systems are managed both for large-scale timber production and cattle (Cubbage et al., 2012). In additional to timber, bark or fruit, trees in silvopastures can used for a variety of practical reasons related to animal husbandry, such as providing additional fodder for animals or protecting them from sun and wind. Including trees in pasture has been shown in many cases to enhance livestock productivity by regulating climate and minimizing heat-stress for animals (Paciullo et al., 2011; Pagiola et al., 2007). This solution can further provide producers with alternative revenue streams (Oviedo et al., 2013). Trees in silvopastures may be planted or permitted to regenerate naturally.

Silvopasture enhances the carbon sequestration capacity of pastureland by both increasing soil carbon stocks and storing carbon in the biomass of trees (Abberton et al., 2010; Dube et al., 2011). Pasture is often degraded, meaning its net primary productivity (NPP), a measure of the amount of carbon an ecosystem produces, is lower than it could be. Integrating trees into pasture may both increase the system’s NPP while also enhancing processes in soil that stabilize and sequester carbon. Numerous studies have shown that following implementation, silvopasture systems have increased total carbon (e.g. biomass and soil carbon) relative to their starting point or control systems that do not include trees (Andrade et al., 2008; Fernández-Núñez et al., 2010; Ibrahim et al., 2007).

Recent global estimates suggest that silvopastures occupy as much as 550 million hectares, making it the second most widespread form of agroforestry worldwide (Lal et al., 2018). Silvopastures are most prevalent in temperate humid or semi-arid climates, although they are also found in cool temperate regions. Other key areas where silvopasture are found include Spain and Portugal with 5.5 million ha, Central America with 9.2 million ha, and Chile with 1.5 million ha (Nair, 2012; Toensmeier, 2016), as well as Argentina, parts of Australia, New Zealand and North America.

***High Sequestration Rates***

Annual sequestration rates for silvopasture are very high when compared to managed grazing alone (Toensmeier, 2016). Table 1.1 average sequestration rates of 4.8 t/ha/yr for silvopasture systems versus 1.4 for managed grazing systems, based on Drawdown model results. Table 1.2 shows silvopasture sequestration rates by region from (Feliciano et al, 2018), which was published after Drawdown’s initial models, but demonstrates very high sequestration rates for Asia and Latin America. Indeed, sequestration potential and rates for silvopasture systems are among the highest of any existing agricultural practice.

**Table 1.1 Sequestration rates (in t/ha/yr) of silvopasture vs. managed grazing**

Source: Drawdown model results.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Solution** | **Model Input** | **Low of Range** | **High of Range** | **# of Data Points** |
| Managed Grazing | 1.4 | -0.2 | 3.0 | 49 |
| Silvopasture | 4.8 | 1.0 | 8.6 | 26 |

***Table 1.2 Mean above-ground biomass (ABG) and soil organic carbon (SOC) sequestration rates by region***Adapted from Tables 3 and 4 from (Feliciano et al, 2018), which was published after the publication of *Drawdown.*

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Continent** | **Agroforestry System Type** | **Aboveground Biomass Sequestration Rate t/ha/yr** | | | **Soil Organic Carbon Sequestration Rate t/ha/yr** | | |
| **Mean** | **Variance** | **# of Observations** | **Mean** | **Variance** | **# of Observations** |
| Africa | silvopasture | .15 | - | 1 | - | - | - |
| Asia | silvopasture | 2.65 | 4.35 | 7 | 6.54 | 2.99 | 6 |
| Australia | silvopasture | .79 | - | 1 | - | - | - |
| Latin America | silvopasture | 2.29 | .29 | 3 | 6.54 | 2.99 | 6 |
| North America | silvopasture | .52 | - | 1 | .06 | .38 | 3 |

