TECHNICAL ASSESSMENT FOR CONSERVATION AGRICULTURE

SECTOR: FOOD

AGENCY LEVEL: FARMER

KEYWORDS: BIOSEQUESTRATION, ANNUAL CROP PRODUCTION

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DRAWDOWN

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EXECUTIVE SUMMARY

Project Drawdown defines *conservation agriculture* as: an annual crop production system that provides biosequestration via crop rotation, cover cropping, and reduced tillage. This solution replaces conventional annual cropping systems with tillage.

The three components of *conservation agriculture* are: minimal soil disturbance (no-till or reduced tillage), permanent soil cover (cover crops), and diversified crop rotations. It is suited to both mechanized and unmechanized contexts. Climate impact from *conservation agriculture* is through reduced emissions from tillage and soil carbon sequestration as well as the potential for net increased albedo and reduced inorganic N fertilizer requirements.

Drawdown models *conservation agriculture* as a bridge technology, which transitions to the similar but more agroecologically sound *regenerative agriculture* over time. Thus, adoption of conservation agriculture initially increases, but decreases over time as farmers transition.

Total new adoption in the *Plausible* Scenario is 196.53 million hectares from 2020-2050. The combined sequestration and emissions reduction impact of this scenario is 15.68 gigatons of carbon dioxide-equivalent between 2020-2050. Net profit margin is $ 292.35 billion 2014 USD.

Total adoption in the *Drawdown* Scenario is 133.58 million hectares from 2020-2050. The combined sequestration and emissions reduction impact of this scenario is 10.74 gigatons of carbon dioxide-equivalent between 2020-2050. Net profit margin is $ 202.99 billion 2014 USD.

Total adoption in the *Optimum* Scenario is 104.99 million hectares from 2020-2050. The combined sequestration and emissions reduction impact of this scenario is 9.07 gigatons of carbon dioxide-equivalent between 2020-2050. Net profit margin is $ 187.51 billion 2014 USD.

Conservation agriculture has spread widely since its development several decades ago. Despite its drawbacks, it's relatively low cost and ease of adoption by farmers have contributed to this remarkable growth and should continue to do so in the future.

1. LITERATURE REVIEW

1.1. STATE OF CONSERVATION AGRICULTURE

According to the FAO, "Conservation agriculture (CA) aims to achieve sustainable and profitable agriculture and subsequently aims at improved livelihoods of farmers through the application of the three principles: **minimal soil disturbance**, **permanent soil cover** and **crop rotations**."[1] Although the FAO definition is the most widely used, and the central definition upon which we base this analysis, other authors have expanded the concept of conservation agriculture to include a wider range of agricultural practices. For example, in their 2015 book on Conservation Agriculture, Farooq and Siddique add a 4th principle, to define Conservation Agriculture more broadly as "a resource-saving agricultural production system that aims to achieve production intensification and high yields while enhancing the natural resource base through compliance with four interrelated principles: minimal soil disturbance, permanent residue cover, planned crop rotations and integrated weed management, along with other good production practices of plant nutrition and pest management." [2]

In our synthesis, we included systems that meet the core definition of conservation agriculture, i.e., minimal soil disturbance and at least one of the two other criteria (cover crops and crop rotations).

Conservation agriculture can be considered as one component of the climate-smart agriculture and sustainable agriculture movements, although varying and geographically dependent perspectives on its economic viability and ability to mitigate climate change influence its integration into these movements. While it can share many commonalities with organic agriculture (see the definition provided in Table 1 Regenerative Agriculture section), it does not explicitly reduce or exclude off-farm or synthetic inputs in its core practices. In fact many large-scale farmers use synthetic herbicides as a central component of the practice. Conservation agriculture's three core practices are defined as follows:

1. Minimal soil disturbance: Conventional agriculture (that often uses a plough to "till" the land) causes a reduction in soil organic matter and thus, long-term soil degradation. When soil tillage is reduced through conservation agriculture, crop residues stay near the surface to produce a layer of mulch that stabilizes soil conditions and increases water infiltration into the soil. This has an additional benefit of reduced on-farm energy requirements.

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[1] ("FAO:AG:Conservation Agriculture" 2015)

[2] (Farooq and Siddique 2015)

2. Permanent soil cover: In conservation agriculture, soil can be covered for protection by crop residues or by living cover crops if there is gap between harvest and crop establishment.

3. Crop rotations: Crop rotations help ameliorate some of the challenges caused by reduced or no-till systems, like soil compaction, as well as increasing combined yields of the relevant crops and reducing pest damage.

Conservation Agriculture can benefit the climate in the following ways:

1. Reducing fossil fuel emissions from fewer tillage events (West and Marland 2002).

2. Protecting and storing soil organic matter (Govaerts et al. 2009; Poeplau and Don 2015) –most importantly carbon and nitrogen, in part from atmospheric removal, reduced erosion, and protection of soil organic matter from decomposition to CO_2 and inorganic nitrogen. The Drawdown CA model accounts for the stored carbon, other benefits are modeled as noted in avoided aggregate emisstions.

3. through retained organic matter and/or integration of leguminous cover crops, CA reduces the need for synthetic nitrogen and phosphorus fertilizers –the manufacture and excess use of which has major negative impacts (see section Nutrient Management)

4. Improving water retention capacity of soil which contributes to better Farmland Irrigation and buffers yield losses from droughts (see related benefits in Regenerative Agriculture section)

5. Typically improved crop yields (Finney, White, and Kaye 2016; Gabriel, Garrido, and Quemada 2013; Miguez and Bollero 2005; M. Quemada et al. 2013) when cover crops are combined with reduced tillage – especially relevant to Women Smallholders

6. Increasing surface albedo (an area of new research and insufficiently developed to include in the model at global scale (Miguel Quemada and Daughtry 2016; Kaye and Quemada 2017)).

