**Technical assessment for**

**Nutrient Management**

Sector: Food

Agency Level: Farmer

Keywords: Emissions Reduction, Annual Crop Production

AUGUST 2019

**Prepared by:**

Dan Kane, Research Fellow,

Martina Grecequet, research fellow



27 GATE 5 RD., SAUSALITO, CA 94965 [info@drawdown.org](mailto:info@drawdown.org) [www.drawdown.org](http://www.drawdown.org)

Table of Contents

[List of Figures 4](#_Toc18442004)

[List of Tables 4](#_Toc18442005)

[Executive Summary 5](#_Toc18442006)

[1. Literature Review 6](#_Toc18442007)

[1.1. State of the Practice 6](#_Toc18442008)

[1.2. Adoption Path 10](#_Toc18442009)

[1.2.1 Current Adoption 11](#_Toc18442010)

[1.2.2 Trends to Accelerate Adoption 11](#_Toc18442011)

[1.2.3 Barriers to Adoption 12](#_Toc18442012)

[1.2.4 Adoption Potential 12](#_Toc18442013)

[1.3 Advantages and disadvantages of Nutrient Management 12](#_Toc18442014)

[1.3.1 Similar Solutions 12](#_Toc18442015)

[1.3.2 Arguments for Adoption 12](#_Toc18442016)

[1.3.3 Additional Benefits and Burdens 13](#_Toc18442017)

[2 Methodology 15](#_Toc18442018)

[2.1 Introduction 15](#_Toc18442019)

[2.2 Data Sources 15](#_Toc18442020)

[2.3 Total Available Land 16](#_Toc18442021)

[2.4 Adoption Scenarios 17](#_Toc18442022)

[2.4.1 Reference Case / Current Adoption 18](#_Toc18442023)

[Project Drawdown Scenarios 18](#_Toc18442024)

[2.5 Inputs 18](#_Toc18442025)

[2.5.1 Climate Inputs 18](#_Toc18442026)

[2.5.2 Financial Inputs 19](#_Toc18442027)

[2.5.3 Other Inputs 20](#_Toc18442028)

[2.6 Assumptions 20](#_Toc18442029)

[2.7 Integration 21](#_Toc18442030)

[2.8 Limitations/Further Development 23](#_Toc18442031)

[3 Results 23](#_Toc18442032)

[3.2 Adoption 23](#_Toc18442033)

[3.3 Climate Impacts 25](#_Toc18442034)

[3.4 Financial Impacts 27](#_Toc18442035)

[4 Discussion 29](#_Toc18442036)

[4.2 Limitations 29](#_Toc18442037)

[4.3 Benchmarks 29](#_Toc18442038)

[5 References 30](#_Toc18442039)

[6 Glossary 33](#_Toc18442040)

# List of Figures

[Figure 1.1: Nitrogen fertilizer use in tonnes from 1961to 2014 in China, Europe, USA and West Africa (source FAO, 2019). 6](#_Toc18442041)

[Figure 1.2: Trends in global nitrous oxide emissions from agriculture soils from1970 to 2012. Data taken from EDGAR greenhouse gas emission dataset (2019) 7](#_Toc18442042)

[Figure 3.1 World Annual Adoption 2020-2050 25](#_Toc18442043)

[Figure 3.2 World AnnualGreenhouse Gas Emissions Reduction 27](#_Toc18442044)

[Figure 3.3 Net Operational cost savings 28](#_Toc18442045)

# List of Tables

[Table 1.1 Food Production Solutions Comparison: On-Farm Impacts 13](#_Toc18442046)

[Table 1.2 Food Production Solutions Comparison: On-Farm Impacts Social and Ecological Impacts 14](#_Toc18442047)

[Table 2.1 Climate Inputs 19](#_Toc18442048)

[Table 2.2 Financial Inputs for Conventional Technologies 20](#_Toc18442049)

[Table 2.3 Financial Inputs for Solution 20](#_Toc18442050)

[Table 3.1 World Adoption of the Solution 24](#_Toc18442051)

[Table 3.2 Climate Impacts 25](#_Toc18442052)

[Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq 26](#_Toc18442053)

[Table 3.4 Financial Impacts 28](#_Toc18442054)

[Table 4.1 Benchmarks 29](#_Toc18442055)

# Executive Summary

Project Drawdown defines *nutrient management*as fertilizer application practices that use right source, right rate, right time and right placement principles. These principles are important for both countries where fertilizer consumption is high and nitrogen use efficiency low (e.g., United States, China) as well as in countries where substantial increases in nutrient inputs on cropland is needed (Sub-Saharan Africa). An opportunity exists for all countries to meet future food security needs while using N fertilizers efficiently.

Nitrogen fertilizers have greatly increased agricultural and food production over the past century. Yet more than than half of the nitrogen applied to agriculture soils is not used by plants, instead nitrogen is lost to the environment and converted to ammonia emissions, nitrogen oxide (both air pollutants), nitrate (water pollutant) and nitrous oxides, a potent greenhouse gas.

Nitrogen fertilizer is routinely over-applied in many countries including United States, China, India and Europe, while in Sub-Saharan Africa is nitrogen deficient, causing long term depletion of agriculture soils. The production and transportation of synthetic fertilizer is an energy-intensive process that produces carbon dioxide emissions, efficient fertilizer application will also have the effect of abating emissions associated with fertilizer manufacture and transportation.