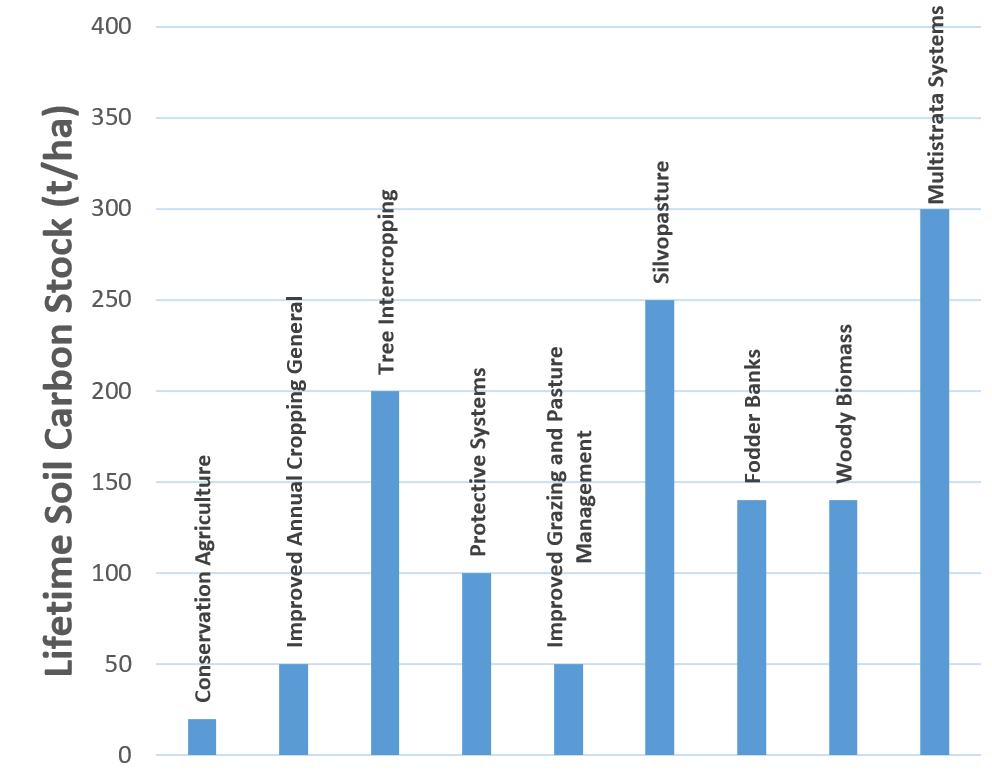
***Lifetime Carbon Stocks***

Carbon sequestration refers to carbon fixed from the atmosphere over a set period of time. Carbon stocks, on the other hand, are a measure of total carbon accumulated in an ecosystem over the course of its lifetime, after years of carbon sequestration. The Drawdown model does not account for existing carbon stocks and all calculations include only annual sequestration rates in soils and vegetation biomass.

It is nevertheless worth exploring the differences between stocks in various farming systems as they differ widely. Carbon stocks accumulate both in soils (soil organic carbon, or SOC) and in above- and below-ground vegetation biomass. Multistrata agroforestry have exceptionally high carbon stocking potential for both of these carbon pools. Aboveground stocks in silvopastures are impressive especially when compared to the essentially absent biomass stocks in annual cropping and grazing systems and can accumulate up to 92 tC/ha (Table 1.3). Lifetime soil carbon stocks in silvopasture systems are up to 250 tons/ha, compared to up to 50 for managed grazing (Figure 1.1). Aboveground biomass carbon stocks in tropical silvopasture systems can accumulate up to 92 tC/ha (Table 1.3).

**Figure 1.1 Lifetime potential soil carbon stocks of various carbon-sequestering agriculture systems compared**

Adapted from (Toensmeier, 2017).



**Table 1.3 Lifetime sequestration rates of aboveground biomass of multistrata agroforestry systems**

Adapted from (Lasco, 2006; Montagnini, 2015). Note that these are carbon stocks, not annual sequestration rates.

|  |  |  |
| --- | --- | --- |
| **System** | **Climate** | **Carbon Stocks t/ha** |
| Trees planted in pasture | Humid tropics, no dry season | 13-58 |
| Pastures with residual trees | Humid tropics, no dry season | 19-74 |
| Fodder banks | Humid tropics, short dry season | 2-7 |
| Trees planted in pasture | Humid tropics, short dry season | 0.3-3.3 |
| Pastures with residual trees | Humid tropics, short dry season | 2-31 |
| Trees planted in pasture | Subtropical with no dry season | 51-92 |
| Silvopasture (Australia) | Humid tropics | 28-51 |
| Silvopasture (N. America) | Humid tropical highlands | 133-154 |
| Silvopasture (N. America) | Humid tropical lowlands | 104-198 |
| Silvopasture (N. America) | Dry lowlands | 90-175 |
| Silvopasture (N. Asia) | Humid tropical lowlands | 15-18 |

## Adoption Path

Current adoption of silvopasture is estimated at about 450 - 550 Mha ((Lorenz and Lal, 2018; Nair, 2012). This figure is likely to increase due to increasing global demand for meat, coupled with increasing recognition of the potential of silvopasture practices and their integration into land-use strategies developed by international organization such as the IPCC, the FAO or the UN, and by a growing number of national governments. Increased recognition of the tangible benefits of the practice remains limited by a lack of data, and increased adoption remains hampered by lack of information for farmers and pastoralists and by economic challenges such as high establishment costs. Nevertheless, increasing focus on “climate-smart” agricultural strategies might contribute to shifting global grazing practices from conventional to silvopasture.

### Current Adoption

While accurate and comprehensive datasets on current silvopasture adoption do not currently exist, recent literature estimates total global extent of silvopasture systems at 450 Mha (Nair, 2012) to 550 Mha (Lorenz and Lal, 2018). Nevertheless, existing regional data indicates that silvopasture adoption is widespread. For instance, estimates for Latin America report a total of 85 Mha for the region of which 16.8 Mha are in Colombia and 4.4 Mha in Nicaragua (Somarriba et al., 2012). (Zomer et al., 2009) report 9.2 Mha of silvopastures in Central America, and a study by (Montagnini et al., 2013) found that as much as 90% of Costa Rican ranches contained dispersed trees. There are 15.1 Mha of silvopasture in Europe, making it the EU’s most widespread agroforestry system (den Herder, 2017). Other regions with documented significant silvopasture extent are North America and Australia and New Zealand, while little or no data is available for Central and Eastern Asia or Africa. Globally, despite the widespread use of silvopasture systems, conventional grazing remains the dominant form of livestock production systems, with current estimates ranging from 2,000 Mha (Lorenz and Lal, 2018) to 3,312 Mha (Houghton and Nassikas, 2017) globally.

### Trends to Accelerate Adoption

Tree-based cropping systems provide a wide range of benefits including soil and water conservation and carbon sequestration (Pimentel et al., 2012)s. For this reason, tree-based food systems like silvopastures, have been gaining traction at the international stage as a strategy for “climate-smart” agriculture, landscape restoration and carbon sequestration. Increased interest in such “climate-smart” practices may provide significant opportunity to scale up the adoption of silvopasture systems, as their impact on both is powerful (Harvey et al., 2014; Montagnini, 2015).

