**Technical assessment for**

**RESIDENTIAL SOLAR WATER HEATING SYSTEMS**

Sector: Buildings and Cities

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Version 2

**Prepared by:**

David Jaber, Research Fellow

Priyanka Desouza, Research Fellow

Chirjiv Anand, Research Fellow

Ryan f Allard, Senior Fellow



[info@drawdown.org](mailto:info@drawdown.org) [www.drawdown.org](http://www.drawdown.org)

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# Acronyms and Symbols Used

**AMPERE –** Assessment of Climate Change Mitigation Pathways and Evaluation of the Robustness of Mitigation Cost Estimates (Project of the EU)

**DOE** – Department of Energy (of the US)

**DSHWS** – Domestic Solar Hot Water Systems

**EIA** – Energy Information Administration (of the US)

**ETP** – Energy Technology Perspectives

**GBPN** – Global Buildings Performance Network

**IEA** – International Energy Agency

**IPCC** – Intergovernmental Panel on Climate Change

**IRENA** – International Renewable Energy Agency

**NPV** – Net Present Value

**NREL** – National Renewable Energy Laboratory (of the US)

**PDS** – Project Drawdown Scenario

**REF** – Reference Scenario

**RefPol** – The Reference Policy Scenario

**REN21** – The Renewable Energy Policy Network for the 21st Century

**RRS** – Reduction and Replacement Solutions (Model of Project Drawdown)

**SHC** – Solar Heating and Cooling Programme (of the IEA)

**SHW –** Solar Hot Water

**SHWS –** Solar Hot Water Systems

**SWH** – Solar Water Heating

**TAM** – Total Addressable Market

**WBDG** – World Building Design Guide

# Executive Summary

Residential solar water heaters are a mature technology that has been around since the 1960s. It heats water using thermal energy from the sun. Despite this technology contributing to only a small fraction of the world’s current hot water demand, in countries such as Cyprus and Israel, favorable government policies have enabled penetration of this technology to 80-90%. This is a hopeful sign for other countries that could greatly benefit from this technology. This report lays out the climate and financial benefits of optimistic adoptions of roof-top solar water heating versus a reference scenario.

Using data mainly from the International Energy Agency (IEA) Solar Heating and Cooling Report (2012), IEA’s Solar Heat World Wide 2015 and 2018 reports, as well as the Renewables 2012 and 2018 Global Status Outlook, Project Drawdown’s Reduction and Replacement Solutions (RRS) model framework estimates the climate and cost impacts of increased global adoption of residential solar water heaters. The global adoption of solar water heaters was at 8% with 394 TWh in 2018. Given the potential of households around the world that could be potential adoption sites for this technology, it is possible that in the next 30 years, global adoption increases by 15% to 50% of the total addressable market (TAM). The TAM was derived from projections made by using IEA data for adoption potential.

The environmental impacts of such an adoption involves a maximum annual emissions reduction of 0.2 to 1 Gt CO2/year with a total cumulative CO2 reduction of 3.6 to 27 GtCO2-eq (depending on scenario)*.* This is a result of adding 0.42 to 2.5 TW of additional capacity by 2050. These environmental benefits come at a cost of $1.0 to $4.8 trillion in cumulative first costs and $0.7 to $4.5 trillion in marginal costs.

Total lifetime cash flow savings are estimated to be negative (-$2.3 trillion to -$334 billion), and net operating savings are also negative owing to low fuel costs (-$110 to -$14 billion). The model assumes that solar water heaters (SHWs) will only serve as a supplemental technology and not replace electric heaters and gas boilers. In the optimistic adoption scenarios, it is assumed that the conventional water heater adoption will remain the same to cater to peak demand when the sun is not shining. However, solar water heating will cater to a greater percentage of water heating. This is purely a supplemental technology, which is why a negative NPV was obtained. Despite the high upfront costs, solar water heaters are an important solution to explore, as they are clean, have low long term (operation and maintenance) costs and has the potential to significantly lower GHG emissions in the future.

# Literature Review

Globally, the buildings sector is one of the largest end-use sectors, accounting for 30% of global final energy usage. Including building construction increases this to 36%. These two together account for 39% of energy-related CO2 emissions (UN Environment & IEA, 2017). Thus, the global building sector needs innovative technologies and approaches to reduce energy consumption while ensuring building operations are not affected. Breaking down the building sector by energy end-use gives us an idea of where the potentials lie. Space heating consumed 32% of final building energy in 2014. The other top uses are cooking energy (22%), water heating (19%), appliances and equipment (16%), and lighting (6%) (IEA, 2017a). Clearly there are many opportunities across the building sector for energy efficiency. Space and water heating energy is affected by windows, walls and heat source, cooking energy is affected by source and cooking technology, appliance energy by appliance efficiency and use, and lighting is affected by light technology and use.

## State of Domestic Solar Water Heating Systems

Conventional technologies for water heating include, electric resistance hot water heaters, boilers, heat pumps etc., that produce up to three times the amount of emissions compared to their low carbon alternatives. Solar energy, being free and renewable when collected and used for water heating, helps displace other fuels thus aiding with GHG emissions reductions.

According to the IEA, solar domestic hot water was first deployed on a large scale in the 1960s in Australia, Japan, Israel, and other countries (IEA, 2015). Based on IEA statistics the deployment per capita, Cyprus, Austria, Israel, Barbados, and Greece were the top five countries at the end of 2012. The penetration of solar water heating in Cyprus and Israel is 90% and 85% respectively. This high penetration is due to legislation passed in the 1980s during the oil crisis that required all new homes to have solar thermal systems installed. In 2012, Cyprus introduced a subsidy for replacement of all solar collectors or entire systems to stimulate adoption of the latest technological systems. The same countries reported in 2012 for total per capita capacity are leading at the end of 2016 but in a different order, with Barbados leading followed by Austria, Cyprus, Israel, and Greece respectively (REN21, 2018). These rankings were estimated to remain unchanged for end of 2017. Region wise, China remained the leader in per capita installations in 2017 followed by Australia and MENA regions (Weiss & Spörk-Dür, 2018).

Markets that have seen strong increased deployment due to subsidies and/or renewable commitments include Austria and Germany (subsidies) and Israel and Spain (solar obligations). In some cases, solar hot water has competitive advantages over alternative technologies (e.g. China, Cyprus). Attractive national subsidy schemes, (Girardeau, 2017; Zhou, 2018) standards, and mandates for use of solar hot water have been successful in contributing to the growing market of solar water heaters in certain regions (Mordor Intelligence, 2018; REN21, 2018). Specific policies include low-cost loans, tax rebates and research grants in China (Zhou, 2018). Combining solar cooling with solar hot water have shown improved economics for solar investment in Southern Europe.

### Domestic Solar Hot Water Technology Overview

Domestic solar hot water systems (DSHWS) mainly are composed of storage tanks and solar collectors. They can be sized to fulfill a desired percentage of hot water demand in a household depending on the local climate. They are typically configured with a conventional water heater as a back-up heater. The solar collectors collect the thermal energy from the sun. This captured heat energy is used to heat water. This technology is also used for space heating as well and is different from solar photovoltaic that use solar energy to produce electricity.

The energy saved from a solar water heater depends on various factors such as size of the collectors as well as the storage tank, appliance efficiency, amount of sunlight, and hot water demand (Natural Resources Canada, 2003). The amount of solar energy available depends on several factors such as temperature, cloud cover, site latitude, season of the year, solar collector tilt (including tilt on flat roofs), orientation to path of sun, shading and local fog, (World Building Design Guide, 2011).

#### Types of Solar Hot Water Systems

SOLAR WATER HEATING SYSTEM

**Active Systems (No Anti-Freeze)**

* Direct circulation
* Indirect circulation

**Passive Systems (No Pumps)**

* Thermosyphon
* Integral collector storage

**Tank types**

One-Tank system

Two-Tank system

**Energy Collector Types**

Flat plate (Glazed and unglazed)

Integral Collector

Evacuated tube collector

Parabolic-Trough collectors

Figure 1.1 Domestic solar hot water heating systems

A solar hot water system typically comprises of a tank and an energy collector. Figure 1.1 illustrates the different types of solar hot water systems (explained in this section). There are two main types of solar hot water systems, active and passive.

