**Technical assessment for**

**System of Rice Intensification**

Sector: Food

Agency Level: Farmer

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# Executive Summary

Project Drawdown defines the *System of Rice Intensification*(SRI) as: an agroecological rice production technique that uses minimal water during the initial stage (just a thin layer), and alternates wetting and drying during the later stage, to increase yield gain and reduce emissions. This practice replaces conventional paddy rice production on smallholdings.

SRI emerged in Madagascar in the 1980s and has become widespread among smallholders, particularly in Asia. SRI’s unique system leads to significant savings in water consumption and enables a more aerobic environment in the rice growth cycle, resulting in reduced methane emissions. Improvement in both organic and inorganic nutrients under SRI result in improved soil conditions, increasing nutrient availability and holding capacity of the soil. Thus, less external fertilizer is required, which in turn reduces the emissions associated with the inefficient use of nitrogen fertilizers.

The *System of Rice Intensification* offers more than 35 percent yield gain, water conservation, and cost savings. The increased yield from the same piece of land could also reduce land clearing for rice cultivation and associated emissions.

Total adoption of the system of rice intensification practices in the *Plausible* Scenario is 40.21 million hectares in 2050, representing 77 percent of the total suitable land for SRI cultivation. Of this, 36.17 million hectares are adopted from 2020-2050. The combined carbon sequestration and emissions reduction impact of this scenario is 3.16 gigatons of carbon dioxide-equivalent between 2020-2050. Net profit margin is US$339.80 billion 2014 USD.

Total adoption in the *Drawdown* Scenario is 52 million hectares in 2050, representing 100 percent of the total suitable land. Of this, 47.95 million hectares are adopted from 2020-2050. The combined sequestration and emissions reduction impact of this scenario is 4.69 gigatons of carbon dioxide-equivalent between 2020-2050. Net profit margin is US$513.85 billion 2014 USD.

Total adoption in the *Optimum* Scenario is 52 million hectares in 2050, representing 100 percent of the total suitable land. Of this, 47.95 million hectares are adopted from 2020-2050. The combined sequestration and emissions reduction impact of this scenario is 5.13 gigatons of carbon dioxide-equivalent between 2020-2050. Net profit margin is US$513.85 billion 2014 USD.

# Literature Review

## State of the Practice

Rice is cultivated on nearly 163 million hectares of land, which is about 12% of the world cropland (FAO, 2012, Figure 1). About 90 million hectares is irrigated rice land (Kritee et al., 2018). Total rice cultivated area increased by 16% since 1970 and it is projected to increase another 5% by 2030 to meet the rice consumption demands of a growing population. Rice production is a major source of livelihoods in the Asia. Asia is also the largest producer and consumer of rice. About 80% of global rice production comes from small holder farms with five hectares or less (Samberg et al., 2016).

Figure .:Rice cultivated area in 1970 and 2012. Data taken from International Rice Research Institute (IRRI)

Figure 1 shows the dominance of Asia in rice cultivation. India has the largest area under rice cultivation, followed by China, Indonesia, Thailand, Bangladesh, Myanmar and Vietnam; while the remaining regions have smaller areas under rice cultivation. In all of these regions, rice is cultivated largely in irrigated fields (paddies). In China 100% of rice is flooded, with more than 90% in Indonesia and Vietnam and around 58% in India.

### Rice: significant contributor to agricultural GHG emissions

*Methane emissions*

Rice cultivation is a major source of methane emissions, accounting for 11% of the total agricultural greenhouse gas emissions (Adhya et al., 2014; Wassmann & Pathak, 2007; Xu et al., 2015, Towprayoon et al., 2005; Cai et al., 1997; Smith et al., 2008). Methane emissions result from the flooded (“paddy”) environment that enables favorable anaerobic conditions for methanogenesis (Buendia et al., 1997; Cicerone & Oremland, 1988; Wassmann et al., 2000; Xu et al., 2015).In contrast to carbon dioxide emissions, methane is a short-lived greenhouse gas. A short-lived greenhouse gas disappears much more rapidly. As long as their emissions remain constant, their concentration and warming effect remain roughly constant. The methane global warming potential over a 100-year time period is 28 times that of carbon dioxide (IPCC, 2011).