Silvopastures can be competitive in comparison with conventional systems. They have been associated with higher profitability for farmers, as the added tree & livestock components of the systems produce similarly than they would in single-component system. improved microclimate for cattle (protection from frost and sun); long-term investment + short-term returns. The inclusion of tree-based crops such as mesquite or cork-oak in grazing systems can contributes to income diversification and risk mitigation, including from forest fires. Trees further increase general ecosystem resilience, leading to less costs for farmers relating to herbicides and pesticides to address weeds, pests or pathogen issues (Cubbage et al., 2012).

Maximizing adoption will entail helping producers to both bear the initial costs of establishing silvopasture systems and educating them about silvopasture and its potential environmental and financial benefits. Costa Rica, Colombia, and Nicaragua have all created programs that pay ranchers for the ecosystem services planting trees on their ranches create (Pagiola et al., 2007). Programs such as these can help to defray some of the first costs by providing more immediate compensation. To encourage producers to consider adopting silvopasture, groups like the Centre for Research on Sustainable Agriculture (CIPAV) in Colombia are utilizing pilot farms, capacity building workshops, and advocating with organizations in the sector and local policymakers (Montagnini et al., 2013).

Silvopasture may also expand simply because cattle ranching is expanding as demand for meat, and specifically beef, increases globally. In the past decade alone, beef production in Latin America has increased over 50% (FAO, 2016). Given the suitability of silvopasture cultivation systems in Latin America, trends in beef consumption and production may help to accelerate its adoption.

### Barriers to Adoption

Increased adoption of this Drawdown solution will need to address a number of constraints, including:

* Silvopastures’ comparatively high water requirements will limit adoption in areas with adequate rainfall to support tree growth. Silvopasture is therefore traditionally practiced in humid and semi-arid grasslands. Nevertheless, an analysis of (Dixon et al., 2014), including supplemental materials, found 773 Mha of humid grasslands and 2,902 Mha of semi-arid grasslands (some but not all of which are likely humid enough to support silvopasture).
* High establishment and management costs present what is perhaps the greatest initial hurdle to ranchers adopting silvopasture. The labor cost of planting several trees and then protecting them from damage by livestock may be prohibitive for some producers. In some cases, first costs can match or exceed annual net profits (Rocha et al., 2013), meaning producers might be operating at a loss during the initial phases of silvopasture implementation.
* Similarly, the financial advantage of silvopasture relative to bare pasture is often due to additional revenue streams such as timber and hunting (Oviedo et al., 2013). Limited access to these markets or knowledge of them may increase risk for some producers, discouraging adoption. Furthermore, the perception amongst producer communities and policymakers is often one that is based on existing models of production that view trees as counter-productive or a hindrance to ranching.

There could be potential competition between trees and forage components. Coupled with complex management requirements (Mercer et al., 2014), this might present an obstacle for farmer adoption (Cubbage et al., 2012).

* Currently, agroforestry solutions such as silvopasture systems are not systematically included in land-use classifications at national and regional levels. This makes their integration into monitoring, reporting and verification systems difficult, in turn preventing recognition of their importance and potential benefits (Rosenstock et al., 2018).

### Adoption Potential

Projections of the adoption potential of silvopastures *as such* are quite rare, and to our knowledge this is the first study or initiative to model estimates at global scales.

## Advantages and disadvantages of Silvopasture Systems

### Similar Solutions

Silvopasture is similar to a few other land-based Project Drawdown solutions but is perhaps most similar to *grazing management*. Both solutions attempt to increase carbon sequestration in grazing lands by maximizing net primary productivity (NPP) and promoting soil processes that sequester carbon. Silvopasture has a far superior mitigation impact but is restricted to the relatively small amount of humid grasslands.

### Arguments for Adoption

Compared to managed grazing and other land-use solutions, silvopasture has a few comparative advantages and disadvantages.

* **Diversified revenue:** Silvopasture provides several additional revenue streams to producers, including timber, forest/tree products, recreation, and ecosystem services. These other revenue streams can greatly enhance the financial productivity and stability of farms. In one analysis of *dehesa* systems in Spain, revenue streams aside from livestock were responsible for keeping operations solvent (Oviedo et al., 2013).
* **Reduced costs:** Depending on the price of feeds, fertilizers and other livestock ranching inputs, farmers may adopt silvopastoral systems as a strategy to decrease ranching costs (Calle et al., 2009). This is particularly true in countries where values of farm inputs fluctuate greatly and in remote areas where transporting fertilizers and feeds is impractical and more costly. Of farmers that implemented silvopastoral systems in a Colombian study, 39% reported financial benefits within several months (Calle et al., 2009).
* **Increased productivity:** Silvopastoral systems can increase productivity, particularly in dairy systems, where cattle health is important for milk yield. Of farmers that implemented silvopastoral systems in a Colombian study, 64% reported a substantial increase in the quantity and quality of fodder and 43% reported an improved livestock body condition (Calle et al., 2009). According to(Cubbage et al., 2012), tree shade contributes positively to animal health, milk production weight gain, and reproduction.
* **Microclimate regulation & climate change adaptation**: In seasonally dry climates trees assist in moderating seasonal water quality and quantity by moderating the microclimate below them (Karki and Goodman, 2015), thus extending the productive pasture season. In some cases, cattle in shaded pasture can reach their target weight 20 days before cattle kept in the sun (Schoeneberger, 2009; Toensmeier, 2016). Trees in pasture also can help farmers adapt to unpredictable weather events. In New Zealand, trees reduced pasture production losses due to landslides during cyclonic events by 13.8%, with each tree saving 8.4 m2 of pasture from failure (Benavides et al., 2009).
* **Increased wildlife habitat:** Including trees in pastures provides additional habitat for wildlife and birds that would otherwise be absent.