Conservation Agriculture is implemented on an estimated 108.93 million hectares worldwide today. It is one of the more widely adopted Drawdown agricultural practices, and has some evidence of its early rate of spread. From 2001-2012, the average global rate of adoption of conservation agriculture was over 7 million hectares per year.[3] Nearly half of conservation agriculture systems worldwide are in South America (45%), 32% in North America (USA and Canada), 14% in Australia and New Zealand, with the remaining 9% in other parts of the world including Asia, Europe, and Africa. [4] However, despite this increasing rate of spread in many regions of the world, conservation agriculture still only occupies 13% of the world's total crop area.[5]

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[3] (Friedrich, Derpsch, and Kassam 2012)

[4] (Farooq and Siddique 2015; Friedrich, Derpsch, and Kassam 2012)

[5] (Friedrich, Derpsch, and Kassam 2012)

South America has been one of the early strongholds of the conservation agriculture approach. In the MERCOSUR countries (Brazil, Argentina, Paraguay, Uruguay) of the Southern Cone, 70% of the cultivated area is within conservation agriculture systems.[6] Major drivers of this trend have been the recognition of decreased erosion and decreased production costs, first in Brazil and Argentina and then throughout the region.[7] Both Brazil and Argentina had research programs dedicated to conservation agriculture as early as the 1970s.[8] The adoption of conservation agriculture has also been accelerated worldwide due to more controversial factors such as herbicide-tolerant or transgenic crops.[9]

Conservation agriculture is a drawdown solution that is already being adopted in many regions of the world, and at a large scale. If a more efficient use of fertilizers accompanies conservation agriculture practices, this solution may have even more reduction potential than shown in our model, given that reduced or no-till agriculture usually leads to direct drops in N2O and CH4 emissions.[10] In addition, while our model does not take into account the emissions reductions that may occur through erosion prevention, in some cases those additional avoided emissions can be quite substantial.[11] New research also points to potential increased albedo from surface crop residue relative to bare fallow practices (Kaye and Quemada 2017).

Recent studies have questioned the magnitude of benefits from conservation agriculture, such as its potential to store soil carbon, increase yields, reduce labor requirements, improve soil fertility and reduce erosion. Powlson et al. (2014) suggest that no-till approaches in absence of the triad of conservation agriculture components may store much less carbon in soil than previously thought, because the apparent increase of soil carbon in soil under no-till vs. conventional tillage may actually be a restructuring of soil carbon nearer to the soil surface, there is often a confounding of soil carbon concentration and mass in the literature, carbon storage in no-till soil may not be long-term due to the labile nature of this soil carbon, and the soil's ability to hold organic carbon is finite. [12] Contrasting research (Alcántara et al. 2016; Poulton et al. 2018) has found that analyses of long-term experimental plots showed soil organic carbon stocks can be built up over many decades under certain management. Giller et al. (2009) cite contradictory evidence about whether conservation agriculture in fact increases productivity, and cites smallholder concerns related to the "decreased yields often observed with conservation agriculture, increased labor requirements when

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[6] (Friedrich, Derpsch, and Kassam 2012)

[7] (Farooq and Siddique 2015)

[8] (Farooq and Siddique 2015)

[9] (Farooq and Siddique 2015)

[10] (Farooq and Siddique 2015)

[11] (Lal 2010)

[12] (Powlson et al. 2014)

herbicides are not used, an important gender shift of the labor burden to women and a lack of mulch due to poor productivity and due to the priority given to feeding of livestock with crop residues."[13] Modest but consistent grain yield increases of about 2 bushels per acre have been reported in the US by farmers who use cover crops with reduced or no-till systems (CTIC 2017), whereas conservation agriculture provided a 7.3% yield benefit in dry regions, but no yield benefit in humid systems (Pittelkow et al. 2015).

Another perceived disadvantage is the use of herbicide, particularly during the transition phase of conservation agriculture, that can lead to a series of environmental consequences such as water contamination and herbicide resistance. The use of GMO seeds in conservation agriculture systems is controversial because it has led to globally ubiquitous use of glyphosate. Subsequently glyphosate resistant weeds become very problematic in some areas, requiring other herbicide applications, and sometimes the need for repeated tillage for weed control. Furthermore, glyphosate has been classified as a probable human carcinogen by the World Health Organization (Guyton et al. 2015). The high costs of herbicide and application equipment are another disadvantage that can prevent farmers from adopting conservation agriculture in the absence of a organic weed management methods. However, it is worth noting that the conversion from conventional agriculture to conservation agriculture with herbicides or GMO seeds is a big step forward in terms of balancing climate change mitigation, economic and ecological benefits.

1.2. ADOPTION PATH

1.2.1 Current Adoption

Conservation agriculture is practiced on about 108.93 million hectares of arable cropland (2014 base year). This estimate encompasses primarily large-scale, mechanized, commercial farms with low to minimal slope. Furthermore, it excludes countries in which no data is available but where conservation agriculture is likely to be constrained by access to land/ land tenure, subsistence farming, and moisture regime.

1.2.2 Trends to Accelerate Adoption

There are also trends that may lead to increased adoption of conservation agriculture. By allowing countries to develop their own action plans, the Paris Climate Agreement open the door to agricultural solutions to reverse global warming which are cited in the overwhelming majority of Intended Nationally Determined Contributions (Food and Agriculture Organization (FAO) 2016). Conservation Agriculture

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[13] (Giller et al. 2009)

falls within the umbrella of Climate Smart Agriculture which is highlighted for socio-economic and environmental co-benefits, especially in the INDCs of many developing countries. Recognition of the potential co-benefits may quicken the transition to Regenerative Agriculture.

Increases in the prices of key inputs for conventional agriculture with increased resource scarcity may accelerate adoption of conservation agriculture. Increases in glyphosate and diesel prices will tend to favor conservation over conventional agriculture because of reduced costs.[14] Whereas a decade ago, the academic community was heavily focused on atmospheric and phytomass pools of carbon, there has been an increasing surge of interest and research on the terrestrial soil carbon sink, and this academic focus has begun to have effects within the international policy community.[15]

1.2.3   Barriers to Adoption

Conservation agriculture is currently being adopted both by large-scale farming operations and smallholders. The benefits and challenges these two demographics face are quite different, and therefore their adoption paths may deviate from the single modeled solution presented here.