Active systems*.* Active systems depend on electric pumps to circulate fluid through the collector. Active circulation systems are of two types direct and indirect.

Direct Circulation Systems: The direct circulation systems, use pumps to circulate water heated with solar energy through the collectors into the household and back again. They use a differential controller that helps to maintain a temperature difference of about 3 to 5°F (1.6 to 2.77°C) between the hot water leaving the collector and the water in the storage tank. As the water in the tank begins to get cooler, the pump is automatically turned on (World Building Design Guide, 2016).

These systems work well in places where temperatures do not go below the freezing point of water since they do not use anti-freezing liquids. They have a flush-type freeze protection valve (lets warm water flow through the collector when temperatures approach freezing). For cold climates, drain back direct circulation active systems are available. They are designed to store all of the water heated by the collector in a “drain-back” tank, stored in a heated portion of the building. In the absence of sunlight, the pump switches off and any water in the collector flows back into the drain-back tank by gravity. Systems like these don’t need heat exchangers since they use water as the heat exchange fluid.

Indirect Circulation Systems: These systems work similarly to the direct systems except that they have two circulating heat transfer fluid loops. In the first loop, a non-freezing, heat transfer fluid circulates though the collector field. A heat exchanger is used to transfer heat from this fluid to potable water. The exchanger can either be directly integrated in the tank (internal) or connected to a second loop (external).

These systems are more suitable in areas that are prone to have temperatures below 0 degrees centigrade since they use an anti-freeze solution (a water and glycol mixture), as a heat transfer medium to avoid freezing. The indirect systems are hence more expensive considering the extra material used in these system compared to the direct circulation systems.

Passive Systems. Passive systems as, do not use pumps. Water moves by convection (heated water moves upwards naturally).

These systems are used on individual buildings for a single heating demand. They are not designed for central heating that serves several buildings (World Building Design Guide, 2016) . They are typically less expensive than active solar water heating systems as they do not have pumps. However, they are less efficient in cooler climates. Due to the fact that these systems do not comprise of moving pumps they tend to last longer. The two main kinds of passive solar water heating systems are, batch or integral collector-storage and thermosiphon systems.

Thermosiphon Systems: In the thermosiphon systems, the difference in density in warm and cold water is used to produce a flow of water into the tank. These systems do not depend on pumps or electricity. The collector must thus be installed below the storage tank so that warm water will rise into the tank. A roof-top water storage tank would be required in these cases and this factor should be incorporated in the roof design, both in new builds and retrofits.

These systems are usually more expensive than integral collector-storage and passive systems (Department of Energy, n.d.) and are typically used in warmer climates such as in Africa, South America, Southern Europe, and the Middle East and North Africa (MENA) region (Weiss & Spörk-Dür, 2018) but can work well in areas with less sunshine as well (World Building Design Guide, 2016).

Batch or Integrated Collector Storage Systems: In the integral collector storage systems (ICS), the tank and the collector are combined in one unit. The storage in these systems may be in the form of tank or large pipes. These systems comprise of black tanks or tubes in an insulated, glazed box. Cold water from the mains first passes through the solar collector to preheat the water (U.S Department of Energy, 2016) and then continues to the conventional backup water heater, providing consistent hot water. Cold water continually flows through the collector from the bottom where it is heated by the sun. Hot water is continually drawn from the top where it is hottest.

These systems are more suited to regions without frequent sub-zero temperatures. If installed outdoors, these systems would require extra insulation or anti-freezing elements. They also work well in scenarios where buildings have high day time and evening hot water needs.

#### Solar Thermal Energy Collectors

Solar water heating systems use collectors. A collector has an absorber, that collects heat from the sun. This heat is captured in the fluid flowing through the tubes attached to the absorber. Since the collectors are located outside, they tend to lose heat in cooler environments. The absorber therefore is covered, with a transparent cover, on the top and insulated on the sides and the bottom to reduce heat loss. Typically, the top cover used is a special solar glass. It does allow some reflection to be radiated out to the atmosphere. The collector needs to be protected from rain, snow and wind. A housing for the collector is typically used to provide this protection. Aluminum, steel, plastic or wood are the typical materials used for the housing (World Building Design Guide, 2016). It is estimated that 20 square feet of collector area is required for a family of two. An additional 8 square feet would be required for each additional person in areas with abundant sunlight and 12-14 square feet in areas with lesser sunlight.

There are different types of collectors including, unglazed, flat plate (glazed), evacuated tube and parabolic trough. Glazed flat plate and evacuated tube collectors are most relevant to domestic applications. The type of the collector chosen depends on the required operating temperature and the given ambient temperature range. There is an upper limit to the temperature of the water output which depends on collector type (see Table 1.1).

Table 1.1 Maximum temperature provided by collector type

|  |  |
| --- | --- |
| **Collector Type** | **Maximum Temperature** |
| Unglazed EPDM | below 90 °F (32 °C) |
| Flat plate | below 160 °F (71 °C) |
| Evacuated tube | Up to 350°F(177°C) |
| Parabolic trough | Up to 570°F(299°C). |

Source: (World Building Design Guide, 2016)

Flat Plate Collectors: Flat plate collectors, developed by Hottel and Whillier in the 1950’s, are the most common types of collectors dominating the market in most of the top 20 countries for solar thermal installations (REN21, 2018). Flat plate collectors are of two types glazed and unglazed.

Glazed Flat Plate Collectors:Most flat plate collectors are glazed. Glazed collectors contain a dark absorber plate under one or more glass or plastic (polymer) covers. They heat water to higher temperatures than air temperature. They comprise of insulated weather-proof boxes that consist of water flowing over a dark absorber plate. The absorber plate is typically made of metal such as aluminum or polymer that is efficient at absorbing solar heat.

According to IEA for 2012, the estimated cumulative capacity of solar thermal collectors worldwide (including district heating) was 269.3 GW (th) (IEA-SHC, Solar Heating and Cooling, 2012). The top countries were China (180 GW (th)), Germany and Turkey (each 11 GW (th)), Brazil and India (each 4 GW (th)), then USA and Australia (each 2 GW (th)) of glazed capacity .

Unglazed Flat Plate Collectors*:* These collectors can be rolled out on the roof. They do not have a glass cover or enclosure and are best used when ambient temperatures are close to the desired temperature for example in pool heating and hence there are no optical losses. Flat plate collectors are designed to heat water to medium temperatures (approximately 140 °F or 60 °C).

They are less expensive compared to evacuated tube collectors as they made with plastic. They tend to be the most cost effective due to their simple design. However, their efficiency compared to other collectors is also low. China, in 2017 saw an increased use of flat plate collectors (8%) and a decreased use of vacuum tube or evacuated tube collectors, in its installations. In Europe (2nd largest market for solar water collectors), 82.9% of the total installations in were also flat plate collectors (Weiss & Spörk-Dür, 2018).

Evacuated Tube Collectors: The evacuated tube collectors often have a high efficiency design, a high heat capacity per square foot, and operate well in cold climates due to their design, that reduces heat loss and a selective coating, maximizing heat absorption. They have a small collecting surface that is encased by the evacuated glass tubes to reduce heat loss. Evacuated-tube solar collectors are more sophisticated and consist of a row of evacuated parallel tubes that contain a metal absorber tube attached to a fin. The fin's coating absorbs solar energy but inhibits radiative heat loss. The vacuum inside the tubes prevents any form of heat loss from conduction or convection thereby largely reducing heat losses in the system (Department of Energy, n.d.). They are designed to deliver high temperatures (approximately 300 degrees Fahrenheit) and are more frequently used in commercial applications (Hamola, n.d.).

In India and China, vacuum tube collectors accounted for more than two-thirds of the 2017 increase whereas they accounted for approximately 50% in Turkey. However, in China, consumers are transitioning to the safer, more aesthetic flat-plate collectors, which has accelerated due to increasing demand for façade and balcony integrated applications (REN21, 2018).

Parabolic Trough Collectors:These collectors are also known as concentrating collectors. They use curved mirrors to focus sunlight onto a receiver tube. The receiver tube runs through the middle of the trough. These systems are capable of heating the heat transfer fluid to a temperature of about 299°C and are best suited for desert areas where there is high direct solar radiation. They are generally used for large systems, require maintenance, and particularly benefit from economies of scale (World Building Design Guide, 2016).