*Disadvantages:*

* **Water demand:** Since trees often require higher levels of annual precipitation to thrive, silvopasture is a solution that is likely only viable in areas with sufficient annual precipitation to support them. Since a substantial amount of global grazing lands are in arid/semi-arid climates, this is a disadvantage of silvopasture compared to managed grazing, which is more applicable in arid systems.
* **Establishment/management costs:** Managed grazing often only requires a transition in practice for ranchers, which might incur an opportunity cost but requires few material expenditures. Silvopasture, on the other hand, can often incur extremely high startup costs that may be cost-prohibitive for some producers, limiting adoption.
* **Management limitations:** While the literature suggests that silvopasture can greatly increase the biological and financial productivity of land, it may simultaneously limit producers’ options on how to utilize those parcels. For example, depending on the design of a silvopasture system, a field may not be able to be used to easily produce hay.

**Information access for farmers:** Perception of high establishment costs and lack of knowledge and resources available to farmers about the practice might similarly present an obstacle for more widespread farmer adoption (Calle, 2008; Orefice et al., 2017).

### Additional Benefits and Burdens

Here this solution is compared with other solutions in the food production cluster for farm, ecosystem, and social impacts. While silvopasture is associated with high start-up costs and a long delayed profit period, it is also associated with medium yield gains, high net profits, high climate impacts and high ecosystem service benefits compared to other solutions land-use and food solutions.

**Table 1.4 Food Production Solutions Comparison: On-Farm Impacts**

**Yield Gains:** loss of yield “loss”,no impact “n/a”,1-9% low, 10-24% medium, 25%+ high. **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+. **Delayed Profit Period:** Short is 0-2, Mid is 3-6, Long is 6+

|  | **Yield Gains** | **Startup Cost** | **Net Profit** | **Delayed Profit Period** |
| --- | --- | --- | --- | --- |
| Conventional cropping | n/a | n/a | Medium | n/a |
| Conventional grazing | n/a | n/a | Medium | n/a |
| Conservation agriculture | Low | Medium | High | Mid |
| Farmland restoration | High | Medium | Medium | Short |
| Farm water use efficiency | n/a | Expensive | Medium | Short |
| Improved rice | Loss | Free | High | Mid |
| Managed grazing | Medium | Medium | Medium | Mid |
| Multistrata agroforestry | n/a | Expensive | High | Long |
| Nutrient management | n/a | Free | Low | Short |
| Regenerative agriculture | Low | Medium | High | Mid |
| Silvopasture | Medium | Expensive | High | Long |
| System of Rice Intensification | High | Free | High | Mid |
| Tree intercropping | Low | Expensive | Medium | Long |
| Tropical staple tree crops | High | Expensive | High | Long |
| Women smallholders | high | Free | High | Short |

**Table 1.5 Food Production Solutions Comparison: On-Farm Impacts Social and Ecological Impacts**

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

|  | **Ecosystem Services** | **Social Justice Benefits** | **Climate Impact/ha** | **Global Adoption Potential** |
| --- | --- | --- | --- | --- |
| Conventional cropping | n/a | n/a | n/a | n/a |
| Conventional grazing | n/a | n/a | n/a | n/a |
| Conservation agriculture | Low | Relevant | Low | Medium |
| Farmland restoration | Medium | Relevant | Medium | Medium |
| Farm water use efficiency | Low | Relevant | Low | Medium |
| Improved rice | Medium | Relevant | high | Low-medium |
| Managed grazing | Low | Relevant | Low | Medium-high |
| Multistrata agroforestry | High | Relevant | High | Low |
| Nutrient management | Medium | Relevant | Low | High |
| Regenerative agriculture | Medium | Relevant | Low | Medium-high |
| Silvopasture | High | Relevant | High | Low-medium |
| System of Rice Intensification | Medium | Targeted | Medium | Low |
| Tree intercropping | High | Relevant | Medium | Medium |
| Tropical staple tree crops | Medium | Relevant | High | Low-medium |
| Women smallholders | n/a | Targeted | Low | Low |

# 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:

1. Sequestration of carbon dioxide from the atmosphere into plant biomass and soil; and
2. 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. 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]](#footnote-1)) is what constituted the results.

Drawdown’s *silvopasture* solution models future adoption on already established grazing and pasture areas and/or degraded grasslands. This approach rules out adoption on other land-use types such as forest or peatland. Current adoption is estimated at about 450 - 550 million hectares, making it the second most widespread form of agroforestry worldwide (Lal et al., 2018; Nair, 2012). While silvopastures are most prevalent in temperate humid or semi-arid climates they are also found in cool temperate regions.

*Agency Level*

The rancher or pastoralist is selected as the agency level for this solution. Though certainly other agents can, do, and should play an important role in this solution, the decision-maker on the ground is the most critical player in implementation.

## Data Sources

Data for the model was drawn from a review of 54 peer-reviewed publications, grey literature (e.g government reports and university financial resources for farmers), as well as public sector sources such as the FAO’s online statistical service, and spans most grazing areas of the world except for Africa, for which no specific sources were found to date. Total available land for silvopasture future adoption is calculated by the Drawdown model and based on total global grazing areas in all grasslands except those under arctic and boreal climate conditions.

## Total Available Land

Drawdown’s agricultural production and land use model approach defines the Total Land Area for each solution as the area of land (in million hectares) suitable for adoption a given solution. Determining this figure for Total Land Area is a two-part process.

1. First, the technical potential is determined, based on: current land cover or land use; the suitability of climate, soils, and slopes; and degraded or non-degraded status. Relevant data on global land-use and availability 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).
2. In the second stage, land is allocated using the Drawdown Agro-Ecological Zone model, based on priorities for each class of land. 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 (see Section 2.7 for more details).