Because conservation agriculture can be more effective using specialized machinery, particularly for large-scale farming operations, access to machinery and training for building and maintaining modified farm implements will be critical in the spread of conservational tillage strategies[16]. Smallholder farmers often seek an immediate return on their investment and have less of a financial buffer to weather the "trough" between up-front costs and benefits of conservation agriculture. Giller et al. (2009) cite the high cost of herbicides, the lack of smallholder agricultural technical support, and unstable macroeconomic environments for their observed lack of uptake of conservation agriculture in sub-Saharan countries, aside from a few select adopter groups.[17] Because of these numerous upfront obstacles, policy changes that provide indirect incentives that address price distortions and secure land rights (Hellin and López Ridaura 2016), in addition to direct technical and financial assistance may be instrumental in overcoming upfront costs, while social capital and civil society networks may be important in inspiring locally adapted adoption of and education related to conservation agriculture practices.[18]

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[14] (Nail, Young, and Schillinger 2007)

[15] (Scharlemann et al. 2014)

[16] (Farooq and Siddique 2015)

[17] (Giller et al. 2009)

[18] (Knowler and Bradshaw 2007)

1.2.4   Adoption Potential

{Formatting Citation} estimated the maximum potential adoption of conservation agriculture at 352 million hectares, though their definition only includes cover crops. Prestele et al. (2018) estimate that between 122 – 215 Mha is currently managed within conservation agriculture systems, using a systematic downscaling of national-level data (predominantly from 2012), and attributed almost entirely to large-scale commercial farms. They further estimate that the potential future extent ranges from 533- 1130 Mha (38-81% of global arable land). By applying their maximum extent of 81% to the Project Drawdown's TLA available for Conservation Agriculture, a maximum adoption of 641 million hectares was applied in the model, including modest adoption by smallholders.

1.3 ADVANTAGES AND DISADVANTAGES OF CONSERVATION AGRICULTURE

1.3.1   Similar Solutions

As mentioned above, there are potential agricultural solutions that are similar to conservation agriculture, namely the organic, sustainable, and climate-smart agriculture movements. Conservation agriculture's various definitions often overlap with other agricultural forms or can involve mixing and matching appropriate and place-based strategies from a suite of recommended practices. For example, the Rodale Institute, which has many resources for conservation agriculturalists, identifies many of their projects as organic no-till[19]. Conservation agriculture has also been included in the newly popularized suite of practices within "Climate-smart agriculture", which include management of water, soils, energy, and genetic material for upscaling the sustainable production of crops, livestock, forestry and aquaculture under increasing impacts of climate change.[20]

A related sustainable land management solution to increase C sequestration is tree intercropping, which combines trees into annual cropping systems. Currently, tree intercropping is adopted on 457 million ha of croplands, which is much greater than the adoption of conservation agriculture (108.93 million ha). In addition, due to the use of perennial plants, tree intercropping has much higher C sequestration potentials compared to conservation agriculture. Tree-intercropping systems bring an additional multitude of ecological and socio-economical benefits compared to conservation agriculture. For example, tree intercropping can better conserve biodiversity and provides a protective barrier for lands and people against wind hazards and severe dust storms.

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[19] Rodale Institute, "Rodale Institute : Organic Pioneers since 1947," http://rodaleinstitute.org/.

[20] FAO, "Climate-Smart Agriculture," http://www.fao.org/climate-smart-agriculture/en/.

The comparison between tree intercropping and conservation agriculture in terms of establishment costs and financial implications need to be assessed on a case-by-case basis, due to the wide range of costs and net revenue for both solutions. These two solutions can also be integrated; for example, the World Agroforestry Centre and its partners developed a new farming system called Conservation Agriculture with Trees[21] and combined the principles of conservation agriculture and agroforestry.

1.3.2   Arguments for Adoption

Experience has shown that conservation agriculture can be readily adopted by mechanized farmers when returns on investment of time, labor, and costs are likely to be realized through stable land tenure and market prices. Despite its relatively low climate impact on a per-hectare basis, its rapid adoption and large potential adoption area make for significant drawdown capacity.

1.3.3   Additional Benefits and Burdens

Table 1.1 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

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[21] (Mutua et al. 2014)

	Yield Gains	Startup Cost	Net Profit	Delayed Profit Period
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 1.2 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 CO_2-eq/ha/yr (0-1tC), Medium 3.8-11.0 t CO_2-eq/yr (1-3 tC), High 11.1+ tCO_2-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

	Ecosystem Services	Social Justice Benefits	Climate Impact/ha	Global Adoption Potential
Tree intercropping	High	Relevant	Medium	Medium
Tropical staple tree crops	Medium	Relevant	High	Low-medium
Women smallholders	n/a	Targeted	Low	Low

2 METHODOLOGY

2.1 INTRODUCTION

Project Drawdown's models are developed in Microsoft Excel using standard templates that allow easier integration with each other since integration is critical to the bottom-up approach used. The template used for this solution was the Land Model which accounts for sequestration of carbon dioxide from the atmosphere into plant biomass and soil, and reduction of emissions for a solution relative to a conventional practice. These practices are assumed to use land of a specific type that may be shared across several solutions. The actual and maximum possible adoptions are therefore defined in terms of land area (million hectares). The adoptions of both conventional and solution were projected for each of several Drawdown scenarios from 2015 to 2060 (from a base year of 2014) and the comparison of these scenarios with a reference (for the 2020-2050 segment[22]) is what constituted the results.

Conservation agriculture is modeled as a bridge technology, which transitions to *regenerative agriculture* over time. Converting from *conservation agriculture* to *regenerative agriculture* only requires the addition of one more practice (compost application, organic farming, or green manure use). The soil health movement, the International Federation of Organic Movements' "Organic 3.0", and the many farmers working to implement organic no-till agriculture are all evidence that this transition is underway.

Agency Level

The land manager, farmer, or rancher 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.

2.2 DATA SOURCES

Key sources include Farooq and Siddique (2015) eds *Conservation Agriculture*, Prestele et al. (2018), and Pittelkow et al. (2015). The model uses 63 peer-reviewed sources.

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[22] 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.

2.3 TOTAL AVAILABLE LAND

Drawdown's agricultural production and land use model approach defines the Total Land Area as the area of land (in million hectares) suitable for adoption 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 total available land for a Drawdown solution is less than the land area that is technically feasible for the solution.