Since solar energy is less available in certain regions solar electric boost and solar gas boost (Solahart, 2018) technology options are also available, where solar heat could act as the new conventional technology and electricity and gas the supplemental sources for water heating, via boosters.

#### ***Storage Tank***

Solar heated water can be stored in to a one-tank system, where the conventionally heated water is stored, or, it could be stored in a separate tank, that feeds into the conventionally heated hot water storage (two-tank system). A larger storage tank would be required if solar heat is used for space heating as well. Table 1.2 shows the tank and collector sizes for small-large households. Storage tanks would need to be insulated to reduce heat loss. If the tank is placed outside, a weather proof cover may also be required. Tank sizes differ based on demand.

Table 1.2 Tank and Collector sizes

| **Family Size (In Persons)** | **Average Hot Water Usage** | **Suggested Solar Water Heater System Size** | **Collector Size** | **Equivalent Existing Water Heater Tank Size** |
| --- | --- | --- | --- | --- |
| 2 | 150 liters/day | Small  No pre-heat tank | About 3m2 | 180 liters |
| 3-4 | 225 liters/day | Medium  Pre-heat tank required | 5-6 m2 | 270 liters |
| >5 | 300 liters/day | Large  Pre heat tank required | >6 m2 | 270 liters |

Source:(Natural Resources Canada, 2003)

#### Installation of Solar Water Heaters

The proper installation of a SWH depends on various factors such as insolation (amount of sun energy), climate, local building codes, and safety needs (“Solar Water Heaters | Department of Energy,” 2015). Installation in new buildings is more common that in existing buildings. Most solar water heaters can be easily retrofitted in an existing home. More space would be required if a water storage tank and a heat transfer unit are required. For the collector, an area of about 3m2 would be required per collector. Most installations require 1-2 collectors. A small path would also be required for piping from the collector to the storage tank. In the northern hemisphere, a south facing roof or wall (south east or south west orientation for maximum performance) is considered the best location for placement of a solar collector, set at an angle of 18-50 degrees from the horizontal plane (Natural Resources Canada, 2003). The reverse is true in the Southern Hemisphere. A solar collector at a shallow angle may compromise winter performance and will not assist in snow removal. In situations where roof or wall mounting of the heaters is not possible, the heaters can be ground mounted. To avoid ultraviolet degradation, and decrease heat losses, piping should be protected, using a sleeve such as a down spout. Solar water heaters are available for seasonal as well as year-round use. The seasonal heating systems are less expensive given they do not require extra insulation to avoid freezing.

### Current Market for domestic Solar water heaters

About 90% of the worldwide annual installations are small scale solar water heating systems (Weiss & Spörk-Dür, 2018). In 2016, 94% of worldwide solar thermal was used for heating domestic and non-industrial hot water. Small scale systems in single family houses held the largest share at 67%, followed by larger scale applications, in multi-family homes, schools and hotels etc. at (27%). Swimming pool heating accounted for 4% and solar combi-systems for 1% of the total energy used for water heating.

## Adoption Path

### Current Adoption[[1]](#footnote-1)

For the base year of 2014, the adoption of solar water heaters was at 355 TWh, and this is estimated to have grown to 394 TWh in the latest year in the model (the current year), 2018. This 2018 adoption satisfies 8.1% of the total water heating demand of up to 4,891 TWh in 2018. By the end of 2017, the cumulative solar thermal global capacity in operation was at an estimated 472 GW (th) (675 million square meters of collector plat area). The total energy supplied in 2017 by solar thermal systems was 388 TWh (th) (approximately saving 41.7 million tons of oil and 134.7 million tons of CO2) (Weiss & Spörk-Dür, 2018). The newly commissioned glazed and unglazed collectors by the end of 2017 was 35 GW (th). This annual global capacity was 4% down from 2016, where the capacity was 36.5 GW (th) (REN21, 2018). This is a significant decline considering the annual global added collector capacity was 18% in 2010-2011. The decline is evident in the markets of China (6% decline) and Europe due to competitive technologies such as heat pump and solar photovoltaics (Weiss & Spörk-Dür, 2018). On the other hand, market growths were recorded in India (26%), Mexico (7%) and Turkey (4%).

The six leading countries for new installations in 2017 were China, Turkey, India, Brazil, the United States and Germany, the largest installations being in China of about 26.1 GW (th) in 2017. China accounted for 71.2% (i.e., year-end total of 325 GW (th)) of the total cumulative global capacity (456 GW (th)) by the end of 2016. China’s rural retail market continued to decline in 2017 due to reduced construction activity and market saturation. This was partly offset by rising demand for solar heating for large real estate projects (REN21, 2018). Turkey’s strong construction market maintained the demand for solar water heaters without subsidies. Vacuum tube collectors were mainly used in Turkey’s colder regions, whereas natural circulation systems were mostly used in residential installations and forced circulation systems were used mostly in commercial installations (REN21, 2018).

The global thermal capacity of solar collectors for water heating was 456 GW (th) in 2016 and 472 GW (th) at the end of 2017 (REN21, 2018). In 2017, 7 European countries were among the top 10 countries worldwide for additions to solar water heating capacity. The six leading countries in terms of cumulative capacity at the end of 2016 were China (325 GW (th), followed by United States (18 GW (th)), Turkey (15 GW (th)), Germany (14 GW (th)), Brazil (10 GW (th)), India (7 GW (th)) (REN21, 2018). It should be noted that China is a much larger contributor to the global capacity of installed SWH systems compared to all the other leading countries following China and that 4 out of 6 of these top installations are in developing countries (United Nations Environment Programme, 2015).

Annual growth rates of solar thermal heating have ranged from 9% - 34% from 2000 – 2012 (“IEA SHC || Solar Heat Worldwide Markets and Contribution to the Energy Supply,” n.d.). Since 2011, growth rates have been slowing (e.g. 17.6% in 2010/2011, 10.6% in 2011/2012, and 3.3% in 2012/2013 in China). Global installed solar thermal capacity was 234.6 GW (th) in 2012, including district heating and solar space heating systems. Global solar thermal heating in buildings grew annually at an average of 12% and reached 0.7 EJ in 2011.

In China, the world’s fastest-growing market, installed capacity increased more than seven-fold, between 2000 and 2011, to 152 GW (th). The solar thermal final energy use for building heat in China grew eleven-fold, between 2000 and 2011, to 0.46 EJ, nearly all for hot water provision (IEA, 2015). In 2017 however, a 6% decline in new installations was observed in China. A decline in new installations has been reported for the fourth year in a row in China.

### Trends to Accelerate Adoption

Monthly savings on utility bills (estimated at about 25% of total residential monthly utilities) (Mordor Intelligence, 2018; “Residential Guide to Solar Hot Water,” n.d.), desire for energy independence, increased control over energy choices, concern about pollution, the environment and climate change have been cited as reason for installation of solar hot water systems. Creation of local jobs and supporting local businesses are also seen as incentives of adoption of solar energy for water heating (“Residential Guide to Solar Hot Water,” n.d.). A strong construction market is also cited as strong factor in adoption of solar water heaters, driving the sales in Turkey and declining the adoption in rural China due to reduced construction activity (REN21, 2018).

Reduction in cost of the solar water heaters as well as their installation costs in addition to operational savings would be appealing to home owners and strengthen investments in the adoption of domestic solar water heaters. SWH, due to their cost and availability, are more common practice in rural China compared to urban areas. Competitive incentives for adoption of solar hot water systems are thus essential for higher adoption especially by poorer families (Zhou, 2018). Loans without interest programs have been shown to boost market development in Lebanon and Bangladesh (Girardeau, 2017). On the contrary, Greek loan programs in the past have not been successful due to the long pay back periods of solar water heaters (Girardeau, 2017). Collaboration between firms, in addition to university-industry collaborations is said to expand the market for SWH, similar to the case of solar PV (Zhou, 2018). Technical knowledge in repairs of SWH is also listed as a significant factor in SWH purchase decisions (Girardeau, 2017).

