**Technical assessment for**

**Sustainable Clothing**

Sector: Industry

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# Acronyms and Symbols Used

* Acronym – explanation
* .......
* ……

# Executive Summary

Clothing and textile production have a long and complex supply chain and life cycle, due to the variety of feedstocks used to create textiles, methods of treatment and production of finished goods, distribution, as well as complex environmental impacts from the use phase and disposal, and as an industry cause over 1.2 billion tons of CO2 emissions globally. This solution models interventions to improve the sustainability of this industry through several implementable solutions, which can be broadly summarized as better materials and efficient manufacturing. Production of apparel from recycled feedstocks or more sustainably grown natural materials have environmental benefits in terms of greenhouse gas emissions, land disruption, water consumption, and more. Process efficiencies include advancements that can decrease the emissions footprint of clothing production through simply using new machinery or techniques.

This solution identifies potential increases in both better materials and efficient manufacturing from less than 1% of the market currently to between 7% and 56% by 2050, depending on the level of aggression of adoption. These adoption scenarios, because the market is so large, can result in between 3 to 36 Gt of CO2 reduction, making this one of our most significant solutions. However, there are significant costs associated with implementing these changes, between 35 and 300 billion USD of first costs by 2050.

# Literature Review

## State of Sustainable Clothing

Textile production causes over 1.2 billion tons of CO2 emissions globally, of which the vast majority is used for clothing production. (MacArthur Foundation, 2017) Polyester production alone was 700 million tonnes in 2015. (Macarthur Foundation, 2017) Clothing and textile production have a long and complex supply chain and life cycle, due to the variety of feedstocks used to create textiles, methods of treatment and production of finished goods, distribution, as well as complex environmental impacts from the use phase and disposal. 97% of estimated fiber production is from virgin feedstocks, as opposed to recycled fibers, and the vast majority of those fibers (63%) are manmade plastic fibers, as opposed to natural fibers like cotton, linen, hemp, wool, etc. (Macarthur Foundation, 2017) Fossil consumption to produce manmade fibers like polyester, nylon, polyurethane etc., deplete non-renewable resources and can be difficult to recycle – as it stands, there is less than 1% closed loop recycling in the clothing industry, and only 12% cascaded recycling with loss in value; 87% of material is landfilled or incinerated after use. (Macarthur Foundation, 2017) One obvious approach to increasing the sustainability of the clothing industry, therefore, is replacement of conventional materials with more sustainable materials. Production of apparel from recycled feedstocks or more sustainably grown natural materials have environmental benefits in terms of greenhouse gas emissions, land disruption, water consumption, and more. (Ellen Macarthur Foundation, 2017; REFS)

The second function of a sustainable clothing model includes process efficiencies. Significant technological advancements have been made that can decrease the emissions footprint of clothing production through simply using new machinery or techniques. Some of these might be low-liquor or waterless dyeing, natural dyes, high efficiency weaving and knitting, heat recovery, waste reduction, and more. (GFA; Muthu, 2014) Energy consumption in the textile industry is predominantly thermal energy, and is consumed in large part in spinning, chemical processing, and weaving. (Muthu, 2014) A lot of the interventions to reduce these are relatively low cost and simple to implement. (Greer et al., 2014)

Since this is a mature, and extremely widespread and influential, industry, there are significant existing LCAs and studies that clearly show the climate impacts of the major raw materials and processes as well as their potential solutions. In fact several industry groups and organizations exist dedicated to furthering these options, such as the Better Cotton Initiative, Textile Exchange, Global Fashion Agenda, and more. These organizations are able to produce high resolutions views of trends in materials consumption (Fig 1.1), as well as estimates of environmental impact.

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Figure . Global Fiber Production in 2019 (Textile Exchange)

## Adoption Path

As described above, the two primary levers for adoption of a Sustainable Clothing industrial process are responsible materials and better manufacturing.