The total land area allocated to *conservation agriculture* and *regenerative agriculture* is the same: 685 million hectares of non-degraded croplands with minimal slopes, which is allocated differently under different custom adoption scenarios. In all scenarios, *conservation agriculture* grows until at least 2030 and then starts declining, but never shrinks below its 2014 extent of 108.93 million hectares.

2.4 ADOPTION SCENARIOS

Two different types of adoption scenarios were developed: a Reference (REF) Case which was considered the baseline, where not much changes in the world, and a set of Project Drawdown Scenarios (PDS) with varying levels of ambitious adoption of the solution. Published results show the comparison of one PDS to the REF, and therefore focus on the change to the world relative to a baseline.

Seven custom adoption scenarios were developed for *conservation agriculture*. All begin with current adoption [3]of 108.9 million hectares. Some scenarios use the current global annual adoption rate of 0.36 percent, while others use 1.24 percent, which is the rate from South America, the highest regional annual growth rate. The conservative scenarios assume adoption to continue through 2050, while the aggressive scenarios assume that the adoption of *conservation agriculture* will reach its peak by 2030 and begin to decline as land area under *conservation agriculture* converts to *regenerative agriculture*. This conversion to regenerative agriculture was justified based on the increasing demand for organic and semi-organic

agricultural products. However, the area under conservation agriculture never goes below to the level of 2014 adoption in any future year of adoption.

The details on each of the seven custom adoption scenarios are listed below:

1. ***Custom scenario one***: An annual growth rate of 0.36% was used to forecast regional adoption. Regional adoption of conservation agriculture in the year 2050 was calculated and their percentage to the total arable land area was estimated. It is also assumed that 100% of the projected adoption will be achieved by 2030. As, it is a bridge solution to regenerative agriculture, the area under conservation agriculture will decline post 2030 and will remains to only 80% of the estimated adoption by 2050. These projections are capped at 485 million hectares, the likely maximum extent of the 788 million hectares available to the Conservation Agriculture solution based on Drawdown Agroecological Zone Model.

2. ***Custom scenario two***: Adoption of conservation agriculture was reported maximum in Brazil, across the globe. Thus, its annual growth rate of 1.24% was used to forecast regional adoption. Regional adoption of conservation agriculture in the year 2050 was calculated and their percentage to the total arable land area was estimated, and are used as assumptions 1-5, below. It is also assumed that 100% of the projected adoption will be achieved by 2030. As, it is a bridge solution to regenerative agriculture, the area under conservation agriculture will decline post 2030 and will remains to only 80% of the estimated adoption by 2050.

3. ***Custom scenario three***: This scenario assumes 100% adoption of conservation agriculture in every region by 2030.

4. ***Custom scenario four***: This is scenario 2, with the assumption that the 80% of the total projected adoption of conservation agriculture will be achieved by 2030 and after that, it will reduce to 60% by 2050.

5. ***Custom scenario five***: This is scenario 1, with the assumption that the 80% of the total projected adoption of conservation agriculture will be achieved by 2030 and after that, it will reduce to 60% by 2050.

6. ***Custom scenario six***: In this scenario, the maximum likely extent was increased to 641 million hectares, based on the Prestele et al. (2018) projection, and using their top-down approach for estimating intermediate growth rates by region, under the scenario 4 and 5 assumptions that 80% of the total projected adoption of conservation agriculture will be achieved by 2030 and after that, it will reduce to 60% by 2050.

7. ***Custom scenario seven***: This is scenario 6 using maximum growth rates based on Prestele et al. (2018) bottom-up projections of the future extent of CA, achieved by 2050. Where those area-

based projections surpass Project Drawdown's regional TLA, 100% adoption is assumed. Thus, in this scenario OECD, Eastern Europe, Asia (sans Japan) and LAC have all allocated land in the solution, whereas MEA achieves adoption of CA on 32% of the TLA.

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

2.4.1 Reference Case / Current Adoption[23]

Reports on the current adoption of conservation agriculture were found to vary between 64-450 Mha. We have used an average of three adoption estimates based on the summation of regional adoption interpolated from 2005-2060 to obtain the global current adoption for the year 2014: 108.93 million hectares. These sources are: 1) the FAO historical data available for different regions; 2) projections of CA extent from Prestele et al. (2018) top-down approach which uses an intermediate adoption rate to 2050, based on Canada's historical adoption trend as applied with exclusion factors that constrain CA land primarily to large-scale commercial farms on low slopes; and 3) Prestele et al. (2018) bottom-up estimate for a likely future maximum extent of arable lands by country, which includes some CA uptake by smallholders.

2.4.2 Project Drawdown Scenarios

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

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[23] 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.

Plausible Scenario - This scenario was determined through analysis of the seven custom adoption scenarios (represented by the "high of all" custom adoption scenarios), in which the land area under conservation agriculture reaches to its peak (402 million hectares) by 2034 and then declines to 305 million hectares by 2050. The 96 million hectares lost from conservation agriculture are assumed to be converted to regenerative agriculture.

Drawdown Scenario – This scenario represents the "custom adoption scenario two" custom scenario, the land area under conservation agriculture reaches its peak (309 million hectares) by 2034 and then declines to 242 million hectares by 2050; the difference of 67 million hectares is added to regenerative agriculture.

Optimum Scenario - This scenario represents the "average of all" custom adoption scenarios, results in the adoption of 280 million hectares by 2034, which declines to 214 million hectares by 2050. The difference of 66 million hectares is added to regenerative agriculture.

Usually, the adoption area under any solution increases from the *Plausible* to *Optimum* Scenario; however, this is not the case for *conservation agriculture*, due to its transition to *regenerative agriculture*. Thus, a continuous decrease in *conservation agriculture* leads to a continuous increase in *regenerative agriculture* from the *Plausible* to *Optimum* Scenarios.