Methane emissions from rice cultivation decreased over the past 40 years (EDGAR, 2018). The reduction is mostly driven by changes in agriculture practices in China and India. One key practice that leads to reduction of methane emissions is better water management - draining rice paddy fields in the middle of the rice-growing season — a practice that most farmers have adopted since the 1980, around 80% of Chinese farmers routinely using this approach since 2000 (Li et al., 2002). This practice not only reduces methane emissions but also increases rice yields and saves water. In contrast, this practice is not fully adopted in other countries, such as Vietnam, Indonesia and Thailand that are increasing the methane emissions from rice cultivation (EPA, 2013; EDGAR, 2018).

Figure .:Methane emissions (CH4) in Gigatons (Gt) per year from rice cultivation in 1970 and 2012. Data are taken from the EDGAR database

*Nitrous oxide emissions*

Nitrous oxide is a long-lived greenhouse gas that traps more heat compared to methane emissions. Rice paddies are considered to be a less important source of nitrous oxide emissions. Nitrous oxide emissions are emitted primarily during microbial nitrification and denitrification processes. Water management practices control the oxygen supply of the paddy rice soils by providing suitable conditions for microbial growth and activity and restricting oxygen supply to microsites by filling soil pores and creating anaerobic conditions.  Recent research shows that intensive use of intermittent irrigation of rice fields increases a nitrous oxide emissions by three times in India (Kritee et al., 2018a, EPA, 2013). Globally nitrous oxide emissions from rice paddies may reseach 1.42 million metric tons per year (Kritee et al., 2018b).

Figure .:Potential N2O emissions in millions of metric tons (MMT). Modified from Kritee et al., 2018

*Carbon sequestration*

Rice fields can function as a temporal sink and take up a carbon, which may compensate for nitrous oxide and methane emissions. In general, every kilogram of soil organic carbon represents 3.7 kg of carbon dioxide removed from the atmosphere. Rice soils retain a higher amount of carbon compared to other ecosystems. Jarecki and Lal (2003) reported that potential of soil organic carbon sequestration for rice is 401 kilogram of carbon per hectare per year. Carbon sequestration in rice soils can be improved for example by adopting integrated nutrient management practices that allows to conserve carbon or by using high yielding rice cultivars and adopting the system of rice intensification (SRI) practices. SRI is discussed into more detail below.

### The System of Rice Intensification

The System of Rice Intensification (SRI) was synthesized in the early 1980s by Fr. Henri de Laulanié, S.J. with an objective to improve rice cultivation practices in Madagascar. SRI is a set of agronomic principles and practices used for increasing the productivity of paddy rice by changing the management of plants, soil, water and nutrients. SRI practices lead to lower greenhouse gas emissions and create agriculture that is resilient to the negative impacts of climate change. SRI has been adopted by smallholder farmers in China, India, Vietnam, Indonesia and Cambodia who have apply this practice for the cultivation of other crops as well. In 2013, the total cultivated area with SRI management accounted for 3.4 million hectares. Since then, the cultivated area and number of farmers have doubled, accounting for 6.8 million hectares and 20 million farmers in 2018 (Uphoff, 2018, Personal communication).

The System of Rice Intensification has four basic principles which make it different from other rice production systems (Uphoff et al 2006).

* Early, quick and healthy plant establishment
* Reduced plant density
* Improved soil conditions through enrichment with organic matter
* Reduced and controlled water application

SRI uses the same inputs as conventional methods. The difference lies in the way they are used in the entire growth cycle of irrigated rice. SRI improves soil conditions and nutrient and water management.

**Improvement in soil conditions:** In SRI, soils are enriched with the organic matter. This helps to improve the soil bio-physio-chemical structure that in turns improves the water and nutrient holding capacity.

**Efficient water management:** Paddy rice is grown in flooded conditions, however in SRI only a minimal amount of water is applied during the vegetative growth period. As per the SRI recommendations, a 1-2 cm layer of water is introduced into a rice field and the next layer is provided only when the cracks on the soil surface becomes visible. This continues until the reproduction phase, and is then replaced by alternate wetting and drying during the grain filling period, before draining the rice 2-3 weeks before harvest.

**Efficient nutrient management:** The improvement in soil’s bio-physio-chemical structure makes the nutrients readily available to the plant. Moreover, it also improves the nutrient holding capacity of the root zones, and releases nutrients only when there is a need to the plant. Thus, instead of applying large amount of fertilizers, as is the case with the conventional rice cultivation, the SRI practice needs only a minimal amount of fertilizer.