Though direct replacement of some materials is quite straightforward for apparel manufacturers, some have significant barriers. The most significant barrier across the board is cost of materials. More sustainable materials that have a lower life cycle carbon footprint are significantly more expensive for manufacturers to buy. Despite this, there is significant consumer interest in responsible clothing, driving adoption. (REFS) Recycled polyester has increased from 8% of polyester production in 2008 to 14% in 2019, and Better Cotton (encompassing certified organic cotton, recycled cotton, cleaner cotton, fair trade, etc.) has increased from 10% of cotton in 2013 to 25% in 2019. (Textile Exchange, 2020) Manmade cellulosics and other plant based fibers are also increasing. (Textile Exchange, 2020) However, substitution still faces significant obstacles, since replacement of plastic-based fibers with plant-based might require new sourcing as well as new machinery and techniques for processing. Furthermore, replacement of virgin materials with recycled fibers is dependent on availability of those materials, which currently have very low collection and recycling rates – there’s less than 1% closed loop recycling in the apparel industry, and only 12% cascaded recycling, with the majority of material ending up being landfilled or incinerated (73%). (Ellen Macarthur Foundation, 2017)

Better manufacturing includes increased resources efficiency in the form of energy, water, heat, and physical resources like materials and dyes and waste prevention. These take the form of efficient spinning, weaving, and knitting to process fibers into fabrics, waterless or low liquor dyeing, heat recovery practices, environmentally friendly chemicals, less washing and drying, batch dyeing, and more.

Increased supply chain transparency is necessary to improve the sustainability practices of the apparel industry, since supply chains are extremely long and complex, originating often with the harvesting or production of raw materials, turning those materials into fibers, the fibers into fabrics, treating these fabrics and fibers, cutting, sewing, finishing, and then shipping, and all of these steps frequently occur in different locations with different environmental and social regulations.

### Current Adoption

Current Adoption is described in Section 2.4.1.

### Trends to Accelerate Adoption

Consumers are very interested in making more sustainable choices, 43% of consumers in 2020 said they intend to spend more money on sustainable fashion. (ThredUp, 2020) This is an increase from 18% in 2018. Consumer interest is an important motivator for companies to focus on implementing sustainable choices, as pressure from buying trends is critical to influencing market trends.

### Adoption Potential and Barriers

Further potential for increasing Sustainable Clothing includes improving the distribution, use phase, and end of life phases of apparel life cycles. These areas are not within the system boundary for this model, however. Improved distribution efficiency falls within the Drawdown Transportation sector, which has a holistic view of shipping and delivery systems, and their global improvement. End of life, increasing clothing recovery and recycling, while critical to the adoption of recycled fibers, should be incorporated into the Drawdown Waste models. Finally, use phase is difficult to model and predict consumer behavior. Washing and drying, for example, consume significant amounts of water and energy, and potentially release pollution into wastewater streams in the form of plastic microfibers, and others. These are all areas with opportunity for improvement, as well as with existing technologies that could be adopted and are, at some level, implemented. However, adoption is highly dependent on consumer behavior and policy or external forcing, which cannot be effectively predicted. Adoption, therefore, has an even more significant potential outside of the defined cradle-to-gate system boundary.

Furthermore, the improved manufacturing subsector of technology changes associated with the solution functional unit in this analysis include transitioning to machinery and techniques that are more efficient: waste heat recovery, low water dyeing, high efficiency knitting, etc. Another aspect of improved manufacturing is the transition to renewable energy sources. However these type of changes at the grid scale are, again, encompassed in a different Drawdown analysis. Transition to renewable energy, while mentioned in significant analysis and discussions about improving sustainability in the clothing sector, are included in the Energy sector analysis of grid transitions as well as distributed renewables.

Within the existing definition for the Sustainable Clothing model, however, there is potential even beyond the identified adoption scenarios. Industry contacts suggest that adoption of responsible materials is slow, due to availability, but also the challenges associated with completely shifting highly ingrained and complex supply chains that exist within the materials manufacturing industry.

## Advantages and disadvantages of Sustainable Clothing

The major limitation is that sustainable materials are often significantly more expensive than traditional materials. However, operating savings from resource efficiency might eventually be enough to offset these costs. The apparel sector is one of the most environmentally impactful, so decreasing the carbon footprint by improving materials and manufacturing processes can have a significant impact on climate change globally. However, the apparel sector has environmental impacts beyond just greenhouse gas emissions. Water and soil pollution are significant negatives of the apparel sector as well, so while improving the greenhouse gas footprint of manufacturing is necessary, it may still not necessarily make for a completely sustainable system. Beyond this, consumer behavior is hard to both model and influence, so the use phase and end of life phase of the apparel life cycle cannot be modeled with the same resolution as manufacturing and production.