*Nutrient management* has an important climate impact globally. Farmers save money by reducing the over-application of fertilizer. It reduces the emissions of a powerful greenhouse gas and improves air and water quality by reducing runoff from farms.

Total adoption of the nutrient management practices in the *Plausible* Scenario is 773 million hectares in 2050, representing 55% percent of the total suitable land for nutrient management. Of this, 634 million hectares are adopted from 2020-2050. The emissions reduction impact of this scenario is 11.36 gigatons of carbon dioxide-equivalent between 2020-2050. The operational cost saving is 28 billion 2014 USD.

Total adoption in the *Drawdown* Scenario is 1163 million hectares in 2050, representing 83% percent of the total suitable land. Of this, 1023 million hectares are adopted from 2020-2050. The emissions reduction impact of this scenario is 18.35 gigatons of carbon dioxide-equivalent between 2020-2050. Net profit margin is 36 billion 2014 USD.

Total adoption in the *Optimum* Scenario is 1399 million hectares in 2050, representing 100% percent of the total suitable land. Of this, 1260 million hectares are adopted from 2020-2050. The emissions reduction impact of this scenario is 22.39 gigatons of carbon dioxide-equivalent between 2020-2050. Net profit margin is US$ 57 billion 2014 USD.

# Literature Review

## State of the Practice

Since, 1970, mineral fertilizer consumption has increase worldwide, except for Africa, where nitrogen input via synthetic N fertilizers is among the lowest in the world (Figure 1). As a consequence of low fertilizer inputs in Africa (an average of 13 kg of nitrogen per hectare compared to 149 kg of nitrogen per hectare in the United States) the nitrogen removal through crop harvest and erosion over the last several decades has led to negative nutrient balances, declining grain yields, and consequently to insufficient food intake to meet dietary protein and energy requirements. The absolute numbers of stunted children in African countries are in fact still increasing: from 50.4 million in 2000 to 58.5 million in 2016 (World Health Organization, 2017).

Figure .: Nitrogen fertilizer use in tonnes from 1961to 2014 in China, Europe, USA and West Africa (source FAO, 2019).

In contrast, the increased amount of reactive nitrogen in agricultural ecosystems lead to decrease of biodiversity due to widespread eutrophication and acidification of aquatic and terrestrial ecosystems, impairment of air quality and global warming. While some of these problems have been reduced by local and international policies (US Clear Air Act, the Convention on Long Range Transboundary Air Pollution), nitrogen-related problems are still far to being solved.

Agriculture is the largest source of anthropogenic nitrous oxide emissions. Application of nitrogen fertilizers, animal manure and livestock management accounts for about 60% of the global nitrous emissions from agriculture (Syakila and Kroeze, 2010). Nitrous oxide is a particularly potent greenhouse gas. It’s residency time in the atmosphere is 114 years and is roughly equivalent to 298 parts of carbon dioxide in terms of global warming potential. The most important factors affecting nitrous oxide emissions from fertilized fields are climate, soil, organic carbon content, soil texture, soil drainage, abundance of nitrate and soil pH and management practices (type of crop, nitrogen rate applied to the soil, application technique, timing, tillage, and irrigation) (Snyder et al., 2009). When soil is saturated with water, making oxygen levels in the soil low, denitrifiers use nitrate as a final electron acceptor in their metabolic pathway, converting it through a series of steps into nitrous oxide emissions. Some nitrous oxide emissions are further converted to non-reactive nitrogen, but a portion of it is lost to the atmosphere.

Figure 2 shows increasing trends in nitrous oxide emissions from 1970 to 2012 that correlate with increasing use of nitrogen fertilizers. Since 1970 nitrous oxide emissions doubled. Projections of global nitrous emissions from agriculture are predicted to reach as high as 7.6 tera-grams by 2030 with the majority of that coming from soil management.

Figure .: Trends in global nitrous oxide emissions from agriculture soils from1970 to 2012. Data taken from EDGAR greenhouse gas emission dataset (2019)

**Nutrient Management**

Project Drawdown defines nutrient management as a set of practices that use four principles - right source, right rate, right time and right placement of fertilizer. Collectively, these principles aim to improve nitrogen use efficiency (NUE), which is defined as the ratio of plant productivity to nitrogen applied. These principles are important both for countries where nutrient consumption is high and nitrogen use efficiency low (e.g., United States, China) as well as in countries where substantial increases in nutrient inputs on cropland is needed (e.g., Sub-Saharan Africa). An opportunity exists for all countries to meet future food security needs while using N fertilizers efficiently.

Choosing the **right source** is primarily about matching fertilizer choices with plant needs or equipment limitations. Fertilizers come in a variety of forms both dry and liquid with different nitrogenous compounds that require different delivery mechanisms. These different types are often specifically useful for different purposes, specific crops, or certain points in the season. Studies have demonstrated that fertilizer source can have a significant impact on the amount of nitrous oxide emitted from agricultural soils (Gagnon et al., 2011). Soil oxygen levels likely play a strong role, though, in dictating how much nitrogen is lost as a nitrous oxide emission, with nitrate-based fertilizers emitting more under low oxygen conditions and ammonium-based fertilizers emitting more when oxygen levels are sufficiently high for aerobic activity (Tenuta and Beauchamp, 2003).