SRI farmers are given recommendations on the basis of the above-mentioned principles. Farmers can then further adapt the recommendations based on their biophysical and socioeconomic conditions. SRI is equally applicable to irrigated and rainfed rice cultivation. These differential management practices allow rice farmers to significantly increase their yields while decreasing their use of water, seed, fertilizers and pesticides (Berkhout et al., 2015; Sinha & Talati, 2007; Thakur, 2010; McDonald et al., 2006; Satyanarayana et al., 2006; Dobermann, 2007).

### SRI and greenhouse gas emission reduction and carbon sequestration

SRI has the potential to reduce methane emissions (Gathorne-Hardy et al., 2013). Emissions reductions in SRI are because of the minimal use of water as opposed to the frequent flooding method, which creates anaerobic conditions that results in methane emissions. The emissions reduction can also be attributed to the improved soil conditions which in turn demands lower intake of synthetic fertilizers. According to different studies, SRI practices result in 20-72% in methane emissions (Choi et al., 2014; Dill, Deichert, & Thu, 2013; Jain et al., 2013).

Rice paddy fields with less flooding may increase nitrous oxide emissions (Kritee et al., 2018). Although most of the studies that have assessed nitrous oxide emissions from SRI rice paddies concluded that there is a net-reduction of greenhouse gas emissions (the effect of methane emissions reduction is larger than increase of nitrous oxide emissions). However, nitrous oxide emissions vary due to environmental condition, crop variety used, and nutrient management, thus it is difficult to generalize based on the limited number of studies.

SRI also results in soil carbon sequestration because the rice grows a much larger root system which remains in the soil to decompose,and also because of more soil biota from an expanded root system. Only a few studies have measured carbon sequestration so far. For example, a study conducted by Johansen (2009) in Cambodia, found a carbon sequestration rate of 0.35 tons carbon per hectare per year. Similar results have been found by Jarecki & Lal (2003), where the carbon sequestration was estimated at 0.40 tons of carbon per hectare per year.

Overall, SRI has potential to reduce methane and nitrous oxide emissions and increase carbon sequestration, however the extent remains to be systematically measured across different regions (Thankur and Uphoff, 2017).

### Co-benefits

* **Higher yield gains**: The biggest advantage of SRI is potential for higher yields per unit of land. The yield gains in SRI range from 20-50%, with some cases of more than 100% yield gain (Choi et al. 2014, Uprety and Morang 2005, Fazli et al. 2014, Xiaoyun et al. 2005, Jain et al 2014, Geethalakshmi, V. et al. 2016). Production of more rice on existing farmland is also beneficial for meeting the rice demand of the growing. This also reduces the clearing of forest for rice cultivation.
* **Cost savings**: Reductions in water and fertilizer result in significant cost savings. Increasing prices of chemical fertilizers are making SRI more popular among smallholder farmers (Africare, Oxfam America, WWF-ICRISAT Project 2010).
* **Water conservation**: SRI practices reduce irrigation water demand by 20-50% (Uphoff 2006). This not only saves the cost of irrigation but also saves significant amount of water, which can either be used for other crops or stored in aquifers. SRI seems to be a promising choice for cultivating rice in water scarce situations.
* **Increased resilience to climate change**: Crop loss due to lodging (falling of plant) as a result of intense rainfall and strong winds is a common phenomenon. SRI practices produce stronger stalks (tillers) and larger, deeper root systems that make rice plants less susceptible to lodging.
* **Ease of operation and benefits to women:** The non-flooded conditions provide an easier environment for farmers to work in the rice fields compared to flooded and muddy rice fields. As women spend most of the time in the fields, the dry conditions reduce skin irritations, gynecological ailments, and other illnesses that occur due to un-sanitary conditions.
* **N2O emissions:** Recent research recognizes that intermittently flooded rice fieldsare a source of nitrous oxide emissions (Choi et al., 2014; Jain et al., 2013, Oo et al., 2018). Kritee et al. (2018) shows that multiple aeration events lead to higher microbial activity, enhanced mineralization and nitrification-denitrification, and more redox cycles (Figure 1.3.) Until recently the increase of nitrous oxide emissions was considered negligible or small and nullified with the much larger methane emission reductions.
* **Increased growth of weeds:** The non-flooded conditions also promote weed growth. This is one of the key challenges to the success of SRI. To address this problem, manufactures have developed a rotary hoe – a simple, inexpensive, mechanical push-weeder. This not only helps in weed control but also improves the soil organic matter by allowing the weeds to decompose in the soil, aerating the soil, stimulating root growth by root pruning, and increases nutrient availability by mixing water with organic matter enriched top soil (Uphoff 2006).
* **Decline in female employment**

SRI can lead to decline in female employment, which is the most vulnerable group in India a key rice producer. For example, Gathorne-Hardy et al. (2016) estimated that on average SRI reduced causal labor renumeration by 50%. Thus, adoption of SRI may potentially lead to reduced pay and increased unemployment.