## Solution Definition

This solution includes production of clothing and apparel from sustainable materials and using more efficient manufacturing practices. This includes replacing conventional materials, such as polyester, that are made from non-renewable resources, increased use of low-impact natural fibers like organic cotton and hemp, and decreased energy and water use and waste production.

# Methodology

## Introduction

To model the potential impact the adoption of sustainable clothing models may have as a carbon emissions reduction strategy, a scenario analysis is performed. Sustainable Clothing as a Drawdown Solution is defined for this model as the adoption of responsible materials and improved manufacturing processes. It does not include use phase or end of life consumer behavior changes.

Project Drawdown’s models are developed in Microsoft Excel using standard templates that allow easier integration since integration is critical to the bottom-up approach used. The template used for this solution was the Reduction and Replacement Solutions: Industrial Processes (RRS.IP) which accounts for reductions in energy consumption and emissions generation for a solution relative to a conventional technology. These technologies are assumed to compete in markets to supply the final functional demand which is exogenous to the model, but may be shared across several solution models. The adoption and markets are therefore defined in terms of functional units, and for investment costing, adoptions are also converted to implementation units. The adoptions of both conventional and solution were projected for each of several scenarios from 2015 to 2060 (from a base year of 2014) and the comparison of these scenarios (for the 2020-2050 segment) is what constituted the results.

The RRS.IP Model varies from the RRS Solution in that it includes several additional sheets to develop a higher resolution SOLUTION functional unit and CONVENTIONAL functional unit with several component parts.

## Data Sources

Critical data sources include:

* *The Ellen Macarthur Foundation*’s New Plastics Economy
* *Textile Exchange*’s Preferred Fiber Market Reports (2019, 2020)
* *Fibre2Fashion*’s Textile Market Price Trend Report
* *Global Fashion Agenda*’s Pulse of the Fashion Industry Reports (2017)
* *Muthu* Roadmap to Sustainble Textiles (2014), Sustainbility in the Textile and Apparel Industries Production Process Sustainabiltiy (2020)
* *Better Cotton Initiative*’s Annual Report

## Total Addressable Market

The Total Addressable Market is based on four industry projections.

The Ellen Macarthur Foundation New Plastics Economy (2017), projects 3% market growth by volume to 160 MMt in 2050.

The Global Fashion Agenda’s Pulse of the Fashion Industry (2019) projects growth to 102 MMt by 2030.

The Quantis Report Measuring Fashion (2020) projects growth to 93 MMt by 2030.

And the Textile Exchange report

## 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.

### Reference Case / Current Adoption

The reference case assumes the current adoption of sustainable solutions remains constant from current year to 2050. This includes 2% of fibers being recycled polyester and 6% being improved cotton (organic, or otherwise), and 11% of fibers being cellulose fibers. The complete market breakdown is described below in 2.5.1 as the Conventional Functional Unit.

### 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:

* **Scenario 1**: the case in which solutions on the Drawdown list are adopted at a realistically vigorous rate over the time period under investigation, adjusting for estimated economic and population growth. This results in sustainable solutions increasing to 8% of the market by 2050.
* **Scenario 2**: the case in which the adoption of solutions is optimized to achieve drawdown by 2050. This is accomplished by sustainable clothing solutions being adopted by 32% of the market by 2050.
* **Scenario 3**: the case in which solutions achieve their maximum potential, fully replacing conventional technologies and practices within a limited, competitive market. This scenario is based on technical potential and is not necessarily representative of a realistic adoption without significant incentives or behavioral changes. This is accomplished by an ambitious 56% market adoption of sustainable solutions by 2050.