More recently, fertilizer manufacturers have begun making enhanced efficiency fertilizers that slow down dissolution after application. In so doing, the delivery of nitrogen from these products is better synchronized with plant demand, reducing the amount of nitrogen that goes unused and is lost from the system as N2O. Recent studies indicate that use of these enhanced efficiency fertilizers may help increase crop yields while minimizing environmental nitrogen losses (Kanter and Searchinger, 2018, Snyder, 2017).

**“Right time”** and **“right place”** are focused on managing fertilizer applications to deliver nitrogen when and where crop demand is highest. Crop demand for nitrogen is not consistent throughout the growing season. Plants typically require much more nitrogen as they near growth stages when plant mass increases exponentially or when plants are developing fruit or grains. Timing the delivery of nitrogen with these increased periods of demand increases the amount that is utilized by plants and reduces losses. To simplify production and reduce the possibility of equipment damaging plants, producers will often apply fertilizer at planting or just after, times when plant demand for nitrogen is very low. Splitting total annual fertilizer into two applications – one at the beginning of the season and one when plants are more mature and their demand for nitrogen is higher – reduces the likelihood that fertilizer will go unused and be lost as nitrous oxide (Drury et al., 2012) Similarly, ensuring that fertilizer is delivered closer to plant roots through fertilizer “banding” can improve plant uptake of nutrients, but such improvements may actually increase nitrous oxide emissions as they can lead to more rapid nitrate-N accumulation in the soil (Engel et al., 2010).

Arguably the most important decision in reducing nitrous oxide emissions from fertilizer application is choosing the **right rate**. The rate, or amount of fertilizer to apply per unit area, is determined by calculating the amount of nitrogen necessary to achieve the projected yield goal. Such calculations are often very locally specific and based on the yield potential of local soils and climate. But producers will often apply more fertilizer than what is recommended in an attempt to buffer against potentially poor growing conditions. Furthermore, although soil organic matter provides a significant portion of the necessary nitrogen to crops, producers don’t always consider how this source of nitrogen might displace some of the fertilizer they require, allowing them to reduce their rate.

**Co-benefits**

* **Low risk in high production areas:** Extensive research in intensive cropping systems has established optimum fertilizer application rates for different areas and different crops. Frequently, optimum rates are below the rates typically used by farmers, meaning moderate reductions to fertilizer input are unlikely to significantly decrease yields.
* **Cost savings:** Since fertilizer is sold by weight, any reduction in applications means an immediate cost savings to farmers.
* **Continuous benefit:** Solutions that are focused on sequestering carbon may lose effectiveness over time as systems become saturated. Since nutrient management is primarily about avoiding emissions from soil, its benefits can continuously compound into the future.
* **Reduced air, water and soil pollution:** Nitrogen fertilizer applications are also source of ammonia emissions, an important air pollutant, while leaching of nitrogen fertilizer into groundwater leads to major downstream pollution problems. Elevated levels of nitrogen in terrestrial and in aquatic systems have been shown to cause acidification and eutrophication responsible for changes in natural ecosystems. Thus, balanced nitrogen fertilizer applications could also reduce air and water related problems.
* **Associated reduction in fertilizer production:** The production of fertilizer through the Haber-Bosch process requires substantial energy inputs (currently about 1-2% of global energy demand. Reducing fertilizer use may have the additional effect of reducing or abating fertilizer demand/production, offsetting associated carbon emissions and increasing the overall impact of the solution.

**Trade-offs**

* The fertilizer industry is a key player in setting environmental policy, and will likely oppose policies that threatens their profits from reduced use of traditional fertilizers. To avoid strong opposition, Kanter et al. (2014) propose to consider the economic impacts of improved nitrogen management policies on the fertilizer industry and identify new profit opportunities (e.g. enhanced efficiency fertilizers).
* Studies in Europe found that some measures that aim to reduce ammonia emissions may increase emissions of nitrous oxide and nitrate leaching (Velhof et al., 2007).

## Adoption Path

Regulations concerning fertilizer application and use differ by country. In Europe Union, the Nitrate Directive (1991) aims to decrease nitrate leaching from agriculture sources to groundwater and surface water. This includes the leaching of nitrate from mineral fertilizers applied to the field. The Nitrate Directive requires European Member States to design the Nitrate Vulnerable Zones where farmers apply the Code of Good Agriculture Practices, that includes reduced nitrogen application rates or not fertilizing at certain times of the year, for example during the winter, on frozen and snow-covered ground (http://ec.europa.eu/environment/water/water-nitrates/index\_en.html). The total area of Nitrate Vulnerable Zones has increased since 2012, from 1,951,898 km2 to about 2,175,861 km2 in 2015 representing approximately 61% of agricultural area with balanced fertilizer application.

In contrast, in the United States all federal agriculture policy related to nutrient management is voluntary, except the National Pollutant Discharge Elimination System of the Clean Water Act, that affect large animal operations. Two key voluntary programs, the Environmental Quality Incentives Program (https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip) and Conservation Stewardship Program (https://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/) are providing payments to farmers that adopt improved nutrient management. Although the funding of these programs increased, the are of land with improved nitrate management has been decreasing. The USDA recently proposed the goal of reducing nitrous oxide emissions by 7 metric tones of carbon dioxide equivalents by 2025 (Kanter and Searchinger, 2018).