## Adoption Path

### Current Adoption

SRI is used in 60 countries around the world. However, data on current adoption is based on information from a survey from five Asian countries: China, India, Vietnam, Indonesia, and Cambodia, collected by SRI-Rice at Cornell University at the end of 2013. The total area under SRI practice was estimated to be 3.4 million hectares, adopted by 9.5 million farmers in 2013. The annual growth rate is assumed to be about 15%. Thus, the cultivated area in 2018 is estimated to be 6.8 million hectares and adopted by 20 million farmers (Uphoff, 2018, Personal communication).

### Trends to Accelerate Adoption

The strategies needed to implement these solutions globally are:

**Participatory trials:** Participatory trials on farmer’s fields in order to bridge the gap between scientist field-based results and on-farm results.

**Customized solutions:** Customizing solutions to different bio-physical and socio-economic settings in order to meet location specific needs.

**Awareness:** Awareness and wider demonstration of these practices. Farmer adoption is difficult since SRI is different from centuries old traditional practices of rice cultivation. This necessitates efforts in awareness, communication, farmer field demonstrations, farmer to farmer success story sharing, and learning from failures.

**Incentives and motivation:** Greenhouse gas emission reduction solutions are not offering any direct incentives to farmers. Farmers are primarily concerned about costs of cultivation, yield, and income. Water saving technologies lower the cost of cultivation, but considering the yield variation, it does not appear to be a significant incentive to farming communities, especially in regions where farmers are getting heavy subsidies for irrigation (e.g., India). Hence, thoughts should be given to some additional incentives that would motivate farmers to adopt these solutions.

**Support:** Technical assistance to farmers has to be provided in order to sustain the practices long enough to see results. It has been observed that, in the absence of continuous feedback to farmers on the implemented solution, farmers stop implementing those solutions. Adequate services are required for full training and livelihood impacts to be realized.

**Integrated solutions:** There is a need for integrated greenhouse gas emission reduction in rice cultivation. Little research in GHG mitigation has occurred in last two decades to analyze integrated solutions (e.g., water, nutrient, cultivar, and tillage practices together as a package). This research is important to look for cumulative benefits of integrated solutions.

**Policy advocacy:** It is equally important that these solutions get mainstreamed into the policy framework of all nations, especially the key rice-producing countries, so that it can be scaled up.

### Barriers to Adoption

**Technical limitations:**

Different seedling management and the use of mechanical weeders go against traditions (Reddy and Venkatanarayana, 2013).

Seedlings must be planted within a short time window, so erratic monsoons can potentially devastate crops.

There is a wide gap between scientist’s experimental trials performed under optimal conditions and the situation in farmers’ fields. In implementing alternate wetting and drying measures, farmers need reliable control over irrigation water as well as well-leveled fields to assure water levels do not drop too far in parts of the field. While these facilities are available in developed countries like the US, developing countries lack well-placed irrigation systems that depend largely on groundwater. Farmers using surface irrigation are reluctant to interrupt irrigation when water is available because of uncertainty of water availability in the. In some locations, dry seeding may be an effective means of reducing methane emissions and a single flooding may be feasible (Adhya et al., 2014).

Efforts have not been made to upscale the experimental farm studies to a wider level.

### Adoption Potential

The adoption potential for SRI is roughly 37 million hectares by 2030, if we apply the annual growth rate 15% (Uphoff, personal communication). The SRI practices are spreading and they are used at least partially in 60 different countries. Although reliable estimates are available only for China, India, Vietnam, Indonesia and Cambodia.

## Advantages and disadvantages of System of Rice Intensification

### Similar Solutions

The solution to which is most closely related is *Improved Rice Cultivation.* Both solutions are implemented on rice land, and both reduce methane emissions via practices including dry periods. There are several key differences. SRI is currently limited to smallholder operations only, while improved rice is scale-neutral. Another key difference is yields – SRI tends to dramatically increase yields, while improved rice may decrease yields slightly.