2.5 INPUTS

2.5.1 Climate Inputs

Sequestration rates are set at 0.78, 0.38, 0.61, and 0.25 tons of carbon per hectare per year for tropical humid, temperate/boreal humid, tropical semi-arid, and temperate/boreal semi-arid zones, respectively. These are the result of meta-analysis of 57 data points from 34 sources. Emissions reduction rates from *conservation agriculture* are 0.23 tons of carbon dioxide-equivalent per hectare per year, based on meta-analysis of 16 data points from 7 sources.

Table 2.1 Climate Inputs

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Emissions reduction	*tCO2-eq/ha/yr*	-0.02-0.49	0.23	14	7
Biosequestration tropical humid	*tC/ha/yr*	0.31-1.24	0.78	22	13
Biosequestration temperate/boreal humid	*tC/ha/yr*	0.11-0.65	0.38	12	9
Biosequestration tropical semi-arid	*tC/ha/yr*	-0.20-1.42	0.61	5	4
Biosequestration temperate/boreal semi-arid	*tC/ha/yr*	0.10-0.38	0.25	6	4

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[24].

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 (Poulton et al. 2018; Mayer et al. 2018).

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

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[24] 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.

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.

2.5.2 Financial Inputs

Financial inputs for *conservation agriculture* were determined via meta-analysis of 33 data points from 11 sources. First costs are estimated at US$355.05 [4] per hectare; for all agricultural solutions, it is assumed that there is no conventional first cost, as agriculture is already in place on the land. Net profit is US$530.39 per hectare per year, compared to US$474.21 for the conventional practice.

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*	$195.87-$752.54	$474.21	84	42
Operating Cost (Conventional)	*US$2014/ha*	$0.00-$1,329.35	$943.57	79	4

Table 2.3 Financial Inputs for Solution

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
First costs (Solution)	*US$2014/ha*	$175.73-$534.38	$355.05	9	6
Net profit (Solution)	*US$2014/ha*	$308.23-$752.56	$530.39	21	5

	Units	Project Drawdown Data Set Range	Model Input	Data Points (#)	Sources (#)
Operating Cost (Solution)	*US$2014/ha*	$489.35-$708.70	$599.03	19	4

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 10 data points from 6 sources shows that in the case of implementation of improved annual cropping solutions, net profits per hectare do not exceed business-as-usual for 3.4 years. To account for this delay in profitability, the Drawdown model assumes that net profit per hectare is 25% of the conventional rate until 4 years have elapsed.

2.5.3 Other Inputs

Yield gains compared to business as usual annual cropping were set at 7.2 percent, based on meta-analysis of 10 data points from 5 sources.

2.6 ASSUMPTIONS

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

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

Assumption 1: The maximum area under conservation agriculture was limited by the percentage of the large farmholders, as it is assumed that they will be the initial adopters of conservation agriculture due to the availability of the required machinery at their end.

Assumption 2: This solution is assumed to be the bridge solution to regenerative agriculture, which is the organic form of this solution. Thus, it is assumed that initially the farmers will adopt conservation agriculture and later they will shift to regenerative agriculture pertaining to the increasing demand for organic food. Thus, the adoption of conservation agriculture shows an initial increase and then decline.

Assumption 3: The total area under conservation agriculture will never go below the level of current adoption as of 2014, in any of the future years of adoption.

Assumption 4: It is assumed that the area which will be left out due to the declining trend in later years of conservation agriculture will be added to regenerative agriculture, as discussed above.

2.7 INTEGRATION

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

Conservation agriculture 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 perennial crops 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 geophysical 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 used in Drawdown calculations is less than the technical potentially available land.

The total land area allocated to *conservation agriculture* and *regenerative agriculture* is the same: 788 million hectares of non-degraded croplands with minimal slopes.

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 resulting from 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.

Adoption of *conservation agriculture* was constrained by several factors. These include: limiting adoption to cropland of minimal slope, competition for said cropland with rice solutions, and a higher priority for *regenerative agriculture*. The combined *conservation/regenerative agriculture* practice is assigned third-level priority for non-degraded cropland of minimal slopes. Only rice-based solutions are more highly prioritized.

2.8 LIMITATIONS/FURTHER DEVELOPMENT

The influence of local geophysical and management conditions for conservation agriculture contribute variabilities in global accounting of the impact of conservation agriculture. In terms of reducing warming potential, a key factor is the use of cover crops within conservation agriculture systems which generally provides greater sequestration, reduced fertilizer use and downstream NOx emissions, as well as greater yield gains for conservation agriculture relative to cash crop residue retention under reduced tillage, dependent on local growing conditions. New research has highlighted the potential net cooling effect of albedo within conservation agriculture, similar in magnitude to the climate impact of reduced tillage, but empirical measurements are extremely limited.

Methods are under development to more accurately detect conservation agriculture areas through satellite remote sensing (Daughtry et al. 2006; Miguel Quemada and Daughtry 2016; Transon et al. 2018). Newer global satellites such as Sentinel have better spatial resolution and more frequent data collection that allows scientists to assess farmland at important planting and harvest dates. The satellite spectral data could be used to better categorize the climate impact of conservation agriculture areas according to the amount of residue or soil disturbance that is detected.

3 RESULTS

3.1 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. Note that the TLA set for this solution is shared with Regenerative Agriculture, therefore the adoption has never gone above 45%, and it is assumed that by 2050 majority of the farmers will adopt regenerative agriculture which is a bridge solution to conservation agriculture.

Total adoption in the Plausible Scenario is 305.45 million hectares in 2050, representing 45 percent of the total available land. At peak adoption, 196.53 million hectares are adopted from 2020-2034.

Total adoption in the Drawdown Scenario is 242.51 million hectares in 2050, representing 35 percent of the total available land. At peak adoption, 133.58 million hectares are adopted from 2020-2034.

Total adoption in the Optimum Scenario is 213.92 million hectares in 2050, representing 31 percent of the total available land. At peak adoption, 104.99 million hectares are adopted from 2020-2033.