Countries like China that rely more on domestic production for food security as well as revenue from export markets often prioritize production over environmental impacts. Smith and Siciliano (2015) highlight how in China national objectives of domestic self-reliance and food security undermine public demand for improved environmental quality and related policy/enforcement efforts.

Countries with less productive capacity and greater food insecurity, such as countries sub-Saharan Africa, may require more fertilizer use to close yield gaps and ensure adequate food supply. Given the importance of fertilizers to global agricultural production, nutrient management should focus on both reducing nutrient loads in areas with excess of nutrients and increasing nutrients in areas with history of soil mining.

### Current Adoption

The information on total area of cropland that use any form on nutrient management as defined by Project Drawdown is inconsistent. However, data is available on nutrient use efficiency (NUE) – total nutrients in harvested crops divided by total nutrient input in the country, assuming that the optimal level of NUE range from 70-80% (Our Nutrient World, 2013). If the NUE is bellow this range, it indicates the risk of high nutrient losses while the value of NUE above this range indicate soil mining. In 1990 total crops land area with NUE between 70-80% was 70 Mha, which increased to 101 Mha by 2009 (Lassetta 2014).

### Trends to Accelerate Adoption

Adoption of this solution globally will require education and assistance, as well as substantial incentives for farmers or increased regulation that limits the amount farmers can apply. How to balance the extent of each of these tools depends on local context and their political feasibility. In the US, for example, studies have shown that some farmers are more amenable to incentives and educational programs than they are to regulations. Groups like the American Carbon Registry have been working with researchers to develop a carbon offset methodology focused on fertilizer rate reductions that would allow farmers to participate in projects that would ultimately provide them with payments from the carbon offset market.

Future adoption of this solution may also become more widespread as improved nutrient management technologies become available and penetrate the agricultural market. For example, fertilizer manufacturers are beginning to produce granular fertilizers coated with polymers that delay dissolution, creating a slow-release fertilizer supply that is better synchronized with crop demand. In more mechanized agricultural economies, equipment manufacturers have begun to produce high-tech equipment that can detect crop N demand based on chlorophyll content and deliver more precise doses of fertilizer based on those readings, reducing fertilizer waste.

### Barriers to Adoption

The central challenge for areas with too little nutrients is to improve access to affordable nutrient sources. Many farmers in Sub-Saharan Africa do not have access to affordable mineral fertilizers, where lack of local sources and poor supply infrastructure increases prices and limit agricultural yields (Denning, 2009).

In US farmers struggle to obtain accurate information about benefits of sustainable agriculture practices including nutrient management. Governmental support programs often fail to encourage adoption due to lack of funding, inappropriate design and effective targeting of incentives. Social barriers may include access to infrastructure or land tenure (Rodriguez et al., 2008).

Recent review by Liu et al. (2018) found that lack of cash or credit and limited cash flow on the farm, the cost of maintenance and capital cost associated with best management practices hinder the adoption, so does the uncertainties in market prices.

### Adoption Potential

The potential adoption area is all world cropland, which is roughly 1,500 Mha.

## Advantages and disadvantages of Nutrient Management

### Similar Solutions

Changes in diets may affect amount of nitrogen use for crop production. The *nutrient management* solution is thus closely linked to plant-rich diet as well as reduction of food waste. Decreasing demand for food will results in decreasing demand for nutrient use.

Nutrient management is also part of the improved rice cultivation, system of rice intensification and conservation agriculture.

Other sources of nitrogen represent alternative fertility approaches, including the use of green manures and use of nitrogen-fixing trees in agroforestry systems.

### Arguments for Adoption

Recent studies show that environmental and health costs associated with air, water and soil pollutions are often much larger than the cost of measures to reduce nitrogen pollutants.

Making better use of nutrients will reduce environmental pollution and global warming, while improving food and energy production.

### Additional Benefits and Burdens

Nutrient management is compared with other solutions in the food production cluster for farm, ecosystem, and social impacts. It is notable for very low cost and low delated profit period.

Table . 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 . 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 sequestration of carbon dioxide from the atmosphere into plant biomass and soil, and reduction of emissions for a solution relative to a conventional practice. These practices are assumed to use land of a specific type that may be shared across several solutions. The actual and maximum possible adoptions are therefore defined in terms of land area (million hectares). The adoptions of both conventional and solution were projected for each of several Drawdown scenarios from 2015 to 2060 (from a base year of 2014) and the comparison of these scenarios with a reference (for the 2020-2050 segment[[1]](#footnote-1)) is what constituted the results.

*Agency Level*

The farmer 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 on nitrous oxide emissions from different rate of nitrogen fertilizer application are taken from Scherbak et al. 2014 who collated measurement of nitrous oxide emissions from different parts of the worlds and under different agronomic and environmental condition. The dataset contains the emissions rate and averaged emission factor data from 78 studies. We use difference of nitrous oxide emission rates for max nitrogen fertilizer and minimum nitrogen application rate convert these to avoided emissions on a per hectare annual basis (t N2O-CO2-eq ha-1yr-1).