## Inputs

### Climate Inputs

The climate impacts of the materials and processes associated with sustainable clothing were collected for several individual materials and processes, and then compiled into a composite functional unit with the following definitions:

Solution Functional Unit (1 MMt of Sustainble Clothing Production):

* 68% Recycled Polyester, 22.5% Improved/Responsible Cotton, 8.5% Cellulose fibers, 1% Other Protein Fibers
* Improved Dyeing, Improved fabric production, drying/washing, pretreatment, garment production (cutting/sewing)

Conventional Functional Unit (1 MMT of Conventional Clothing Production):

* 20% conventional cotton, 6% improved/responsible cotton, 55% polyester, 2% recycled polyester, 6% other manmade fibers, 11% cellulose fibers
* Conventional Dyeing, Conventional fabric production, drying/washing, fabric pretreatment, garment production (cutting/sewing)

Table . Climate Inputs

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Conventional Cotton | *tCO2/MMt* | 839098-468973 | 2764416 | 12 | 11 |
| Conventional Polyester | *tCO2/MMt* | 2729547-5038881 | 3884214 | 8 | 8 |
| Recycled Polyester | *tCO2/MMt* | 1034542-3540969 | 1787756 | 10 | 7 |
| Other Manmade Fibers | *tCO2/MMt* | 3076603-8489634 | 5783119 | 11 | 7 |
| Cellulose Fibers | *tCO2/MMt* | -368846445 - 2348210558 | 989682056 | 9 | 6 |
| Protein Fibers | *tCO2/MMt* | 4240699-73869800 | 39055250 | 4 | 3 |
| Improved Cotton | *tCO2/MMt* | 473067-1199192 | 836129 | 9 | 7 |
| Garment Production (Cutting/Sewing) | *tCO2/MMt* |  | 1746500 | 8 | 3 |
| Conventional Dyeing | *tCO2/MMt* | 1459428-5294572 | 3377000 | 11 | 9 |
| Improved Dyeing | *tCO2/MMt* | 242722-2138108 | 1190415 | 8 | 6 |
| Drying/Washing | *tCO2/MMt* | 134384-964616 | 549500 | 4 | 3 |
| Fabric Production (Spinning/Knitting) | *tCO2/MMt* | 4137069-19280564 | 11708816 | 20 | 9 |
| Improved Fabric Production | *tCO2/MMt* | 848710-2859062 | 1853886 | 6 | 4 |
| Fabric Pretreatment | *tCO2/MMt* |  | 725500 | 2 | 2 |

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[[1]](#footnote-1).

### Financial Inputs

The financial impacts of the materials and processes associated with sustainable clothing were collected for several individual materials and processes, and then compiled into a composite functional unit with the following definitions for first costs and operating costs:

Solution Functional Unit (1 MMt of Sustainble Clothing Production):

* Material First Costs: 68% Recycled Polyester, 22.5% Improved/Responsible Cotton, 8.5% Cellulose fibers, 1% Other Protein Fibers
* Material Operating Costs: 100% Natural Dyes
* Material Manufacturing Operating Costs: 100% Solution Textile Mill Operating Cost

Conventional Functional Unit (1 MMT of Conventional Clothing Production):

* Material First Costs: 20% conventional cotton, 6% improved/responsible cotton, 55% polyester, 2% recycled polyester, 6% other manmade fibers, 11% cellulose fibers
* Material Operating Costs: 100% Conventional Dyes
* Manufacturing Operating Costs: 100% Conventional Textile Mill Operating Costs

Table . Financial Inputs for Conventional Technologies

|  | **Units** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Conventional Cotton | *US$2014/MMt* | 870-3195 Million | 2032.5M | 3 | 3 |
| Polyester | *US$2014/MMt* | 957M-1963M | 1,460 M | 5 | 2 |
| Recycled Poly | *US$2014/MMt* | 1456M-2417M | 1941M | 3 | 2 |
| Other Manmade | *US$2014/MMt* | **1048M-3286M** | **2167M** | 8 | 1 |
| Cellulose Fibers | *US$2014/MMt* | 1655M-3799M | 2777M | 4 | 2 |
| Protein Fibers |  | 1,625M-15,174M | 8,400M | 4 | 3 |
| Improved Cotton |  | 2080M-2681M | 2381M | 3 | 1 |
| Conventional Textile Mill Operating Cost |  |  | 249.8M | 1 | 1 |
| Solution Textile Mill Operating Cost |  |  | 184.7M | 1 | 1 |
| Conventional Dyes |  |  | 177.6M | 2 | 2 |
| Natural Dyes |  |  | 233M | 1 | 1 |