Table 3.1 World Adoption of the Solution

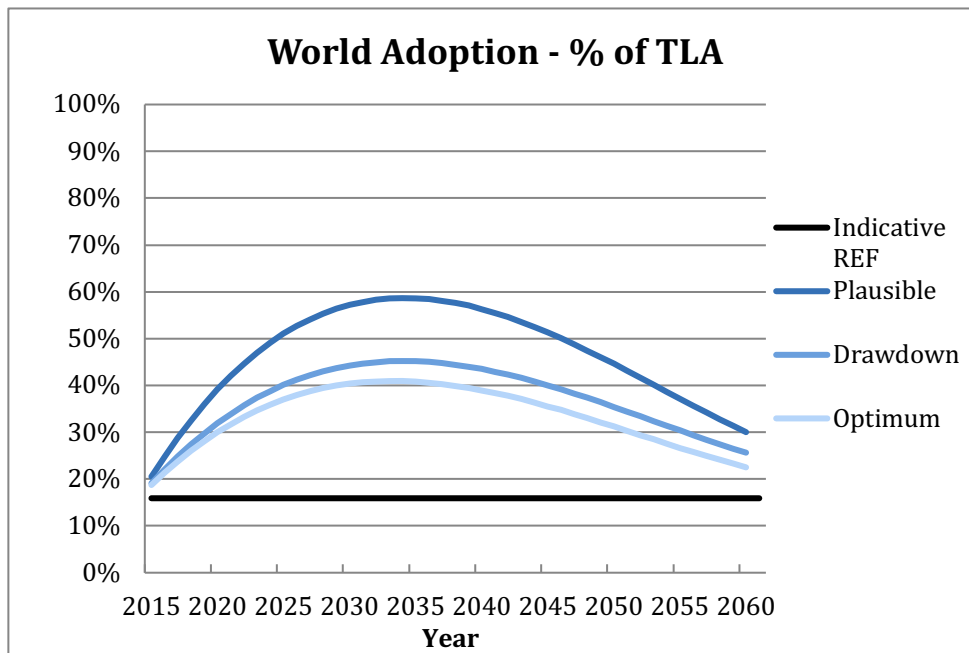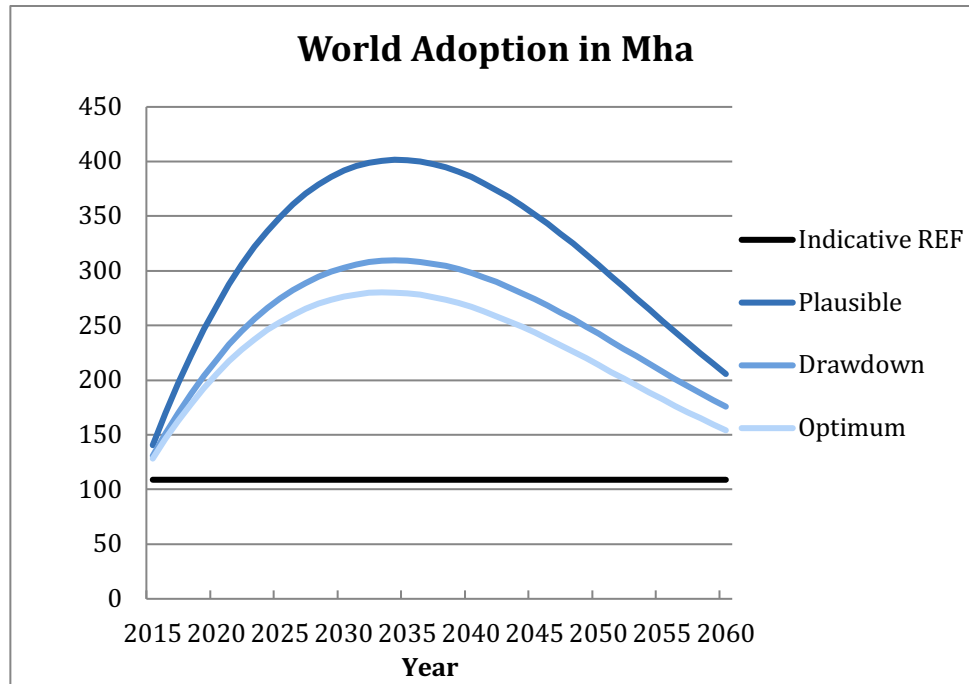| Solution	Units	Base Year (2014)	New Adoption by 2050		
			Plausible	Drawdown	Optimum
Conservation Agriculture	Mha	108.93	196.53	133.58	104.99
	% Total Land Available	15.9%	45%	35%	31%

Figure 3.1 World Annual Adoption 2020-2050

3.2 CLIMATE IMPACTS

Below are the emissions results of the analysis for each scenario which include total emissions reduction, atmospheric concentration changes, and sequestration where relevant. For a detailed explanation of each result, please see the glossary (Section 6).

Biosequestration impact is 15.68, 10.74, and 9.07 gigatons of carbon-dioxide equivalent in the *Plausible,*
Drawdown, and *Optimum* Scenarios respectively.

Table 3.2 Climate Impacts

Scenario	Maximum Annual Emissions Reduction	Total Emissions Reduction	Max Annual CO$_2$ Sequestered	Total Additional CO$_2$ Sequestered	Total Atmospheric CO$_2$-eq Reduction	Emissions Reduction in 2030	Emissions Reduction in 2050
	(Gt CO$_2$-eq/yr.)	*Gt CO$_2$-eq/yr. (2020-2050)*	*(Gt CO$_2$-eq/yr.)*	*Gt CO$_2$-eq/yr. (2020-2050)*	*Gt CO$_2$-eq (2020-2050)*	*(Gt CO$_2$-eq/year)*	*(Gt CO$_2$-eq/year)*
Plausible	0.05	1.79	0.36	13.89	15.68	0.58	0.40
Drawdown	0.03	1.22	0.24	9.51	10.74	0.40	0.27
Optimum	0.02	1.03	0.19	8.03	9.07	0.34	0.22