The carbon dioxide emissions from the manufacturing and transportation of fertilizers were estimated using the Global Warming Potential (GWP) coefficients specific for the US fertilizer mix, which is estimated to be about 4kg of CO2/kg of nitrogen applied, for Europe we use GWP coefficient of 3.7 kg of CO2/kg of nitrogen applied (Robberts et al., 2012) and 8.3 kg of CO2/kg of nitrogen applied ( Huang et al., 2013).

We utilized FAOSTAT to collect datasets on fertilizer consumption and cropland area by region to estimate the average use of fertilizer on a per hectare basis in every country. Based on these rates, we then calculated what a 10% rate reduction (kg reduced ha-1) would be for every country, except for China where we assume that nitrogen use can be reduced by 30% (Ju et al al., 2009). In Sub-Saharan Africa nitrogen application rates are increased by 50- 200% (note that average application of nitrogen fertilizers in SSA region was 12-15 kg per hectare, although some countries such as Malawi or Botswana have 50 kg per hectare). Projections of future food needs predict that Africa will need to triple food production by 2050 which will require substantial increases in nutrient input on cropland (Mueller et al. 2012). These nitrogen inputs need to be in part from synthetic fertilizers (Sanchez et al., 2005, Richards et al., 2016)..

## 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 the total available land is less than the technical potential.

Total available land for *nutrient management*is 1,473 million hectares (essentially all annual and perennial cropland). [[2]](http://www.drawdown.org/solutions/food/nutrient-management#_edn2)Current adoption [[3]](http://www.drawdown.org/solutions/food/nutrient-management#_edn3) is estimated at 101 million hectares. In the absence of data on current adoption of *nutrient management*, this figure is based on estimates of crop nutrient use efficiency. Cropland area that have balance crop nutrient use efficiency ranging from 70-80% are considered in to adopt nutrient management practices.

## 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.

Future adoption projections for *nutrient management*used the same scenarios as *conservation agriculture* (again assuming a link between these two solutions), and applied to the total available land of 1,417 million hectares (excluding the cropland area allocated for sustainable rice intensification (SRI), assuming that will be totally organic in nature). The details on each of the five custom adoption scenarios are given below:

1. ***Custom adoption scenario one***: This scenario projects the future adoption of the solution based on the average annual future growth rate of conservation agriculture.
2. ***Custom adoption scenario two***: This scenario projects the future adoption of the solution based on the high annual future growth rate of conservation agriculture.
3. ***Custom adoption scenario three***: This is an aggressive scenario assumes adoption of the solution in 100% of the TLA by 2050 in all regions.
4. ***Custom adoption scenario four***: This is scenario 2, assuming 60% of the total adoption will be achieved by 2030.
5. ***Custom adoption scenario five***: This is scenario 1, assuming 60% of the total adoption will be achieved by 2030.
6. ***Custom adoption scenario six***: This scenario is based on maximum global area that achieved 70% of nutrient use efficiency in past years estimated by Lassaleta et al., 2014. Future projection is assuming conservative growth rate.
7. ***Custom adoption scenario seven***: This scenario is based on maximum global area that achieved 70% of nutrient use efficiency in past years as estimate by Lassaletta et al., 2014. Future projection is assuming moderate growth rate.
8. ***Custom adoption scenario eight***: This scenario is based on maximum global area that achieved 70% of nutrient use efficiency in past years as estimate by Lassaletta et al., 2014. Future projection is assuming high growth rate.
9. ***Custom adoption scenario nine:*** This scenario is based and maximum global rea that achieved 70% of nutrient use efficiency by 2020 as estimate by Sutton et al. (2013).

### Reference Case / Current Adoption[[2]](#footnote-2)

Current adoption is estimated at 139.1 million hectares. In the absence of data on current adoption of *nutrient management*, this figure is based on current adoption for *conservation agriculture and areas that achieved 70% of nutrient efficiency*.

National level NUE for 124 countries from 1961-2009 (Lassetta et al, 2014) were combined with total cropland area available at UN Food and Agriculture Organization (2011). Only countries that have NUE in 70-80% range were considered in estimates of cropland that adopt nutrient management practices. Our estimates show that in 1990 total cropland area with NUE (70-80%) was 70 Mha while in 2009 total area was 101 Mha. We used aspirational goal defined for 2020 defined in the report Our Nutrient World that result in 336 Mha.

### Project Drawdown Scenarios

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

#### Plausible Scenario - A conservative approach is adopted for the plausible scenario, and future growth of the solution is estimated based on the “average of all” custom adoption scenarios as listed above.

#### Drawdown Scenario – For the drawdown scenario, 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.

#### Optimum Scenario – For the optimum scenario, custom adoption scenario that is giving maximum growth based on the existing prognostication is considered, which is represented by the “custom scenario 3”.

## Inputs

### Climate Inputs

Emissions reduction is 0.50 tons of carbon dioxide-equivalent per hectare per year in reduced emissions from the manufacture and transportation o of nitrogen fertilizers. An additional reduction of 0.49 tons of carbon dioxide-equivalent per hectare per year comes from reduced nitrous oxide from fertilizer application.