The total land allocated for each solution is capped at the solution’s maximum adoption in the *Optimum* Scenario. Thus, Drawdown estimates of total available land are very conservative as final allocation numbers are less than those determined purely through technical potential. Drawdown new adoption potential for silvopasture is modeled specifically on non-degraded grassland with minimal or moderate slopes in humid and semi-arid climates.

Based on this existing data regarding global available degraded grassland area as well as land allocation as determined through the Drawdown Agro-Ecological Zone model, the maximum area allocated to silvopasture is 910 million hectares. This figure is used throughout the Drawdown model for this solution. As noted above, according to Dixon (2008), globally there are 773 Mha of humid grasslands and 2,902 Mha of semi-arid grasslands. Current adoption of *silvopasture* is estimated at 500 million hectares. This value was determined based on the global area reported under silvopasture by (Nair, 2012) and (Lal et al., 2018), as well as an estimate of the percentage of global pasture area (FAO, 2016; Houghton and Nassikas, 2017; Lorenz and Lal, 2018) already under silvopasture (Nair et al., 2009).

## Adoption Scenarios

Two different types of adoption scenarios were developed: 1) a Reference (REF) Case which was considered the baseline, where not much changes in the world; and 2) 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.

In the absence of limited data available either on historical growth rates of silvopasture or of any future projections, Drawdown’s future adoption is based on linear projections of current global data on documenting areas under silvopasture and grazing and pasture. Seven custom adoption scenarios were developed based on a) regional areas under >30 percent tree-cover as determined by (Zomer et al., 2014), b) estimates of historic adoption rates reported in (Nair, 2012) and (Lal et al., 2018), c) a meta-analysis of current area of grazing or pasture land already under silvopasture practice, and d) a meta-analysis of current area of grazing or pasture land under improved pasture. Details are given below:

1. ***Custom adoption scenario one***: This is a proxy adoption scenario which is created in the absence of any data available either on historical growth rate of silvopasture or any future projections. Thus, the present scenario builds the future adoption using the (Zomer et al., 2014) information available on tree coverage in the agricultural area. Country level data on agricultural area with > 30 percent tree cover was available at (Zomer et al., 2014). This data was compiled at the Project Drawdown regions, which is then used to get their percent with respect to the total agricultural area. Those percentages were then applied on the grassland area to get the regional grassland area under >30 percent tree cover. The future adoption of the silvopasture area under was thus projected based on the regional linear trend applied to the grassland area with >30 percent tree coverage. The projections were based on the regional linear trend..
2. ***Custom adoption scenario two***: In this scenario, the future area in silvopasture is projected based on scenario one, in addition it was assumed that there will be some extra area available for silvopasture by the conversion of 0-10 percent/11-20 percent tree coverage grassland area to >30 percent tree coverage areas as required for a silvopasture system. The projections are based on regional linear trends.
3. ***Custom adoption scenario three***: In the absence of comprehensive historical data for silvopasture adoption, this scenario uses available global adoption estimates reported in peer-reviewed publications. Data points from 2012 (Nair, 2012)and 2018 (Lal et al., 2018) were used for a linear interpolation of future adoption based on historic expansion of silvopasture adoption.
4. ***Custom adoption scenario four***: Future area in silvopasture is projected based on the proportion of current area of grazing or pasture land under silvopasture practice in the EU, which currently has the highest regional proportion of grazing land under silvopasture worldwide (35%), as reported by (den Herder, 2017) (see VMA, Variable 31). This percentage was applied to the total global grazing area to obtain a medium estimate of potential projected area for future silvopasture adoption. This scenario assumes 60 percent of future silvopasture adoption by 2050.
5. ***Custom adoption scenario five***: Future area in silvopasture is projected based on the proportion of current area of grazing or pasture land under silvopasture practice in Nicaragua, which currently has the highest national proportion of grazing land under silvopasture worldwide (45%), as reported by (Somarriba et al., 2012) (see VMA, Variable 31). This percentage was applied to the total global grazing area to obtain a high estimate of potential projected area for future silvopasture adoption. This scenario assumes 60 percent of future silvopasture adoption by 2050.
6. ***Custom adoption scenario six***:This is a proxy adoption scenario which is created in the absence of any data available either on historical growth rate of silvopasture or any future projections on silvopasture. In this scenario future adoption of silvopasture area was projected using the (Thornton and Herrero, 2010) future adoption rates given for improved pasture. The silvopasture adoption is projected based on the average annual adoption percent (0.60%) increase in the improved pasture area given for the five countries (Mexico, Honduras, Nicaragua, Costa Rica, and Panama) by (Holmann et al., 2004) and reported by (Thornton and Herrero, 2010). With the limitation of data at the regional level, the projections are made only at the global scale.
7. ***Custom adoption scenario seven***:This is a proxy adoption scenario which is created in the absence of any data available either on historical growth rate of silvopasture or any future projections on silvopasture. In this scenario future adoption of silvopasture area was projected using the Thorton 2010 future adoption rates given for improved pasture. The silvopasture adoption is projected based on the maximum annual adoption percent (1.30%) increase in the improved pasture area given for the five countries (Mexico, Honduras, Nicaragua, Costa Rica, and Panama) by (Holmann et al., 2004) and reported by (Thornton and Herrero, 2010). With the limitation of data at the regional level, the projections are made only at the global scale.