### Arguments for Adoption

Farmers, their households and urban consumers of rice can benefit from more abundant use of SRI that leads to lower prices of rice and more production as SRI has potential for much higher yield than conventional rice cultivation. SRI is climate resilient to negative impact of climate change and minimizes greenhouse gas emissions. This relatively new way of growing rice is proving popular in water-stressed countries like Kasmir in India.

The United Nation supports SRI in countries Mali, Cambodia, and Vietnam. The World Bank promotes SRI in India and Egypt.

### Additional Benefits and Burdens

SRI is compared with other solutions in the food production cluster for farm, ecosystem, and social impacts. Key distinctions are that it is targeted to smallholders (unlike most solutions which may be relevant but are not targeted), has high yield gains and very low startup cost.

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 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.

## Data Sources

The rice yield data, implementation cost and marginal profit for conventional rice filed cultivation and SRI were obtained from the SRI Rice- International Center of the Cornell University and the FAO Statistical Service. A total of 10 peer-reviewed studies and international agencies reports were used in the model to estimate nitrous oxide and methane, carbon dioxide emissions reduction potential and carbon sequestration rate.

## 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 *System of Rice Intensification*is 52 million hectares, the total area of smallholder rice production.

## Adoption Scenarios

Two different types of adoption scenarios were developed: Reference (REF) Scenario which was considered the baseline, assuming not much changes in 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 a Reference Scenario.

Future adoption is based on SRI growth trends found for China, India, and Indonesia by IRIN (<https://reliefweb.int/report/world/why-rice-intensification-matters-asia>), and SRI-Rice International center.

At the end of 2013 there were about 9.5 million farmers using full or partial practices of SRI on over 3.4 million hectares. It is assumed that SRI cultivated area doubled over last five years. The rate is about 15% annual growth.

Table .: SRI cultivated area in millions of hectares for selected countries in 2007, 2011 and 2013. Data taken from reliefweb (2012) and SRI-Rice International Center.

|  |  |
| --- | --- |
| Country Year | SRI cultivated area (Mha) |
| China 2007  2011  2013 | 200,000  700,000  1,000,000 |
| India 2013 | 1,800,000 |
| Indonesia 2011  2013 | 100,000  300,000 |
| Vietnam 2013 | 366,000 |
| Cambodia 2013 | 40,000 |

The given data was interpolated using linear trend and future adoption value was calculated for these three countries. The global value was generated based on the average growth rate of these three countries. The adoption scenarios are thus built based on the average, medium and high projections given for these three countries. Seven custom adoption scenarios were created, some of the scenarios involve an early adoption of 100% by 2030, detailed as listed below:

* *Scenario 1*: This scenario projects the future adoption of SRI based on the “average” growth rate by 2050, based on the interpolated data of the given three countries.
* *Scenario 2*: This scenario projects the future adoption of SRI based on the “high” growth rate by 2050, based on the interpolated data of the given three countries.
* *Scenario 3*: This is scenario 1 with 100% adoption by 2030.
* *Scenario 4*: This is scenario 2 with 100% adoption by 2030.
* *Scenario 5*: This scenario projects the future adoption of SRI based on the average of scenario 1 and scenario 2 growth rate by 2050, based on the interpolated data of the given three countries.
* *Scenario 6*: This is scenario 5 with 100% adoption by 2030.
* *Scenario 7*: In this scenario, the future growth is projected based on the world adoption of SRI in 2013 and 2018, based on the information received from personal communication through Prof. Norman Uphoff, Cornell University

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

Current adoption is 4.05 million hectares based on the interpolation of historical data.

### 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 4” where future adoption is projected based on the high early growth rate.

## Inputs

### Climate Inputs

Reduced emissions from methane are set at 1.32 tons of carbon dioxide-equivalent per hectare per year, based on 16 data points from 7 sources. Emissions reduction from carbon dioxide is set at 1.3 tons per hectare per year, based on 4 data points from 3 sources. Reduced emissions from nitrous oxide are calculated at -0.08 tons of carbon dioxide-equivalent per hectare per year, based on 8 data points from 5 sources. Sequestration rates are set at 0.29 tons of carbon per hectare per year, based on 3 data points from 2 sources.