In the IEA ETP B2DS, water heating savings account for more than half (or nearly 120EJ) of the cumulative energy savings to 2060 and beyond (International Energy Agency, 2017a). This is estimated achievable by increase in solar thermal by tenfold compared to 2017 in the 2BDS scenario along with other steps to decarbonize water heating, such as use of heat pumps and low-carbon district energy. In particular, in the 2BDS scenario, solar thermal water heating would help to avoid 65EJ of fossil fuel and electricity demand (cumulative) growth compared with the RTS. The main driver to achieve this is lowering the cost of solar thermal technologies by 40% (International Energy Agency, 2017a).

### Barriers to Adoption

Cost is one of the main barriers to adoption of DSWHS. Solar water heating has higher installation costs and lower operation and maintenance (O&M) costs than conventional technologies. Globally, installation costs for a domestic hot water systems can vary by a factor of almost 25 (USD 100/kW (th) to USD 2,400/kW (th)) (IEA, 2012.). These costs however, are lower for larger systems (USD 350/kW(th) – USD 1040/kW(th) (Anselm Eisentraut & Adam Brown, 2014). The Renewables 2015 Global Status report also provides a comprehensive list of costs of different kinds of roof-top solar water heating systems (Ürge-Vorsatz et al., 2015). Cost related barriers include, high upfront costs (Gautam, Chamoli, Kumar, & Singh, 2017) compared to conventional technologies, integration into existing buildings, lack of or inadequate financing, import tariffs and other taxes on equipment (United Nations Environment Programme, 2015), low fossil fuel prices, (REN21, 2018; United Nations Environment Programme, 2015), and competition for rooftop space with decline in solar PV prices (Gautam et al., 2017). Rents and businesses may not find it favorable to invest in solar water heaters given the uncertainty in, their occupying a certain property, and the payback period (Dutzik, Kerth, & Sargent, 2011). In addition, there are legal barriers to adoption in cases where additional costs and installation time leads to delays in completion of a project (International Renewable Energy Agency, 2015). In countries with high levels of insolation[[2]](#footnote-2), solar thermal systems can be cost-competitive with electric or fossil fuel-based technologies. In other regions large scale technologies can provide economies of scale (International Energy Agency, 2017a). However, installations in hot climatic regions demonstrate a low reduction of CO2 emissions with SWH installations, due to low hot water requirements in these areas, which leads to low electricity usage and hence lesser emissions in the conventional scenario (Bessa & Prado, 2015). The fact that solar thermal systems cannot be a part of programs such as the net metering systems adopted in the U.S., in which the consumer can sell the excess electricity to the grid, is also a barrier to choosing solar heat for hot water. Solar thermal systems also have to compete with technologies such as heat pumps for heating and cooling services which is an established, affordable technology.

A general lack of awareness at various levels and perceptions that SWH systems are too complicated also act as barriers in adoption of this technology in developing countries (United Nations Environment Programme, 2015). Slow innovation, measured as the number of patents, in SWH technology has been identified as a barrier to higher adoption of SWH in the market, in China. In regions where solar installations are not yet common, there is a lack of skilled labor. Solar thermal systems have proved to be effective in countries where governments have mandated their deployment in new construction sites which seem to have mitigated these entry barriers.

### Adoption Potential

The adoption potential of solar water heaters is provided by very few sources. Solar water heaters have the potential to reduce emissions in buildings. However, this potential varies by region and their respective climates. Reduction potential as mentioned in Section 1.2.3 is lower in hot climatic regions. At regional levels, in certain communities within China, SWH are reaching market saturation while at national levels, several countries including China, have set targets for installation of higher numbers of solar water collectors (Richardson, 2013). Particularly, UAE is considered to have a large potential for adoption of solar water heaters given the country has some of the highest insolation in the world (Mordor Intelligence, 2018). The adoption potential depends on the available irradiance. Adoption is more beneficial in areas such as the US and Southern Europe, where the irradiance is high (Greening & Azapagic, 2014).

Deployment of technical potential is primarily limited by roof space availability and heating demand. Studies have estimated the technical potential for solar water heating by assuming inputs like the available roof area and the irradiance per region (Hoogwijk and Graus, 2008). One study found a global solar water heating technical potential of 3,415 TWh/yr (or 123 EJ/yr). By way of comparison, IEA points out that in 2009 global heating demand final energy was 173 EJ (IEA, 2016). In its 2050 vision for solar heating and cooling, the IEA projects an installed capacity of nearly 3,500 GW (th) for solar collectors (water- and space- heating). This would satisfy annually around 8.9 EJ of energy demand for hot water and space heating in the building sector by 2050, 25 times today’s level. This estimate is based on the IEA Energy Technology Perspectives (ETP) 2 DS scenario that assumes a high growth in the adoption of renewable energy technologies that has previously not been experienced. This implies that for such a deployment to come into being, favorable renewable energy policies, such as those implemented in Cyprus, Barbados, and Israel, need to be adopted in countries in order that solar thermal water systems become affordable.

The IEA ETP 2 DS scenario also projects an optimistic scenario for the growth of the total demand of hot water (solar and non-solar) of ~25 EJ. As a comparison to the IEA projection, studies by IPCC author Diana Ürge-Vorsatz forecasts the total REF scenario energy for hot water (solar and non-solar) in 2050 will be 33 EJ (Ürge-Vorsatz et al., 2015). There are a range of assumptions that go into the building of this optimistic scenario. There is a dearth of projections of domestic solar hot water into the future. The IEA ETP 2DS is the only one found to provide estimates until 2050. A 32% increase in production of renewable heat globally is required between 2014 and 2025, to achieve the 2DS goals (International Energy Agency, 2017b), including other heating technologies such as biomass, and heat pumps.

## Advantages and Disadvantages of Solar Hot Water

### Similar Solutions

There are a variety of water heaters available in the market aside from solar water heaters that are oil, gas (natural gas or propane) or electric based. One of the most common type of water heaters are the storage tank water heaters. These heaters can be electric, or gas or oil fired. Water that flows into the storage tank is heated via a thermostat-controlled burner or electric element. Hot water is stored and available in this tank. The water entering the tank to replace the used water is again heated to maintain the temperature (Natural Resources Canada, 2012). These tanks are available at different efficiency levels with higher levels of insulation.

Tankless on demand water heaters do not have storage tanks and heat water when needed. They typically have an electric or a gas burner element. The electric version of these heaters is not typically the main water heater. These heaters are used more in “point of use” installations wherein they supply hot water where the demand is very low example cottage or for only one specific use in the house and are typically installed for areas of a house where there is hot water need but the location is away from the main water heater. The gas version of these heaters however has the capacity to fulfill the water heating demands of an entire house. The amount of hot water supplied per minute however, changes with the temperature of water that needs heating. The rate of supply per min therefore is lower in the winter. These systems have a pilot light (uses energy even when no hot water is needed) or electronic ignition system. They are an option that can be used as a supplemental technology with solar water heaters.

Combination space and water heating systems in these systems the water heater is used for space heating as well, generally where the space heating demand is low. Some of these systems use a hydronic boiler. The heated water from the boiler is pumped via pipes either in baseboards located around the outer perimeter of the home or through in-floor radiant systems (special piping embedded in the floor) (Weil-McLain Canada, 2018).

Heat pumps do not generate heat instead they move it from one place to another using electricity. Heat pump water heaters typically remove heat and humidity from the air. They are less advantageous in winter when space heating is required. They are considered to be cost effective in milder climates despite their higher initial costs compared to electric storage tanks. Other types of heat pumps include, ground source heat pumps that use energy from the earth or from ground water and, heat pump water heaters that are powered by solar energy. A heat pump water heater needs only a third of the PV modules to generate electricity compared to a resistive electric tank. Heat pump water heaters generally use electricity from grid. They can help to balance the grid by lower the peak load when used with thermal storage. In 2016, water heating heat pumps supplied 10% of Japan’s household water heating market.

Electric resistance (electric powered) storage water heaters are also very common however, they are the most inefficient types of electric water heaters (Maguire, Fang, & Wilson, 2013). They generally consist of a glass-lined steel tank, with two heating elements that cycle through the water when the water temperature drops. Similar to heat pump water heaters, the electric resistance is an expensive technology. High electricity costs add to the operational expenses of this technology.