### Reference Case / Current Adoption

Current adoption of *silvopasture* is estimated at 500 million hectares. This value was determined based on the global area reported under silvopasture (Lal et al., 2018; Nair, 2012), as well as an estimate of the percentage of global pasture area (FAO, 2016; Houghton and Nassikas, 2017; Lorenz and Lal, 2018) already under silvopasture (Nair et al., 2009).

### Project Drawdown Scenarios

Three Project Drawdown scenarios (PDS) were developed for each solution with the goal of comparing the impact of an increased adoption of the solution to a reference case scenario. They are as follows:

#### 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 – The drawdown scenario presents results based on the medium growth, as represented by scenario “custom adoption scenario four”.

#### Optimum Scenario – For the optimum scenario, an ambitious approach is adopted, and future growth of the solution is estimated based on the “high of all” custom adoption scenarios as listed above, with a standard deviation of 0.5.

## Inputs

### Climate Inputs

Carbon sequestration rates of *silvopasture*are set at 2.74 tons of carbon per hectare per year. This is the result of meta-analysis of 14 data points from 7 sources.

**CH4 emissions reduced:** Embedded methane emissions due to cattle were estimated using the IPCC 2006 (Dong et al., 2006) regional estimates for per head beef cattle annual emissions factor (CH4 head-1 yr-1). This rate was multiplied by an assumed stocking rate of 1 animal unit per hectare to generate estimated per hectare CH4 emissions for each region in the Land model. This stocking rate is likely not representative of all regions. Drawdown’s goal was to generate a rough estimate to assess whether carbon emission reductions from *silvopasture* have the potential to offset embedded animal emissions. Nevertheless these emissions were not included in final model outputs.

**Table 2.1 Climate Inputs**

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Biosequestration | *tC/ha/yr* | -0.35 – 5.84 | 2.74 | 14 | 7 |

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[[2]](#footnote-2).

*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 *silvopasture*) 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.

### Financial Inputs

First costs are estimated at US$1,180.65 per hectare. For all agricultural solutions, it is assumed that there is no conventional first cost, as conventional grazing (in this case) is already in place on the land. Results are based on meta-analysis of 20 data points from 9 sources. Net profit per hectare is US$1152.56 per year (20 data points from 9 sources), compared to US$154.12 per year for the conventional practice (18 data points from 13 sources).

**Table 2.2 Financial Inputs for Conventional Technologies**

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| First costs (Conventional) | *US$2014/ha* | $0 | $0 | n/a | n/a |
| Net profit (Conventional) | *US$2014/ha* | $69.49-$323.38 | $154.12 | 18 | 16 |
| Operating Cost (Conventional) | *US$2014/ha* | $28.06-$684.58 | $328.42 | 9 | 8 |

**Table 2.3 Financial Inputs for Solution**

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| First costs (Solution) | *US$2014/ha* | $198.84 - $2,162.45 | $1,180.65 | 20 | 9 |
| Net profit (Solution) | *US$2014/ha* | $2628.58 - $27.74 | $1,152.56 | 20 | 9 |
| Operating Cost (Solution) | *US$2014/ha* | $2085.79 - $508.29 | $1,034.12 | 15 | 8 |

Farmers and ranchers transitioning to carbon-friendly practices face a period of reduced income. This reflects an individual learning curve, customization of the system to their farm or ranch, and time for the practice to begin to have in impact on productivity. Meta-analysis of 12 data points from 7 sources shows that in the case of implementation of silvopasture, net profits per hectare do not exceed business-as-usual for 6.1 years. To account for this delay in profitability, the Drawdown model assumes that net profit per hectare is 25% of the conventional rate until 6 years have elapsed.

### Other Inputs

Yield gains compared to business-as-usual annual grazing were set at 11.1 percent, based on meta-analysis of 6 data points from 2 sources.

## Assumptions

Six overarching assumptions have been made for Project Drawdown models to enable the development and integration of individual model solutions: 1) infrastructure required for solution is available and in-place; 2) policies required are already in-place; 3) no carbon price is modeled; 4) all costs accrue at the level of agency modeled; 5) improvements in technology are not modeled; 6) first costs may change according to learning. Full details of core assumptions and methodology will be available at [www.drawdown.org](http://www.drawdown.org). Beyond these core assumptions, there are other important assumptions made for the modeling of this specific solution. These are detailed below:

**Assumption 1:** Animal methane emissions in silvopasture systems were considered a sunk cost and are not accounted for in the Drawdown model. Similarly, possible changes in methane emissions due to changes in forage/fodder or changes in stocking rates are not included in the model. As Drawdown assumes that the TLA for the solution is already under some kind of grazing management and not another type of land use, the implementation of silvopasture would not necessarily change animal emissions unless stocking rates or per head emissions factors also changed. No evidence for those types of changes was found in the literature.

**Assumption 2:** Although silvopastoral systems have longer productive periods than conventional pastures, and therefore might reduce deforestation at forest-agriculture frontiers (Yamamoto et al., 2007), avoided emissions due to avoided deforestation are not included in the model. While this dynamic might increase the climate mitigation capacity of silvopasture, it is contingent on human behavior/decisions in such situations.

**Assumption 3:** Drawdown models assume that silvopastures do not reach a carbon saturation point within the 30-year time period modeled. It is likely that the carbon sequestration rate of silvopasture systems will decrease over time and begin to approach zero – possibly within the 30 years. However, given the constraints of our model and a lack of data on time to carbon saturation in reviewed literature, sequestration rates are assumed to remain relatively constant over 30 years. Saturation is difficult to model as reported rates range widely from 10-50 years (Toensmeier, 2016). Drawdown models account for this by excluding sequestration from silvopastures established before 2020, and by further assuming that sequestration will continue up to 30 years from newly-planted silvopastures.