Table . Climate Inputs

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Reduced CO2 emissions transportation and manufacture | *CO2-eq/ha/yr* | 0.08-0.59 | 0.50 | 20 | 14 |
| Reduced N2O emissions application | *CO2-eq/ha/yr* | -0.04-0.56 | 0.49 | 64 | 20 |

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

### Financial Inputs

First cost of *nutrient management* is $0 per hectare. Fo this solution, an assumption that the nutrient will be managed optimally resulting in balanced nitrogen fertilizer use resulting in minimum nitrogen losses into the environment. To calculate the operational cost of this solution, the regional fertilizer use rates on a per hectare basis given by FAO and IFA was multiplied by the 2014 USD price per kg of Urea, DAP and Calcium ammonium Nitrate (since the proportion consumption of these fertilizers per hectare is not clear). We have taken the average of these prices to calculate the average fertilizer cost per hectare for each region. This gives the cost of nitrogen fertilizer under the conventional practices.

There is reduced cost associated with improved nutrient management, because less use of nitrogen fertilizers. We then calculated what a 10% rate reduction (kg reduced ha-1) would be for most of the countries, except for China where we assume that nitrogen use can be reduced by 30% (Ju et al al., 2009). In Sub-Saharan Africa nitrogen application rates are increased by 50- 200%.

In addition, we used estimated cost of improved nitrogen management at 5 US$ per ha of cropland (Smith et al., 2008).

Table . 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 |
| Operating Cost (Conventional) | *US$2014/ha* |  |  |  |  |

Table . Financial Inputs for Solution

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| First costs (Solution) | *US$2014/yr* | - | $0 | - | - |
| Operating Cost (Solution) | *US$2014/yr* | 15- 30 | 23.06 | NA | NA |

### Other Inputs

## Assumptions

There 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](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.

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

1. We It is assumed that the land area for nutrient management will remains same, based on the limited availability of new cropland area.
2. In the study only assume that four principles of nutrient management are fully applied in areas with 70% of nutrient use efficiency.
3. In this study, only direct nitrous oxide emission from application of artificial fertilizer were considered. Data points from studies featuring one or more principles (source, rate, time, placement) were used in meta-analysis.
4. We assume that nitrogen application must increase in countries of Sub-Sharan Africa and consequently this will increase a cost for farmers.

## 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.

*Nutrient management* 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 annual crop 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.

## Limitations/Further Development

Our approach is primarily limited by lack of adoption data. Further development of the model would be enhanced by including more accurate figures on how many farmers are reducing them per-hectare fertilizer rates even while global fertilizer consumption is on the rise. In addition, avoided indirect emissions of nitrous oxide from ground and surface waters are also significant, yet less measurement is available. Nutrient management should also include manure input.

# 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 773.03 million hectares in 2050, representing 55 percent of the total suitable land. Of this, 633.90 million hectares are adopted from 2020-2050.

Total adoption in the *Drawdown* Scenario is 1,162.57 million hectares in 2050, representing 83 percent of the total suitable land. Of this, 1023.44 million hectares are adopted from 2020-2050.

Total adoption in the *Optimum* Scenario is 1,399.29 million hectares in 2050, representing 100 percent of the total suitable land. Of this, 1260.16 million hectares are adopted from 2020-2050.

Table . World Adoption of the Solution

| **Solution** | **Units** | **Base Year (2014)** | **New Adoption by 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Drawdown** | **Optimum** |
| Nutrient management | Mha | 139.13 | 633.90 | 1023.44 | 1260.16 |
| % Total Land Available | 9.9% | 55% | 83% | 100% |

Figure . World Annual Adoption 2020-2050

## Climate Impacts

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

Emissions reduction impact is 11.36, 18.35, and 22.39 gigatons of carbon-dioxide equivalent in the *Plausible, Drawdown,* and *Optimum* Scenarios respectively.

Table . 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*** | 0.63 | 11.36 | - | - | 11.36 | 0.29 | 0.63 |
| ***Drawdown*** | 1.02 | 18.35 | - | - | 18.35 | 0.46 | 1.02 |
| ***Optimum*** | 1.25 | 22.39 | - | - | 22.39 | 0.56 | 1.25 |

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 . 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** | 0.950 | 0.048 |
| **Drawdown** | 1.535 | 0.077 |
| **Optimum** | 1.875 | 0.095 |

Figure . 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. There is no first cost and net profit margin for this solution. The solution is about reduced use of nutrients, thus the savings are only in the form of operational cost.

For the *Plausible* Scenario, cumulative first cost is US$0 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$36.69 billion. Net profit margin is US$0 billion, and lifetime profit margin is US$0. Lifetime cashflow savings NPV is $5.89.

For the *Drawdown* Scenario, cumulative first cost is US$0 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$59.25 billion. Net profit margin is US$0 billion, and lifetime profit margin is US$0 billion. Lifetime cashflow savings NPV is $9.51 billion.

For the *Optimum* Scenario, cumulative first cost is US$0 billion. Marginal first cost is the same as cumulative first cost. Net operating savings is US$72.32 billion. Net profit margin is US$0 billion, and lifetime profit margin is US$0 billion. Lifetime cashflow savings NPV is $11.55 billion.