### Arguments for Adoption

The advantages of solar water heaters technology are obvious. It is a clean, renewable technology compared to conventional water heaters. Like other renewable sources, one major benefit of solar energy is that fuel is free-the sun shines every day at no cost. In other words, the operating costs of a solar thermal system are minimal. Additionally, the total solar resource potential is practically inexhaustible. This is evident from a simple calculation. If average insolation is 1000 W/m2 and the area of radiation circumscribed by the Earth is 1.28 x1014 m2 (the area of a circle with the Earth’s radius), then our planet is constantly receiving 1.28 x 1017 W (1.28 x 105 TW) of power from the sun. Assuming that energy demands in 2050 will rise as high as 30 TW (more than twice today’s final energy consumption), this usage is only a small fraction (~0.02%) of the total available solar energy. Even with losses due to conversion efficiency (~0.02%) of the available solar energy and land area unavailable for solar harvesting, it is still an overwhelming generous source of energy. This unexhaustive resource can be helpful in satisfying the rising demand for energy as a result of rising population. While solar energy availability is abundant in warmer climate areas, modern solar water heaters are able to produce energy even when the temperature outside is well below freezing (Natural Resources Canada, 2003), which is a very beneficial attribute of the solar water heating systems in reducing emissions from colder regions of the world where the water heating demands are comparatively higher.

### Additional Benefits and Burdens

Solar water heaters may have high maintenance costs (Girardeau, 2017) depending on the type of the heater adopted. Maintenance costs could come from need for anti-freeze liquid, pump maintenance from models that depend on pumps. For countries with a growing housing stock, these systems could be a key to meeting the demand for hot water. Larger adoption of solar water heater would help in jobs creation.

Different water heating technologies can be compared across various factors such as efficiency, cost, etc.

Table 1.3 lists technologies compared based on efficiency, initial cost, operating costs, comfort of continuous hot water, information from NREL (Maguire et al., 2013) and overheating information from Ecohome (Reynolds, 2018). Source efficiency and onsite efficiency levels of all technologies are different. Only onsite efficiency is compared in the Table 1.3*.* While initial costs are high for the most efficient technologies, retrofit installation costs remain the same as new installation costs for the solar thermal collectors. The comfort of readily available hot water is not available in all heating systems. Also, in colder regions where anti-freeze material is used in the winters, hot summer months can attract a lot of heat and cause overheating if necessary precautions are not taken.

Table 1.3 Technology comparison

| **Technology name** | **Efficiency (site energy consumption based)** | **Initial Cost** | **Operational costs** | **Ready availability of hot water** | **Usage as a back-up heater** |
| --- | --- | --- | --- | --- | --- |
| Storage Tank Water Heaters | Medium (electric) | Low (electric) | -- | High | -- |
| Tankless On-Demand Water Heater - Electric | Winter efficiency (Medium) | -- | -- | Low | High |
| Tankless On-Demand Water Heater - Gas | High,  Medium (in winters) | High  (condensing type) | -- | Medium (gas based) | -- |
| Combination Space And Water Heating Systems | -- | -- | -- | High | -- |
| Electric Resistance | Low | High | High | -- | -- |
| Heat Pumps | High,  Medium (in winters) | High (in milder climates) | -- | High | -- |
| Solution - Solar Water Heater | High | High | Low | High | High |

# Methodology

## Introduction

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 (RRS) 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[[3]](#footnote-3)) is what constituted the results.

The model for this analysis constructs three high growth Project Drawdown Scenarios (PDS) and a Reference (REF) global adoption pathway for domestic roof-top solar water heating systems. It is assumed therefore that the model perspective is that of a home-owner. First is forecasted a global and regional total addressable market (TAM) which is defined as the functional demand for water heating globally (in TWh). Then the REF scenario is created by assuming future adoption of roof-top solar water heating remains fixed at the current base year percentage of TAM, which in this model is set as 6.51% based on the projection from IEA’s Energy Technology Perspectives for 2016 and 2018. Next PDS scenarios are developed, drawing on existing adoption scenarios for domestic solar thermal systems.

The model contains both financial and climate analyses in order to model the global and regional impacts of adoption in the PDS scenario compared to the REF scenario. What the model prognosticates is the total financial cost and benefits of each PDS case for solar water heating systems for domestic purposes, as well as the contribution this adoption can make to annual and cumulative emissions reductions. The financial cost is based on the solar thermal implementation units installed (in TW) with average annual and lifetime use rates collected from the literature.

## Data Sources

Data inputs for the model came from a variety of sources, primarily from peer reviewed publications and from agency reports. For most variable inputs, a meta-analysis of existing data points in the literature is used to create low, mean, and high estimates. The model conducts a sensitivity analysis of, on average, five data points from the literature and in some cases as many as 20. The quantity of data allows calculation of robust and reliable inputs for the analyses that range from conservative to optimistic estimates for the costs and benefits of adoption.

The current adoption data for this solution was obtained from IEA 2016 and 2018 sources (Mauthner, Weiss, & Spörk-Dür, 2016; Weiss & Spörk-Dür, 2018) providing adoption for 2014 and 2016. In order to project the growth of global water heating demand (in TWh (th)), the model relies on existing estimates from IEA’s Energy Technology Perspectives for 2016 and 2017 (IEA, 2016; International Energy Agency, 2017) and from the Global Buildings Performance Network (Urge-Vorsatz et al., 2015). These data sources are also used to project the regional Total Addressable Market (TAM) for water heating, creating estimates for OECD90, Asia (sans Japan), Middle East & Africa, Latin America, and Eastern Europe, European Union and for specific countries with relatively higher use of solar hot water heaters, such as China, India, and the US.

In this model, it was assumed that solar thermal heaters will not be a stand-alone technology for heating water. Such heaters are also referred to as pre-heat systems (Natural Resources Canada, 2003) . This implies that there will still be a need for conventional water heating technology in the REF as well as the PDS scenarios. Therefore, some data pertaining to conventional technology including first cost, life time capacity, average annual use, conventional fixed operating costs, and direct emissions, were not collected as they were assumed to be replicated in all scenarios and therefore cancelled in the final results.

First cost data for the installation cost (to consumer) of domestic solar water heating systems for residential buildings were not commonly reported in peer-reviewed literature. This data was collected from three agency reports including, IEA (International Energy Agency, 2012), Distributed Generation Renewable Energy Estimates of Costs (National Renewable Energy Laboratories, 2016), and Renewables 2015 (REN21, 2015). The variable operational cost is the operational cost for heating water and was collected from IEA’s heating without global warming report (Anselm Eisentraut & Adam Brown, 2014), and NREL (Cassard, Denholm, & Ong, 2011). Most of the data was available at the regional level.

Data for the lifetime capacity of the solution (i.e. the life time of the solar water heaters) was taken from a few different sources including, International Renewable Energy Agency (IEA-ETSAP and IRENA, 2015), Environment California (Environment California, 2007), Manitoba Hydro (Manitoba Hydro, n.d.), NREL (National Renewable Energy Laboratories, 2016), Energy Star (Energy Star, n.d.) and World Building Design Guide (WBDG) (World Building Design Guide, 2016). Average annual use (i.e. hours of use of the solution) was taken from IEA’s Solar Heat Worldwide market reports of 2016 and 2018 (Mauthner et al., 2016; Weiss & Spörk-Dür, 2018).

Regional data for average electricity consumed per functional unit was obtained from Natural Resources Canada and assumptions were made to estimate global data. Global data for fuel efficiency factor for solution was obtained for U.S (Denholm, 2007) and Brazil (Michels, Mayer, Gallon, Hoffmann, & Serafini, 2008). Since solar water heaters are a supplemental technology, they will only be saving a fraction of the energy conventionally used for heating. Assumptions were made to estimate the global fuel consumed per functional unit number for conventional water heaters. Electricity consumed per functional unit for conventional technology was also estimated using assumptions for global electricity consumption due to lack of data.