**Assumption 4:** Silvopastures are not assumed to impact the total ecosystem respiration of greenhouse gases (GHGs). Similar to Assumption 3, it is very possible that planting trees would alter total respiration rates of GHGs in target systems. Nevertheless, currently available literature does not sufficiently address this point.

**Assumption 5:** As it would be nearly impossible with currently available methodologies to distinguish carbon saturated and unsaturated systems across currently existing silvopastures, Drawdown models assume that all currents silvopastures have reached full saturation and will not sequester more carbon going forward. Silvopasture has primarily been a traditional land use strategy and its growth in recent years is limited, suggesting that most current silvopastures have been established for a considerable time. Nevertheless, this assumption contributes to a conservative estimate of the total carbon sequestration potential of the solution.

## 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.

*Silvopasture* is part of Drawdown’s Food sector, specifically the supply-side set that incorporate food production. Within agriculture it is part of a cluster of solutions based on livestock production.

***The Agroecological Zone model***

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

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

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

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

***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.

***The Biomass Model***

Drawdown’s Biomass model begins with projected global biomass demand through 2060, based on FAO historical data and other sources, in categories including sawnwood, other woody biomass, and herbaceous biomass (which includes crop residues). It determines the impact of demand reduction solutions including *clean cookstoves* and *recycled paper*, resulting in an adjusted demand projection through 2060. Biomass supply reductions are modeled as well, which result from protection of forests from *forest protection, Indigenous Peoples’ forest management, mangrove protection,* and *peatland protection*, reducing biomass availability. Biomass supply increases are modeled through the increased adoption of solutions including *afforestation, bamboo, perennial biomass* andagroforestry 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.* This biomass feedstock allocation was a constraint to the adoption of this solution.

## Limitations/Further Development

In the absence of accurate satellite-based data on historical and current adoption at global scales, Drawdown figures for current adoption are based on estimates reported in peer-reviewed publications (Lal et al., 2018; Nair, 2012). As global or regional projections of silvopasture adoption in the future are similarly lacking, Drawdown predictions are based on: a) data collected by (Zomer et al., 2014) on tree cover in agricultural land, and b) national and regional levels of current silvopasture adoption in relation to total grazing and pasture land area. While this approach may not accurately reflect local realities across different regions it provides an approximation of future silvopasture adoption trends.

This approach is primarily limited by data limitations in the current literature. Most importantly, there is currently very little understanding of how silvopasture might change GHG emissions of pastureland, nor of how quickly some of these systems may saturate aboveground and belowground carbon pools and cease to sequester additional carbon. Such dynamics are highly dependent on local conditions and therefore very difficult to accurately predict through a modeling framework. But since new evidence suggests that some trees may be emitting more methane than previously understood (Covey et al., 2012) and that grassland soils in mesic systems may saturate with carbon relatively quickly with good management (Machmuller et al., 2015), current models may be largely overestimating the global impact of silvopasture on climate. Studies to fill in these gaps in the data would significantly enhance future models.

Furthermore, extrapolating sequestration rates from the few areas represented in the literature we found to all tropical-humid grasslands is likely inaccurate. A more accurate approach might utilize earth systems models that model carbon pools based on localized data inputs, but such an approach is computationally intense and beyond the scope of our work.

Similarly, financial components of our model were based on a limited number of studies from a limited number of areas. Since agricultural markets are highly localized, especially in communities where producers are primarily smallholders, access to markets, input costs, and prices differ broadly.

Current literature acknowledges the lack of data regarding silvopasture systems due to their complexity and diversity (De Pinto, 2017). Given these limitations, Drawdown’s model outcomes should not be taken as completely accurate but as being indicative of the general scale and direction of *silvopasture*’s drawdown capacity given current knowledge.

# Results

## Adoption

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

Total adoption in the *Plausible* Scenario is 698.50 million hectares in 2050, representing 77 percent of the total suitable land. Of this, 198.5 million hectares are adopted from 2020-2050.

Total adoption in the *Drawdown* Scenario is 738 million hectares in 2050, representing 81 percent of the total suitable land. Of this, 238 million hectares are adopted from 2020-2050.

Total adoption in the *Optimum* Scenario is 765.90 million hectares in 2050, representing 84 percent of the total suitable land. Of this, 265.90 million hectares are adopted from 2020-2050.

**Table 3.1 World Adoption of the Solution**

| **Solution** | **Units** | **Base Year (2014)** | **New Adoption by 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Drawdown** | **Optimum** |
| Silvopasture | Mha | 500.00 | 198.50 | 238.00 | 265.90 |
| % Total Land Available | 55% | 77% | 81% | 84% |

**Figure 3.1 World Annual Adoption 2020-2050 in Mha (a) and as a percentage of TLA (b).**

## 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).

Carbon sequestration impact is 35.69, 42.87, and 52.39 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 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*** | 0.00 | 0.00 | 2.00 | 35.69 | 35.69 | 0.86 | 2.00 |
| ***Drawdown*** | 0.00 | 0.00 | 2.39 | 42.87 | 42.87 | 1.06 | 2.39 |
| ***Optimum*** | 0.00 | 0.00 | 2.67 | 52.39 | 52.39 | 1.34 | 2.67 |

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).

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

| **Scenario** | **GHG Concentration Change in 2050** | **GHG Concentration Rate of Change in 2050** |
| --- | --- | --- |
| *PPM CO2-eq (2050)* | *PPM CO2-eq change from 2049-2050* |
| **Plausible** | 3.00 | 0.15 |
| **Drawdown** | 3.62 | 0.18 |
| **Optimum** | 4.40 | 0.20 |

**Figure 3.2 World AnnualGreenhouse Gas Emissions Reduction**

## Financial Impacts

Below are the financial results of the analysis for each scenario. For a detailed explanation of each result, please see the glossary.