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 CO$_2$-eq

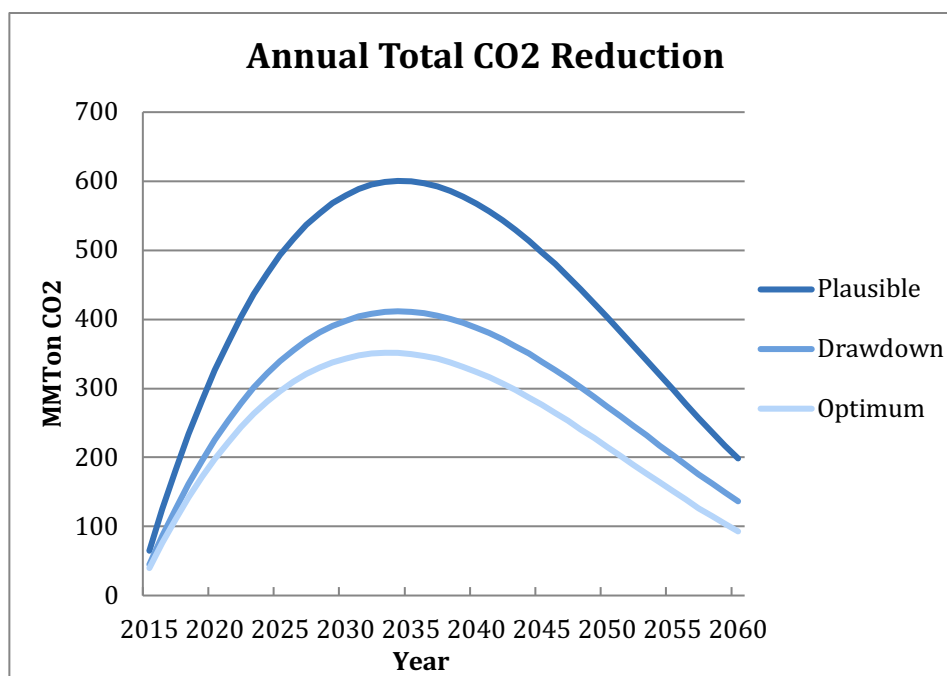| Scenario	GHG Concentration Change in 2050	GHG Concentration Rate of Change in 2050
	PPM CO$_2$-eq (2050)	*PPM CO$_2$-eq change from 2049-2050*
Plausible	1.293	0.020
Drawdown	0.885	0.014
Optimum	0.746	0.010

Figure 3.2 World Annual Greenhouse Gas Emissions Reduction

3.3 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$$152.77 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$2,633.69 billion. Net profit margin is US$292.35 billion, and lifetime profit margin is US$$286.73 billion. Lifetime cashflow savings NPV is US$539.35 billion.

For the *Drawdown* Scenario, cumulative first cost is US$$ 104.98 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$1,803.80 billion. Net profit margin is US$ 202.99 billion, and lifetime profit margin is US$197.73 billion. Lifetime cashflow savings NPV is US$370.89 billion.

For the *Optimum* Scenario, cumulative first cost is US$$ 90.56 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$1,523.08 billion. Net profit margin is US$ 187.51 billion, and lifetime profit margin is US$172.69. Lifetime cashflow savings NPV is $ 319.90 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	$152.77	$152.77	$2,633.69	$ 292.35	$286.73	$ 539.35
Drawdown	$ 104.98	$ 104.98	$1,803.80	$ 202.99	$197.73	$ 370.89
Optimum	$ 90.56	$ 90.56	$1,523.08	$ 187.51	$172.69	$ 319.90
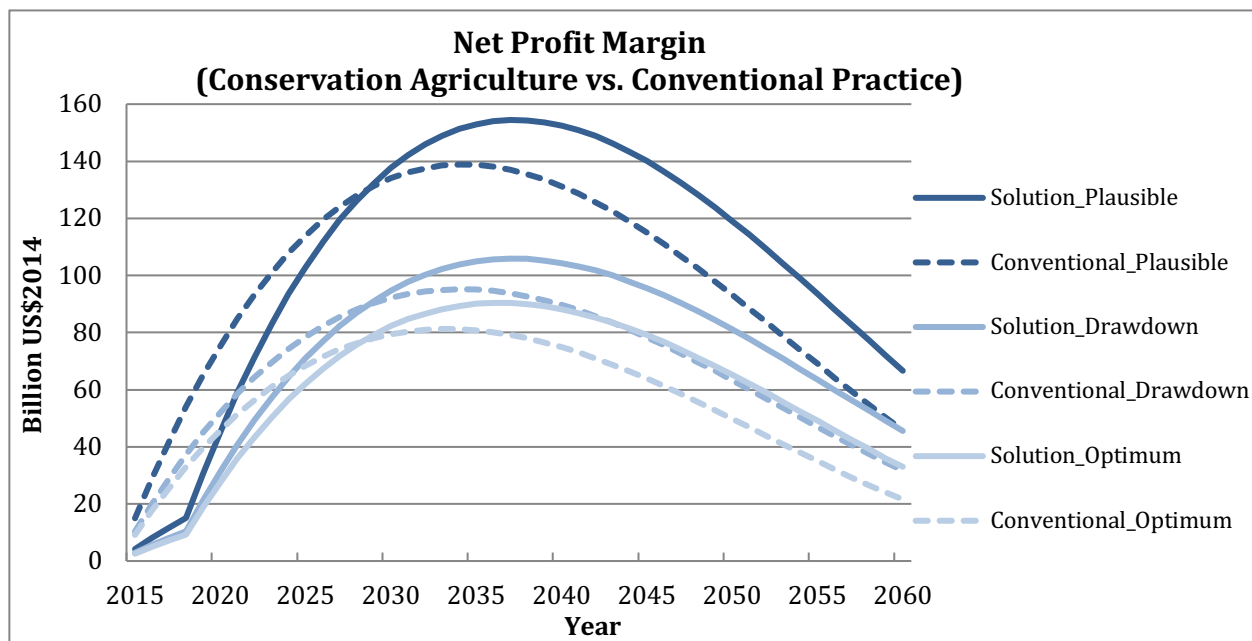
Figure 3.3 Net Profit Margin

3.4 OTHER IMPACTS

Impact on global food production is an increase of 1,884 million metric tons of food from 2020-2050 in the *Plausible* Scenario, with 1,290 and 1,090 million metric tons 2020-2050 for the *Drawdown* and *Optimum* Scenarios respectively.