Conventional fuel hot water efficiency data was taken from the U.S.DOE (U.S. Department of Energy, n.d.) & JRC reports, and published literature presenting data from UK (Greening & Azapagic, 2014) and California (Raghavan, Wei, & Kammen, 2017) . The global data for electricity and natural gas’s share of conventional water heating were obtained from IEA (Anselm Eisentraut & Adam Brown, 2014). Regional data was obtained from Natural Resources Canada (Natural Resource Canada, 2018; Natural Resources Canada, 2017) and Brazil (Matos, Briga-Sa, Bentes, Faria, & Pereira, 2017). The conversion factor for collector area to solar thermal capacity was obtained from IEA.

## Total Addressable Market

The Total Addressable Market (TAM) for Solar hot water depends on the total domestic hot water demand. The SHW model uses data from Energy Technology Perspectives (2016 and 2017 versions), Ürge-Vorsatz (2015) and GBPN (“Tool for Building Energy Performance Scenarios | Global Buildings Performance Network,” 2015). A sensitivity analysis of these sources allows the selection of a trend line and rate of TAM growth through 2060. A 3rd degree polynomial curve was used to project future hot water demand. Water heating energy use per square meter data from Ürge-Vorsatz (2015) and areas were derived from GBPN and IEA, in 2 different scenarios to calculate the different TAM datasets. A total of 8 projections were derived from these sources for different scenarios. For the most climate-aggressive cases, the final energy water heating demand actually declines in later years representing high efficiency technology adoption broadly.

## 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 adoption of the solution. Each published result shows the comparison of one PDS to the REF, and therefore focuses on the change to the world relative to a baseline. IEA’s Energy Technology perspectives (2012) (IEA, 2012) provide the best estimates for future growth of DSHWS. There is a lack of additional global data for growth of solar water heaters through 2060. Since the solution is modeled as a supplementary technology, but the solution variables apply to a unit of solar water heating only (rather than a combination of SWH and a conventional technology), adoption here represents only the fraction of total water heating that is captured by SWH (which can only be a fraction of a single home’s heating demand considering the supplementary status of the technology. Adoption by definition therefore can never reach 100%.

### Reference Case / Current Adoption

This model defines the REF adoption scenario as a fixed percentage of TAM over the modeling period, using the percentage of adoption in the current-year (2018) as the fixed percentage of TAM projecting forward.

### 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. There is a lack of data availability on projections of roof-top solar water heating systems for the PDS adoption scenarios. Multiple scenarios were developed and tested and the most appropriate ones were selected for the PDS scenarios as described below. For each scenario, a second degree polynomial was used.

#### Plausible Scenario

The Plausible scenario compares baseline TAM cases to custom PDS low growth adoption projection that assumes 15% of 2050 baseline TAM cases by 2050. This scenario is a low growth scenario, so it is projected to reach 50% of the final percent adoption by 2030.

#### Drawdown Scenario

This scenario compares conservative TAM projections with conservative custom PDS adoption conservative projection (late growth) assuming an adoption of 30% of TAM in 2050. This scenario is a late growth scenario. It assumes that 45% of its targeted adoption will be reached by 2030. This scenario (late growth projection) was chosen over an early growth conservative adoption projection considering the recent declines in adoption of SWH in the high adoption regions.

#### Optimum Scenario

This scenario compares the average of all baseline TAM projections with an aggressive high growth custom PDS adoption projection assuming to reach 50% of TAM in 2050. It also assumes that 70% of the targeted adoption will be reached by 2030.

## Inputs

### Climate Inputs

Total emissions reduction is a linear sum of the emissions reduction from each modelled source: grid, fuel, and indirect sources. Grid and fuel emissions come from emissions factors applied to the avoided consumption of electricity and fuel (energy consumption variables are listed in the Technical Inputs Section). Emissions factors for electricity generation are derived from the projected energy generation mix from three AMPERE RefPol scenarios in IPCC AR5 model Database (GEM3, IMAGE, MESSAGE) and the IEA’s ETP 6DS scenario, and direct/indirect emissions factors by generation type taken from the IPCC AR5 Model Database, AMPERE3-MESSAGE Base scenario. The reader should note that since this combined reference projection includes a shift away from coal and oil to natural gas, the emissions factors decline over the analysis period. Fuel emissions factors are calculated using the methodology recommended in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Annex 1. The values used are shown in Table 2.1.

Data on indirect emissions was obtained for both conventional and solar water heaters.

#### Updating of Grid Emissions Factors

As electricity sector Drawdown solutions are adopted, the grid becomes cleaner, and the high emissions factor shown in Table 2.1 will decline. This is not calculated directly in the model as is considered an integration issue. This is dealt with in the Integration section of this report.

Table 2.1 Climate Inputs

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Variable** | **Unit** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| Global average REF Grid Emissions Factor | g CO2e/ kWh | 503-593 | Depends on year. Starts at High Input in 2020 declines to Low Input in 2050 | 12 each year | 4 |
| Combined REF Water Heating Fuel Emissions Factor | t CO2e/TJ of fuel | 88.6 | 88.6 | 6 including individual fuel emissions factors and shares | 1 |
| Indirect CO2 emissions (solution) | t CO2-eq/ TWh(th) | 10,200-11,700 | 10,950 | 2 | 1 |
| Indirect CO2 emissions (conventional) | t CO2-eq/ TWh(th) | 7,880-28,647 | 18,263 | 4 | 1 |

Sources: Generation mixes from the AMPERE/MESSAGE WG3 BAU scenario, direct and indirect emission factors by fuel from the IPCC WG3 Annex III Table A.III.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.

### Financial Inputs

#### First Cost for Solution

To calculate operating costs from residential hot water consumption in both the PDS and the REF scenarios, the model uses a range of simulated energy savings estimates. In the optimistic adoption scenario for solar water heaters it is assumed that the size of electric and gas boilers will be the same as in the REF scenario. This is because these boilers will have to cater to peak load in the chance that hot water is needed when the sun is not shining. However, the increase in deployment of solar water heaters will supply more heat where possible. This is why the conventional first cost in the methodology was assumed to be 0.

Recent capital cost estimates from several data sources: IEA Solar Heating and Cooling, REN21, presenting data for all regions contained in the analysis were used to determine the average capital cost of roof-top solar water heating systems. Installation cost ranges from approximately USD 100/kW (th) to USD 2,400/kW (th) (IEA, 2012) for different regions.

#### Learning Rate for Solution

A learning rate for solar water heaters has not been identified in the literature. Solar PV has been studied in greater volume and its learning rate has been estimated at 72%. Unlike Solar PV however, solar water heating has not received as much innovation and hence is unlikely to have such an impressive learning rate. Therefore, a more conservative learning rate of 95% was used for solar water heating. On availability of better data learning rate is expected to improve.

#### First Costs for Conventional

As solar hot water systems often require supplemental technology (conventional heating), and cannot completely replace conventional heating, a first cost for conventional systems is not applied as an assumption: those systems are both in REF and PDS scenarios and so there is no difference between scenarios at the least when installation costs are considered. Capital costs can vary significantly by region, but exhaustive regional data were not available to calculate an average cost weighted by installation size.

#### Operations and Maintenance Costs

Because solar hot water systems need supplemental technology (conventional) as mentioned above, again only the solar hot water equipment maintenance costs that are additional above the REF scenario are accounted for. It is assumed conventional systems are in both scenarios and require operational costs.

Energy savings also factor into operational costs, in the avoided fossil fuel costs allowed by solar thermal energy between REF and PDS scenarios. In order to calculate energy savings, the following methodology was used. The efficiency of water heaters (conventional and solution) accounted for fuel consumption and conversion losses. The efficiency of conventional electric heaters is assumed to be 0.9 (i.e. out of the 1 kWh of energy consumed from electricity, 0.9 kWh is converted to useful heat), and likewise that of gas heaters are 0.67 (Greening & Azapagic, 2014; U.S. Department of Energy, n.d.). Solar water heaters save both fuel and electricity and these are priced by multiplying by the weighted average price of USD 0.072/kWh for electricity and fuel used for conventional water heating.