### Technical Inputs

Table .4 Technical Inputs Conventional Technologies

|  | **Units** | **Model Input** |
| --- | --- | --- |
| Lifetime Capacity (Conventional) | *years* | 20 |
| Average Annual Use (Conventional) | *MMt/MMt* | 1 |

Table .5 Technical Inputs Solution

|  | **Project Drawdown Data Set Range** | **Model Input** |
| --- | --- | --- |
| Lifetime Capacity (Solution) | Min – Max | 20 |
| Average Annual Use (Solution) | Min – Max | 1 |

## 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).

## 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.

The Recycled Materials component of the solution functional unit should be checked against quantity of textile recycling in the MSW Integrated Waste Models, if possible, when a higher resolution view of waste production is available on the material level for textiles.

# 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.

Table . World Adoption of the Solution

| **Solution** | **Units** | **Base Year (2014)** | **World Adoption by 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Drawdown** | **Optimum** |
| Solution Name | 1 Million Metric Ton Clothing | 0.05 | 11.44 | 47.55 | 82.73 |
| *(% Market)* | 0.1% | 7.7% | 32.0% | 55.7% |

Figure 3‑1 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).

Table . Climate Impacts

| **Scenario** | **Maximum Annual Emissions Reduction** | **Total Emissions Reduction** | **Emissions Reduction in 2030** | **Emissions Reduction in 2050** |
| --- | --- | --- | --- | --- |
| *(Gt CO2-eq/yr.)* | *Gt CO2-eq/yr. (2020-2050)* | *(Gt CO2-eq/year)* | *(Gt CO2-eq/year)* |
| ***Plausible*** | 0.31 | 3.44 | 0.05 | 0.31 |
| ***Drawdown*** | 1.28 | 21.04 | 0.48 | 1.28 |
| ***Optimum*** | 2.22 | 36.02 | 0.80 | 2.22 |

The solution was integrated with all other Project Drawdown solutions and may have different emissions results from the models. This is due to adjustments caused by interactions among solutions that limit full adoption (such as by feedstock or demand limits) or that limit the full benefit of some solutions (such as reduced individual solution impact when technologies are combined).

Table . 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** | 0.30 | 0.03 |
| **Drawdown** | 1.77 | 0.10 |
| **Optimum** | 3.03 | 0.17 |

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.

Table . Financial Impacts

| **Scenario** | **Cumulative First Cost** | **Marginal First Cost** | **Net Operating Cost Savings** | **Lifetime Operating Cost Savings** | **Lifetime Cashflow Savings NPV (of All Implementation Units)** | **Cumulative First Cost** |
| --- | --- | --- | --- | --- | --- | --- |
| *2015-2050 Billion USD* | *2015-2050 Billion USD* | *2020-2050 Billion USD* | *2020-2050 Billion USD* | *Billion USD* | *2015-2050 Billion USD* |
| **Plausible** | 35.78 | 35.47 | 0.00 | 0.00 | -35.47 | 35.78 |
| **Drawdown** | 200.56 | 200.14 | 0.01 | 0.01 | -200.12 | 200.56 |
| **Optimum** | 303.11 | 302.63 | 0.01 | 0.02 | -302.60 | 303.11 |

Figure . Operating Costs Over Time

## Other Impacts

Other impacts of adopting a more sustainable clothing system are reduced wastewater pollution, as the textile manufacturing sector produces significant chemical runoff, as well as reduced microplastics from garment shedding in the ocean. These impacts, however, cannot be quantified in GHG emissions.

# Discussion

Improving the materials and practices in the clothing sector are a significant opportunity for greenhouse gas reduction. Consumption of clothing has only continued to increase, so in addition trying to mitigate the per unit impact of apparel production and consumption, it is critical to start to think about how to extend the lifetime of goods in-use, design for recovery, and other interventions that would decrease demand for conventional and high impact production of clothing.

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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. 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-1)