Note that the financial results have changed from those published in the first edition of the *Drawdown* book.

For the *Plausible* Scenario, cumulative first cost is US$ 244.78 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$-2,505.15 billion. Net profit margin is US$1,655.12 billion, and lifetime profit margin is US$3,609.14. Lifetime cashflow savings NPV is $-387.48.

For the *Drawdown* Scenario, cumulative first cost is US$$319.96 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$-3,008.72 billion. Net profit margin is US$2,055.17 billion, and lifetime profit margin is US$4,770.15 billion. Lifetime cashflow savings NPV is US$-531.21 billion.

For the *Optimum* Scenario, cumulative first cost is US$357.08 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$-3,676.77 billion. Net profit margin is US$2,578.85 billion, and lifetime profit margin is US$5,347.71 billion. Lifetime cashflow savings NPV is $-642.23 billion.

**Table 3.4 Financial Impacts**

| **Scenario** | **Cumulative First Cost** | **Marginal First Cost** | **Net Operating Savings** | **Net Profit Margin** | **Lifetime Profit Margin** | **Lifetime Cashflow Savings NPV (of All Implementation Units)** |
| --- | --- | --- | --- | --- | --- | --- |
| *2015-2050 Billion USD* | *2015-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *Billion USD* |
| **Plausible** | *$244.78* | *$244.78* | *$-2,505.15* | *$ 1,655.12* | *$3,609.14* | *$-387.48* |
| **Drawdown** | *$319.96* | *$319.96* | *$-3,008.72* | *$ 2,055.17* | *$4,770.15* | *$-531.21* |
| **Optimum** | *$357.08* | *$357.08* | *$-3,676.77* | *$ 2,578.85* | *$5,347.71* | *$-642.23* |

**Figure 3.3 Net Profit Margin Increase**

## Other Impacts

The introduction of silvopasture practices leads to significant yield increases of 1.36, 1.64 and 2.04 million metric tons compared to conventional grazing, under the *Plausible, Drawdown,* and *Optimum* Scenarios respectively.

# Discussion

Results presented in this report suggests that silvopasture is an agroforestry system with a high potential to sequester carbon, particularly in the Latin American tropics. It is one of the most powerful biosequestration solutions modeled by Project Drawdown.

Drawdown model estimates clearly indicate the importance of increasing adoption to make silvopasture a more effective drawdown solution. Section 1.2 highlights that strategies in Latin America, such as pilot projects led by CIPAV or payments for environmental services in Costa Rica, have helped to encourage producers to adopt silvopasture despite high startup costs and potential risk. Creating similar programming that is locally relevant in target areas where adoption is currently low could increase the drawdown impact of silvopasture globally.

A few key gaps nonetheless remain in the literature on silvopasture; addressing them could provide crucial data that would reduce the impact of silvopasture. Studies including GHG budgets which compare silvopasture systems to control pasture systems remain scarce. Recent evidence shows that trees may emit more methane than previously thought (Covey et al., 2012), and soil moisture dynamics can strongly control soil GHG emissions. Understanding how planting trees in pasture may alter GHG cycles and net emissions within the system will be crucial in more fully understanding the impact of silvopasture. Similarly, as the majority of existing studies were conducted over short time periods it is currently difficult to account for the possibility that silvopasture systems, and particularly the soil component, may reach carbon saturation points after a short time (Machmuller et al., 2015).

Despite significant knowledge gaps in the literature, and inherent limitations in Drawdown’s modeling framework, the results presented in this report outline the general magnitude and direction of silvopasture’s potential given current estimates of adoption rates. The results presented here further highlight the practice’s significant potential in the case of widespread, rapid adoption. As such, silvopasture appears to be a system that warrants more attention and should possibly be supported and promoted by stakeholders.

Silvopasture is the highest ranked of all of Drawdown’s agricultural solutions in terms of mitigation impact, though to date it has received little attention. Adopting the practice should be a priority for scaling up wherever grasslands are humid enough to permit tree growth. This is particularly important given the need to produce climate-friendly livestock products to meet global demand for meat and dairy, even given plant-based diet and reduced food waste projections. Thus, silvopasture should be an essential supply-side food solution in any mitigation program.

## Limitations

This study could be improved with additional, more accurate data points on financials and C sequestration parameters, as well as more accurate data on current and projected adoption, which currently do not exist (Nair, personal communication). Similarly, projections of mitigation impact would greatly improve the accuracy of model results. More research on the suitable area of global grassland, with sufficient rainfall to permit tree growth, is also essential to precisely determine the potential impact of this solution.

## Benchmarks

A recent study by (Lal et al., 2018) estimates a range between 0.55 – 1.90 for the technical potential of C sequestration by silvopastures. Annual impact of *silvopasture* in 2030 is 0.86-1.34 gigatons of carbon dioxide equivalent per year.

Table .: Benchmarks

| **Source and Scenario** | **New Adoption (million hectares)** | **Mitigation Impact (i.e. Gt CO2-eq in 2030)** |
| --- | --- | --- |
| Lal (2018) | n/a | 0.55 – 1.90 |
| Project Drawdown – Plausible Scenario (PDS1) | 199 | 0.86 |
| Project Drawdown – Drawdown Scenario (PDS2) | 238 | 1.06 |
| Project Drawdown – Optimum Scenario (PDS3) | 266 | 1.34 |

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# Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**PDS/ Project 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

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. [↑](#footnote-ref-1)
2. 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-2)