Table 2.2 Financial Inputs for Conventional Technologies

| **Variable** | **Unit** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Installation Cost/ First Cost | US$2014/ kW(th) | 0 | 0 | N/A | N/A |
| Operating Fuel Cost for Water Heating (electricity and fuel weighted appropriately) | US$2014/ kWh(th) | 0.0719 | 0.0719 | 1 | 1 |
| Discount Rate for Future Cash flows | percent | 3%-5% | 4% | 6 | 5 |

Table 2.3 Financial Inputs for Solution Technologies

| **Variable** | **Unit** | **Project Drawdown Data Set Range** | **Model Input** | **Data Points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Installation Cost/ First Cost | US$2014/ kW(th) | 380-2020 | 1,199.89 | 41 | 3 |
| First Cost Learning Rate (Efficiency Rate) | percent | 95%  (5%) | 95%  (5%) | 10 | 1 |
| Variable Operating Cost | US$2014/ kWh (th) | 0.004-0.157 | 0.074 | 8 | 2 |
| Discount Rate for Future Cash flows | percent | 3%-5% | 4% | 6 | 5 |

### Technical Inputs

Besides strictly climate and financial inputs, several general variables were used in the analysis which had important impacts on both the climate and financial results. These are described hereunder.

#### Energy Consumption and Efficiency Variables

The model inputs for energy and fuel efficiency factors are essential for calculating the reductions in energy use for water heating in buildings using solar water heating systems. Efficiency factors listed in Table 2.4 were adopted from peer reviewed publications and research reports.

Table 2.4 Key Technical Inputs for Energy Consumption and Efficiency

| **Variable** | **Unit** | **Project Drawdown Data Set Range** | **Model Input** | **Data-points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Electricity Consumed (Conventional) | TWh(e)/ TWh(th) | 0.258 | 0.258 | 1 | 1 |
| Electrical Consumed (Solution) | TWh(e)/ TWh(th) | 0.036-0.036 | 0.036 | 1 | 1 |
| Fuel Consumed (Conventional) | TJ/ TWh(th) | 4,515 | 4,515 | 1 | 1 |
| Fuel Efficiency Factor (Solution) | percent | 100% | 100% | N/A | N/A |

#### Lifetime variables

A range of life-time assumptions were obtained for the technology from literature (IEA-SHC, 2012.). Typically, collectors last more than 20 years. Chinese solar thermal systems tend to have life times of only 10 years, while other systems can have lifetimes ranging to 30 years. These values (see Table 2.5) are used to calculate the inputs to the model (the reader should keep in mind that the average annual use and lifetime inputs are in *functional units per installed implementation unit*, which is in TWh (th)/ TW. The lifetime was mainly used as an indicator of when replacement units needed to be purchased, and as the conventional technology was not costed in the analysis (assumed to be needed alongside the solution), a nominal lifetime of 1 was entered (as both a lifetime capacity of 1 TWh (th)/TW and an annual average use of 1 TWh (th) /TW/yr.

Table 2.5 Key Technical Inputs for Usage and Lifetime

| **Variable** | **Unit** | **Project Drawdown Data Set Range** | **Model Input** | **Data-points (#)** | **Sources (#)** |
| --- | --- | --- | --- | --- | --- |
| Lifetime Capacity of technology | TWh(th)/TW = h | 8,068-26,484 | 17,275.64 | 11 | 7 |
| Average Annual Use of technology | TWh(th)/TW/yr = h/yr | 691-1,084 | 888 | 18 | 2 |

## 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.

1. There is a lack of data that projects the growth of domestic solar water heating systems. This methodology therefore interpolates existing adoption data of solar water thermal systems for all of the adoption scenario projections. Different growth rates for adoption are assumed.
2. It was assumed that electric heaters have efficiencies of 90% on average, while gas heaters have an efficiency of 67%, as this proved to be the case for commercial models examined. A more in-depth analysis needs to be done for each region.
3. Solar water heaters will need supplemental technology i.e. conventional water heaters. Given their distributed nature, it was posited that this technology will not be responsible for the replacing of conventional electric and gas boilers. This assumption will need to be refined as regional data becomes available. As a result of this assumption, In the PDS case it was assumed that the size of electric and gas boilers deployed will be the same as in the REF case as the sizes of these boilers will still have to cater to peak demand when the sun is not shining, and the solar water heaters do not work

## 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.

Each solution in the Buildings and Cities Sector was modeled individually, and then integration was performed to ensure consistency across the sector and with the other sectors. These solutions require an integration analysis to avoid double counting, as they primarily relate to either reducing demand for space heating and cooling (for residential and/or commercial buildings), commercial lighting, cooking, or water heating. The integration process therefore was addressed through sequential adjustments to the efficiencies of the solutions in a prioritized sequence for each of space heating and cooling, lighting, cooking, and water heating (performed in four separate sequence chains). The prioritized sequence is fixed for all scenarios and is described in the Drawdown Building Sector Integration documentation.

For each solution in an integration sequence, the estimated impact of previous solutions on the emissions savings of the current solution is estimated and a reduction factor is applied. The factor is only applied to emissions and energy savings attributed to adoptions that overlap with previous solutions[[4]](#footnote-4), and for this adoptions are generally assumed independent. Solutions that start each integration sequence are therefore unaffected (unless they are affected by solutions in other sequences), and solutions that apply to different buildings (say commercial and residential) do not affect each other. The method of estimating overlap is based on the percent adoption of the higher priority solution applied to the area adopted in the lower priority solution. For the efficiency factor of this overlapping area only, the reduction factor is applied, it is scaled and used to update the results in the lower priority solution model.

The Solar Hot Water solution (of the water heating sequence) is assumed to interact with the only other solution in the sequence, that is, only Water Saving at Home (although it’s considered a Materials solution). The adoptions of these solutions are converted to reductions in water heating delivered/useful energy in any single year, but no major integration effects are taken into account other than to ensure that the total reduced water heating energy doesn’t exceed the total water heating demand.

In addition to building sector integration, there was an integration process across the grid and electricity efficiency solutions (buildings, transport, materials etc.) which adjusted for the double counting. Double counting of emissions reduction was a factor of using the reference grid emissions factors for electricity-based solutions. As grid solutions (Utility-scale Solar PV and others) are adopted, the grid gets cleaner and the impact of efficiency solutions is reduced (where they reduce electricity demand) or increased (where they increase electricity demand[[5]](#footnote-5)). Grid solutions are adjusted to remove the double counting as described in the Project Drawdown integration documentation.

## Limitations/Further Development

This report documents the modeling of the adoption of solar water heaters globally and the calculation of the climate and financial benefits of this adoption. In making such estimates some required assumptions were made (see Section 2.6). There are only a few sources from where market data is available for solar water heating. Therefore, the projections are dependent on these sources and their estimates. Adoption potential estimates found were even fewer.

SHWS have proven their value over decades of use in countries like Israel and Cyprus where the use of solar water heaters is mandated for heating water. However, this adoption of SHWS depends on several factors. An adoption of 40-60% has been reported in other regions of the world. Due to varying performance, adoption and markets of water heating would be better represented at regional levels to understand the local factors that can improve the overall adoption of this technology. A regional level modeling could incorporate climate appropriate solutions combinations for water heating since solar thermal based heating may not be the ideal solution in emissions reduction in all regions.

There is a need to identify other data sources for the regions in future iterations of this process. Since solar water heaters are not commonly adopted as a sole water heating technology, there is not much impact data on solar water heaters alone. There is data available on impacts of such combination systems, but this cannot be added on to the model, because of inclusion of conventional technology impacts in the solution.

Many factors need to be taken into account in estimating the potential of solar water heaters, including availability of roof area, angle of the collectors, regional irradiance, volume of hot water required per household or per person in case of a building etc., that have not been considered in the methodology. These factors can improve the adoption potential estimation.

### TAM and Adoption

The data inputs used to project future growth in total global water heating demand are from two reputable sources, however, there is a large difference in projections of reference scenarios, where no policies are implemented. These differences are a result of different assumptions and limitations of the sources used. The TAM is based on some of the key primary data that are used by groups such as the IEA and GBPN, which include population, urbanization, and growth rates, among other factors. There were limited data sources to determine the current adoption of solar hot water. There is need for more recent data for estimation of future adoption estimates.

### Climate and Financial Analyses

More data sources are required for estimating indirect CO2 direct emissions. Currently this data is based only on 2 peer reviewed sources for regional data. Similarly, more data sources are needed to estimate the fuel efficiency factors, fuel consumed per functional unit and total energy used per functional unit, electricity consumed per functional unit as well as energy efficiency factors. All these variables have limited data.