Table . 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** | $0.00 | $0.00 | $ 36.69 | $0.00 | $0.00 | $5.89 |
| **Drawdown** | $0.00 | $0.00 | $ 59.25 | $0.00 | $0.00 | $9.51 |
| **Optimum** | $0.00 | $0.00 | $ 72.32 | $0.00 | $0.00 | $11.54 |

Figure . Net Operational cost savings

# Discussion

This is a solution that should be adopted regardless of its climate change mitigation impact. It saves farmers money and reduces air, water and soil pollution. Because it reduces emissions rather than sequestering carbon, it is not limited by saturation and can continue to have an annual impact for centuries to come.

## Limitations

This study could be improved should better data on current adoption of *nutrient management* become available.

## Benchmarks

The Intergovernmental Panel on Climate Change (IPCC) reports that the emissions reduction from all agricultural nitrous oxide (including fertilizers, manure, and other sources) is projected to be 0.9-1.84 gigatons of carbon dioxide-equivalent per year by 2030 (Smith, 2007, Table 8.6). Though this is not a precise benchmark, the Drawdown model calculates 0.29-0.56 gigatons of carbon dioxide-equivalent per year in 2030 from nitrogen fertilizer alone, not including manure and other nitrous oxide sources.

Griscolm et al (2017)’s “Natural climate solutions” calculate 0.63-0.71 gigatons of carbon dioxide equivalent per year in 2030, based on a higher percentage reduction of fertilizer use than that used by Drawdown.

Table . Benchmarks

| **Source and Scenario** | **Mitigation Impact**  **Gt CO2-eq in 2030** |
| --- | --- |
| Smith (2007) all agricultural N | 0.09-1.84 |
| Griscom (2017) reduced fertilizer use | 0.63-0.71 |
| *Plausible* Scenario | 0.29 |
| *Drawdown* Scenario | 0.46 |
| *Optimum* Scenario | 0.56 |

# References

“2016: The State of Food and Agriculture.” UN-FAO, 2016.

Ahlgren, Serina, Andras Baky, Sven Bernesson, Åke Nordberg, Olle Norén, and Per-Anders Hansson. “Consequential Life Cycle Assessment of Nitrogen Fertilisers Based on Biomass – a Swedish Perspective.” *Insciences Journal*, November 27, 2012, 80–101. doi:10.5640/insc.020480.

“AQUASTAT Database Database Query Results.” Accessed September 26, 2016. http://www.fao.org/nr/water/aquastat/data/query/results.html.

Brentrup, F, J Küsters, J Lammel, P Barraclough, and H Kuhlmann. “Environmental Impact Assessment of Agricultural Production Systems Using the Life Cycle Assessment (LCA) Methodology II. The Application to N Fertilizer Use in Winter Wheat Production Systems.” *European Journal of Agronomy* 20, no. 3 (February 2004): 265–79. doi:10.1016/S1161-0301(03)00039-X.

Chantigny, Martin H., Philippe Rochette, Denis A. Angers, Shabtai Bittman, Katherine Buckley, Daniel Massé, Gilles Bélanger, Nikita Eriksen-Hamel, and Marc-Olivier Gasser. “Soil Nitrous Oxide Emissions Following Band-Incorporation of Fertilizer Nitrogen and Swine Manure.” *Journal of Environmental Quality* 39, no. 5 (October 2010): 1545–53.

Drury, C. F., W. D. Reynolds, X. M. Yang, N. B. McLaughlin, T. W. Welacky, W. Calder, and C. A. Grant. “Nitrogen Source, Application Time, and Tillage Effects on Soil Nitrous Oxide Emissions and Corn Grain Yields.” *Soil Science Society of America Journal* 76, no. 4 (2012): 1268. doi:10.2136/sssaj2011.0249.

Ehmke, Tanner. “The 4 Rs of Nutrient Management.” *Crops and Soils Magazine*, 2012.

Engel, R., D. L. Liang, R. Wallander, and A. Bembenek. “Influence of Urea Fertilizer Placement on Nitrous Oxide Production from a Silt Loam Soil.” *Journal of Environment Quality* 39, no. 1 (2010): 115. doi:10.2134/jeq2009.0130.

“Fertilizers.” Accessed October 21, 2016. http://faostat.fao.org/beta/en/#data/RF/visualize.

Gagnon, Bernard, Noura Ziadi, Philippe Rochette, Martin H. Chantigny, and Denis A. Angers. “Fertilizer Source Influenced Nitrous Oxide Emissions from a Clay Soil under Corn.” *Soil Science Society of America Journal* 75, no. 2 (2011): 595. doi:10.2136/sssaj2010.0212.

Griscolm et al, “Natural climate solutions”. *Proceedings of the National Acacemy of Sciences*, 114 (44) 11645-11650.

Lal, R. “Carbon Emission from Farm Operations.” *Environment International* 30, no. 7 (September 2004): 981–90. doi:10.1016/j.envint.2004.03.005.

Licker, Rachel, Matt Johnston, Jonathan A. Foley, Carol Barford, Christopher J. Kucharik, Chad Monfreda, and Navin Ramankutty. “Mind the Gap: How Do Climate and Agricultural Management Explain the ‘yield Gap’ of Croplands around the World?” *Global Ecology and Biogeography* 19, no. 6 (November 1, 2010): 769–82. doi:10.1111/j.1466-8238.2010.00563.x.