Table .: Climate Inputs

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Biosequestration | *tC/ha/yr* | 0.16-0.42 | 0.29 | 3 | 2 |
| Emissions reduction methane | *tCO2-eq/ha/yr* | -0.15-2.80 | 1.32 | 16 | 7 |
| Emissions reduction carbon dioxide | *tCO2-eq/ha/yr* | -0.30-2.95 | 1.31 | 4 | 3 |
| Emissions reduction nitrous oxide | *tCO2-eq/ha/yr* | -0.15 – (-0.02) | -0.08 | 8 | 5 |

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).

*Modeling Saturation*

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

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

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

### Financial Inputs

Farmers transitioning from conventional rice cultivation to SRI practices may face a period of reduced income because the costs of labor inputs are usually higher at first. The Project Drawdown assumes that the first costs are US$0 per hectare, as SRI uses existing equipment and infrastructure.  For all agricultural solutions it is assumed that there is no conventional first cost, as agriculture is already in place on the land. The meta-analysis shows a cost reduction for SRI practices in comparison to conventional paddy. The extent of cost reduction varies depending on country, farmers’ current costs, reflecting how intensive (or non-intensive) their current practices are. On average, the net profit per hectare for SRI is estimated to be US$1039.14 per year (based on meta-analysis of 10 data points from 69sources), while conventional paddy cultivation results in net profit of US$449.16 per year (based on 33 data points from 38 sources).

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 |
| Net profit (Conventional) | *US$2014/ha* | $206.73 - $694.96 | $450.84 | 34 | 17 |
| Operating Cost (Conventional) | *US$2014/ha* | $361.45 to $944.02 | $652.74 | 27 | 13 |

Table . Financial Inputs for Solution

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| First costs (Solution) | *US$2014/ha* | - | $0 | - | - |
| Net profit (Solution) | *US$2014/ha* | $449-$1628 | $1,039.14 | 9 | 6 |
| Operating Cost (Solution) | *US$2014/ha* | $493-$792 | $642 | 10 | 7 |

### Other Inputs

Yield gains compared to business-as-usual annual cropping were set at 35 percent, based on meta-analysis of 43 data points from 9 sources.

## 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](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. It is assumed that the land area for rice cultivation will remains same, based on the limited availability of new cropland area.
2. It is assumed that the future adoption of SRI will be much higher among the smallholder farmers, as currently it is largely adopted by them. This has been considered as one of the added social benefit of this solution. Many of such smallholder farmers includes women.
3. The future adoption scenarios are made based on the projections given for three Asian countries and applied it on a global scale. This was done due to the data unavailability for the entire globe, moreover, rice is grown largely in the Asian countries (more than 90%)[[4]](#footnote-4), where the share of these countries (India, China, and Indonesia) is the maximum.
4. Some of the future adoption scenarios considered a 100% adoption by 2030 of the total projected adoption by 2050. This high early adoption was considered due to the limited area allocated for this solution as well as considering its social and many of the ecosystem services, like, higher yield increase and considerable saving on irrigation.

**Assumption 5:** Although nitrous oxide emissions are associated with this solution, however, the net carbon reduction based on the reduction of methane and carbon dioxide emission outweighs the minimal amount of nitrous oxide emitted under this solution.

## Integration

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

*System of Rice Intensification* 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 climate constraints.

Each unit of land was allocated to a separate solution to avoid overlap between practices. The exception to this is *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.

System of Rice Intensification is the top adoption priority for cropland due to its impressive yield increases.

***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

The first limitation in modelling current and future reduction potential of SRI practices is a lack of adoption data. One of the main reason why we do not have sufficient data is an understanding to what qualifies for SRI practice. In general, SRI is presented as six changes in current agronomic practice, however, farmers do also partial adoption based on climate and environmental condition, their skills and costs.

For example, the most precise figures, from Sichuan, China are no longer collected because the Provincial Department of Agriculture says that SRI practices have spread so much, and they find them also being modified, or only mostly but not fully used.

The second limitation is lack of systematic measurement of emission data for methane and nitrous oxide emissions and carbon sequestration.

# 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 40.42 million hectares in 2050, representing 73 percent of the total suitable land. Of this, 36.93 million hectares are adopted from 2020-2050.

Total adoption in the *Drawdown* Scenario is 48.46 million hectares in 2050, representing 87 percent of the total suitable land. Of this, 44.97 million hectares are adopted from 2020-2050.