4 DISCUSSION

Conservation agriculture has moderately impressive potential for climate change mitigation. Although the per-area carbon sequestration rates of conservation agriculture might be lower compared to other perennial plants-based systems such as agroforestry, it's wide current and wider potential adoption (viable on almost all croplands), could be an important contributor to CO2 reduction.

To realize the maximum potential of conservation agriculture, a number of barriers including access to credit and specialized machinery need to be overcome. The challenges for smallholder farmers and large-scale farms are different and require targeted policy support for each. The reliance on herbicides in many large-scale commercial farm systems is problematic given the growing recognition of negative human health and environmental impacts of glyphosate. Thus transition to regenerative agriculture is of increasing importance.

4.2 LIMITATIONS

Studies examining the impact of conservation agricultural on all relevant greenhouse gases, including soil carbon sequestration, and the resulting net global warming potential are quite limited. Conservation agriculture could impact the different soil greenhouse gas emissions in opposite directions. For example, studies have shown that in no-till systems, increased nitrous oxide might offset the benefits of decrease in methane emissions[25]. Many studies focus on climate impacts of one or other component of conservation agriculture, rather than measuring effects of all three practices combined, and subsequently reviews on the topic are sometimes difficult harmonize. To comprehensively assess the climate impact of conservation agriculture, it is important to measure the major greenhouse gas emissions together, and to conduct a life-cycle analysis when possible.

Data on financial variables is very limited. Our current model did not capture the regional difference in climate and financial impacts. More data is needed to further validate our conclusion.

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[25] Zhao X, Liu S-L, Pu C, et al. Methane and nitrous oxide emissions under no-till farming in China: a meta-analysis. Glob Change Biol 2016;22(4):13725726 {Citation}

This study was constrained by limited access to financial data, at the farm, regional, and global levels. Future work should include collecting additional data on first costs and net profit per hectare. Conservation agriculture is already a potent global force for climate change mitigation. Drawdown's model builds on this success, and projects evolution and improvement in the practice (in the form of regenerative agriculture) to keep it a critical agricultural mitigation strategy into the future.

4.3 BENCHMARKS

The Intergovernmental Panel on Climate Change estimates 0.8 gigatons carbon dioxide equivalent per year by 2030 for cropland management excluding rice and agroforestry (Smith et al. 2007)(Smith, 2007, Figure 8.9). Griscom et al.'s (2017) "Natural climate solutions" calculate 0.25-0.41 gigatons of carbon dioxide equivalent per year in 2030 for "conservation agriculture", though they define conservation agriculture as the use of cover cropping and do not categorize tillage practices. Similarly, Kaye and Quemada (2017) estimate that cover cropping alone could have a net climate impact of 1- 1.5 tonnes CO2e/ha/yr which corresponds to 0.15-0.32 gigatons when applied to half of the projected conservation agriculture lands in 2030 (assuming that cover cropping is unlikely on the roughly 50% of cropland growing winter cereals). For the combined *conservation agriculture* and *regenerative agriculture* solutions (annual cropping excluding rice and agroforestry), Drawdown's model calculates 1.27, 1.35, and 1.46 gigatons of carbon dioxide equivalent in 2030 in the *Plausible, Drawdown, and Optimum* Scenarios respectively. These figures are higher than Griscom et al.'s, as that study was limited to cover crops. Likewise, Kaye and Quemada's (2017) estimates are constrained by assuming that the ~50% of cropland in winter cereals are not available for cover cropping, whereas they are likely suitable for conservation agriculture. They are also higher than IPCC, perhaps because of *regenerative agriculture's* higher sequestration rates.

Table 4.1 Benchmarks

Source	Scenario	Mitigation Impact (i.e. Gt CO_{2-eq} in 2030)
Smith (2007)	Cropland management excluding rice and agroforestry	0.80
Griscom (2017)	Cover cropping	0.25-0.41

Source	Scenario	Mitigation Impact (i.e. Gt CO$_{2\text{-eq}}$ in 2030)
Kaye and Quemada (2017)	Cover cropping	0.15-0.32
Plausible Scenario	Conservation agriculture plus regenerative agriculture	1.27
Drawdown Scenario	Conservation agriculture plus regenerative agriculture	1.35
Optimum Scenario	Conservation agriculture plus regenerative agriculture	1.46

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6 GLOSSARY

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

Approximate PPM Equivalent – the reduction in atmospheric concentration of CO_2 (in **PPM**) that is expected to result if the **PDS Scenario** occurs. This assumes a discrete avoided pulse model based on the Bern Carbon Cycle model.

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

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

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

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

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

Emissions Factor– the average normalized emissions resulting from consumption of a unit of electricity across the global grid. Typical units are kg CO_2e/kWh.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

PDS/ Project Drawdown Scenario – this is the high growth scenario for adoption of the solution

PPB/ Parts per Billion – a measure of concentration for atmospheric gases. 10 million PPB = 1%.

PPM/ Parts per Million – a measure of concentration for atmospheric gases. 10 thousand PPM = 1%.

REF/ Reference Scenario – this is the low growth scenario for adoption of the solution against which all **PDS scenarios** are compared.

Regrets solution has a positive impact on overall carbon emissions being therefore considered in some scenarios; however, the social and environmental costs could be harmful and high.

Replacement Time- the length of time in years, from installation/acquisition/setup of the solution through usage until a new installation/acquisition/setup is required to replace the earlier one. This is calculated as the ratio of **Lifetime Capacity** and the **Average Annual Use**.

TAM/ Total Addressable Market – represents the total potential market of functional demand provided by the technologies and practices under investigation, adjusting for estimated economic and population growth. For this solutions sector, it represents world and regional total addressable markets for electricity generation technologies in which the solutions are considered.

Total Emissions Reduction – the sum of grid, fuel, indirect, and other direct emissions reductions over the analysis period. The emissions reduction of each of these is the difference between the emissions that would have resulted in the **REF Scenario** (from both solution and conventional) and the emissions that would result in the **PDS Scenario**. These may also be considered as "emissions avoided" as they may have occurred in the REF Scenario, but not in the PDS Scenario.

Transition solutions are considered till better technologies and less impactful are more cost effective and mature.

TWh/ Terawatt-hour – A unit of energy equal to 1 billion kilowatt-hours