Millar, Neville, G. Philip Robertson, Peter R. Grace, Ron J. Gehl, and John P. Hoben. “Nitrogen Fertilizer Management for Nitrous Oxide (N2O) Mitigation in Intensive Corn (Maize) Production: An Emissions Reduction Protocol for.” *Mitigation and Adaptation Strategies for Global Change* 15, no. 2 (February 2010): 185–204. doi:10.1007/s11027-010-9212-7.

Napier, T L, and T. Bridges. “Adoption of Conservation Production Systems in Two Ohio Watersheds: A Comparative Study.” *Journal of Soil and Water Conservation* 57, no. 4 (August 2002): 229–35.

“Nitrous Oxide Emissions | Climate Change | US EPA.” Accessed April 6, 2016. https://www3.epa.gov/climatechange/ghgemissions/gases/n2o.html.

“Nutrient Management: Nitrate Vulnerable Zones - GOV.UK.” Accessed October 21, 2016. https://www.gov.uk/guidance/nutrient-management-nitrate-vulnerable-zones.

“Nutrient Management Planning & Land Treatment Planning | Agency of Agriculture Food & Markets.” Accessed October 21, 2016. http://agriculture.vermont.gov/water-quality/farmer-assistance/nmp-ltp.

Reay, Dave S., Eric A. Davidson, Keith A. Smith, Pete Smith, Jerry M. Melillo, Frank Dentener, and Paul J. Crutzen. “Global Agriculture and Nitrous Oxide Emissions.” *Nature Climate Change* 2, no. 6 (June 2012): 410–16. doi:10.1038/nclimate1458.

“Reduced Use of Nitrogen Fertilizer — American Carbon Registry.” Accessed September 26, 2016. http://americancarbonregistry.org/resources/reduced-use-of-nitrogen-fertilizer.

Robertson, G. Philip, and Peter M. Vitousek. “Nitrogen in Agriculture: Balancing the Cost of an Essential Resource.” *Annual Review of Environment and Resources* 34, no. 1 (October 15, 2009): 97–125. doi:10.1146/annurev.environ.032108.105046.

Shcherbak, Iurii, Neville Millar, and G. Philip Robertson. “Global Metaanalysis of the Nonlinear Response of Soil Nitrous Oxide (N2O) Emissions to Fertilizer Nitrogen.” *Proceedings of the National Academy of Sciences* 111, no. 25 (June 24, 2014): 9199–9204. doi:10.1073/pnas.1322434111.

Skowrońska, Monika, and Tadeusz Filipek. “Life Cycle Assessment of Fertilizers: A Review.” *International Agrophysics* 28, no. 1 (January 1, 2014). doi:10.2478/intag-2013-0032.

Smith, L. E. D., and G. Siciliano. “A Comprehensive Review of Constraints to Improved Management of Fertilizers in China and Mitigation of Diffuse Water Pollution from Agriculture.” *Agriculture, Ecosystems & Environment*, Sustainable intensification of China’s agriculture: the key role of nutrient management and climate change mitigation and adaptation, 209 (November 1, 2015): 15–25. doi:10.1016/j.agee.2015.02.016.

Stuart, D., R. L. Schewe, and M. McDermott. “Reducing Nitrogen Fertilizer Application as a Climate Change Mitigation Strategy: Understanding Farmer Decision-Making and Potential Barriers to Change in the US.” *Land Use Policy* 36 (January 2014): 210–18. doi:10.1016/j.landusepol.2013.08.011.

Tenuta, M., and E. G. Beauchamp. “Nitrous Oxide Production from Granular Nitrogen Fertilizers Applied to a Silt Loam.” *Canadian Journal of Soil Science* 83, no. 5 (November 2003): 521–32.

Venterea, Rodney T., Maharjan Bijesh, and Michael S. Dolan. “Fertilizer Source and Tillage Effects on Yield-Scaled Nitrous Oxide Emissions in a Corn Cropping System.” *Journal of Environment Quality* 40, no. 5 (2011): 1521. doi:10.2134/jeq2011.0039.

World Bank. “Agricultural Nitrous Oxide Emissions (% of Total).,” 2015. http://data.worldbank.org/indicator/EN.ATM.NOXE.AG.ZS/countries/1W?display=graph.

Zebarth, B J, P. Rochette, D L Burton, and M. Price. “Effect of Fertilizer Nitrogen Management on N2O Emissions in Commercial Corn Fields.” *Canadian Journal of Soil Science* 88, no. 2 (May 1, 2008): 189–95. doi:10.4141/CJSS06010.

Zhang, Wei-feng, Zheng-xia Dou, Pan He, Xiao-Tang Ju, David Powlson, Dave Chadwick, David Norse, et al. “New Technologies Reduce Greenhouse Gas Emissions from Nitrogenous Fertilizer in China.” *Proceedings of the National Academy of Sciences* 110, no. 21 (May 21, 2013): 8375–80. doi:10.1073/pnas.1210447110.

# 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. Current adoption is defined as the amount of land area adopted by the solution in 2018. This study uses 2014 as the base year due to the availability of global adoption data for all Project Drawdown solutions evaluated.  [↑](#footnote-ref-2)
3. In some cases, the low boundary is negative for a variable that can only be positive, and in these cases the lowest collected data point is used as the “low” boundary. [↑](#footnote-ref-3)