Total adoption in the *Optimum* Scenario is 55.6 million hectares in 2050, representing 100 percent of the total suitable land. Of this, 52.1 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** |
| System of Rice Intensification | Mha | 3.50 | 36.93 | 44.97 | 52.1 |
| % Total Land Available | 6% | 73% | 87% | 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).

Climate impact is 3.24, 4.62, and 6.0 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*** | 0.09 | 2.24 | 0.04 | 0.92 | 3.16 | 0.10 | 0.13 |
| ***Drawdown*** | 0.12 | 3.32 | 0.05 | 1.37 | 4.69 | 0.16 | 0.17 |
| ***Optimum*** | 0.12 | 3.63 | 0.05 | 1.50 | 5.13 | 0.17 | 0.17 |

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** | 0.260 | 0.009 |
| **Drawdown** | 0.383 | 0.011 |
| **Optimum** | 0.416 | 0.011 |

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.

For the *Plausible* Scenario, cumulative first cost is US$0. Marginal first cost is the same as cumulative first cost. Net operating savings is US$$11.27 billion. Net profit margin is US$432.03 billion, and lifetime profit margin is US$744.63 billion. Lifetime cashflow savings NPV is $2.14 billion.

For the *Drawdown* Scenario, cumulative first cost is US$0. Marginal first cost is the same as cumulative first cost. Net operating savings is US$16.74 billion. Net profit margin is US$ 665.55 billion, and lifetime profit margin is US$1,077.33 billion. Lifetime cashflow savings NPV is US$3.40 billion.

For the *Optimum* Scenario, cumulative first cost is US$0. Marginal first cost is the same as cumulative first cost. Net operating savings is US$18.30 billion. Net profit margin is US$758.48 billion, and lifetime profit margin is US$1,242.23. Lifetime cashflow savings NPV is US$4.21.

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 | $11.27 | $ 432.03 | $744.63 | $2.14 |
| **Drawdown** | $0.00 | $0.00 | $16.74 | $ 665.55 | $1,077.33 | $3.40 |
| **Optimum** | $0.00 | $0.00 | $ 18.30 | $ 758.48 | $1,242.23 | $4.21 |

Figure . Net Profit Margin

## Other Impacts

Yield increases due to conversion to SRI increase global rice yields by 383.41, 570.89, and 627.16 million metric tons between 2020-2050 in the *Plausible, Drawdown,* and *Optimum* Scenarios respectively.

# Discussion

Rice is a staple crop of critical importance, particularly in Asia. Rice production is currently a major contributor of methane. Fortunately, low-methane rice production systems including the System of Rice Intensification are ready to be scaled up. Wide adoption of these practices can have a significant impact on climate change mitigation. SRI yield gains more than compensate for the minor yield losses under Drawdown's *improved rice cultivation* solution. Wherever smallholders produce rice, this solution should be closely considered for broadscale adoption.

## Limitations

This study could be improved by obtaining additional data points on emissions reduction and carbon sequestration in SRI systems. Peer-reviewed data on current adoption could also be strengthened.

## Benchmarks

The Intergovernmental Panel on Climate Change (Smith et al, 2007) estimates emissions reduction of 0.2 gigatons carbon dioxide-equivalent per year by 2030 for rice management. Griscolm et al (2017)’s “Natural climate solutions” calculate 0.08-0.26 gigatons of carbon dioxide equivalent per year in 2030. Between the three Scenarios, Drawdown's two rice solutions combined provide 0.45-0.92 gigatons carbon dioxide-equivalent per year by 2030. Drawdown’s figures are likely higher due to the inclusion of carbon sequestration benefits (Table 10 shows that Drawdown’s figures are much closer to the benchmarks when only emissions removal is considered).

Table . Benchmarks

| **Source and Scenario** | **Emissions Reduction**  **Gt CO2-eq in 2030** |
| --- | --- |
| Smith (2007) | 0.20 |
| Griscom (2017) | 0.08-0.26 |
| Project Drawdown  (improved rice cultivation and system of rice intensification, only emission reduction) | 0.22-0.44 |

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# Glossary

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

1. For most results, only the differences between scenarios, summed over 2020-2050 were presented, but for the net first cost, the position was taken that to achieve the adoptions in 2020, growth must first happen from 2015 to 2020, and that growth comes at a cost which should be accounted for, hence net first cost results represent the period 2015-2050. [↑](#footnote-ref-1)
2. 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)
4. <http://ricepedia.org/rice-around-the-world/asia> [↑](#footnote-ref-4)