# 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 3.1 World Adoption of the Solution

| **Solution** | **Units** | **Current Year (2018)** | **World Adoption by 2050** | | |
| --- | --- | --- | --- | --- | --- |
| **Plausible** | **Drawdown** | **Optimum** |
| Rooftop Solar Hot Water | TWh (th) | 394 | 822 | 1947 | 2,642 |
| % market | 8.1% | 15.0% | 30.0% | 50% |

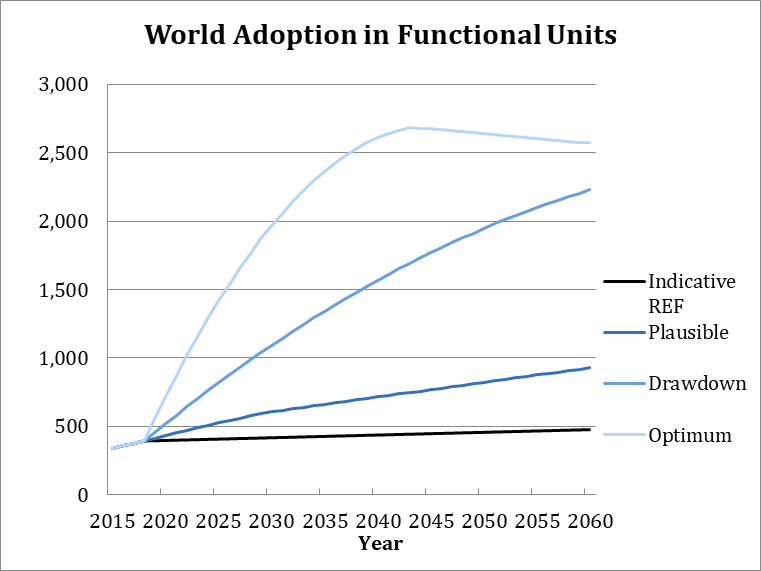


Figure 3.1 World Annual Adoption 2020-2050

## 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.

Table 3.2 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 (2020-2050)** | **(Gt CO2-eq/year)** | **(Gt CO2-eq/year)** |
| Plausible | 0.19 | 3.64 | 0.10 | 0.19 |
| Drawdown | 0.77 | 14.29 | 0.36 | 0.77 |
| Optimum | 1.17 | 27.58 | 0.82 | 1.13 |

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

Table 3.3 Impacts on Atmospheric Concentrations of CO2-eq

| **Scenario** | **GHG Concentration Change in 2050** | **GHG Concentration Rate of Change in 2050** |
| --- | --- | --- |
| **PPM CO2-eq (2050)** | **PPM CO2-eq change from 2049-2050** |
| Plausible | 0.30 | 0.01 |
| Drawdown | 1.19 | 0.06 |
| Optimum | 2.24 | 0.08 |

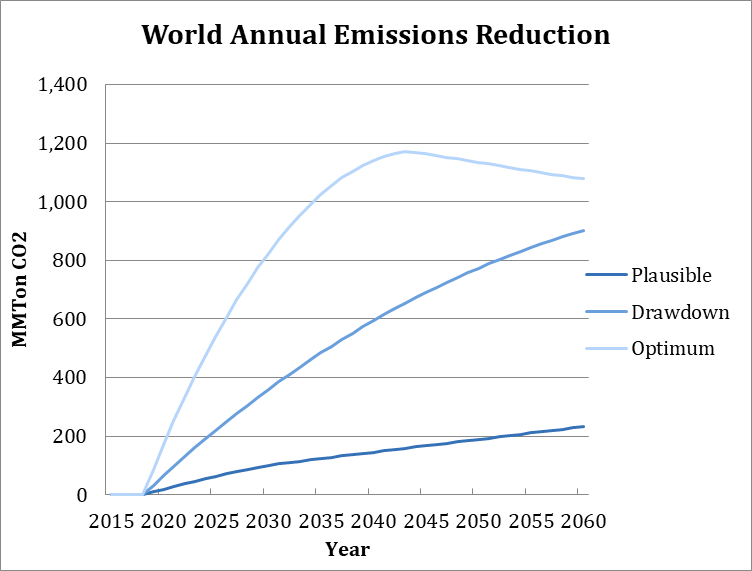


Figure 3.2 World AnnualGreenhouse Gas Emissions Reduction

## Financial Impacts

Table 3.4 shows the financial results of the analysis for each scenario. For a detailed explanation of each result, please see the glossary.

Table 3.4 Financial Impacts

| **Scenario** | **Cumulative First Cost** | **Marginal First Cost** | **Net Operating Savings** | **Lifetime Cashflow Savings NPV (of All Implementation Units)** |
| --- | --- | --- | --- | --- |
| **2015-2050 Billion USD** | **2015-2050 Billion USD** | **2020-2050 Billion USD** | **Billion USD** |
| Plausible | 1,049.61 | 717.39 | -14.58 | -334.22 |
| Drawdown | 3,006.82 | 2,674.60 | -57.30 | -1,238.58 |
| Optimum | 4,875.82 | 4,543.60 | -110.26 | -2,296.86 |

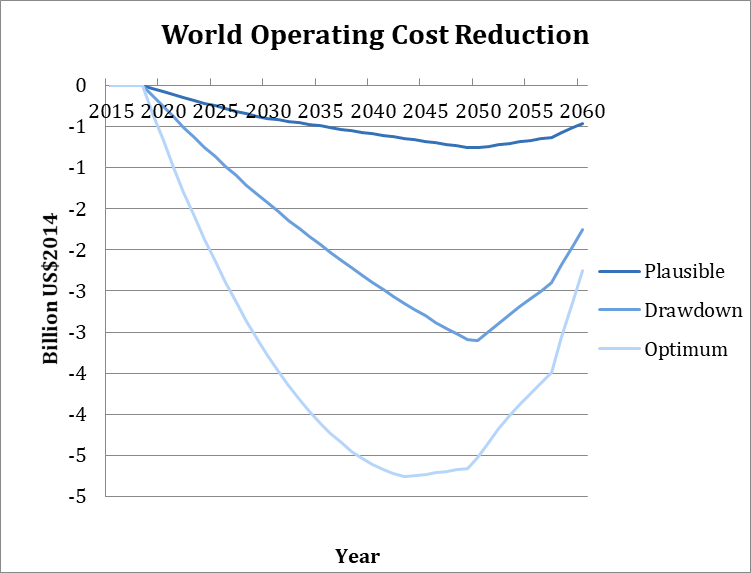


Figure 3.3 Net Profit Margin /Operating Costs Over Time

## Other Impacts

When a broad range of impacts are considered, solar water heaters have higher impacts (60%) from the manufacturing stage. When only global warming is considered, the manufacturing impacts are 30%. The manufacturing impacts are highest (about 90%) for the indicators of ecotoxicity potential (ETP) and human toxicity potential (HTP) (Greening & Azapagic, 2014). These other impacts however, have not been included in the drawdown model. The high impacts in other environmental indicators are in low irradiance regions such as the UK, higher than the impact from conventional technologies such as boilers, making boilers the preferred choice when a broad range of impact indicators area considered.

# Discussion

Solar hot water systems are an old technology. However, growth in their adoption is limited, and based on the most recent reports, declining. Their adoption has gained popularity both in rural and urban areas due to their potential to reduce energy bills. They have a high potential of reducing operational emissions for water heating but are limited in their adoption rate. Policies and incentives in support of adoption of this technology could be key drivers in its adoption. The lack of data of projections of adoptions of roof-top solar water heating hindered this analysis. The latest global projections available are from IEA’s technology roadmap published in 2012. Projections for the future were available for the IEA ETP 2 DS scenario. For the global adoption projections, another scenario was also devised by interpolating the adoption of solar thermal heaters from 2005 to 2014, and extrapolating to 2050.

The current adoption is dominated by China. Although not comparative by far, the high adoption of China is followed by adoption in EU, India, and United States, making them important regions and countries to study for solar water heating systems. Areas with highest solar heat availability are expected to increase adoption in future. However, the need for hot water is highest in areas where sunlight may not be as abundant, thus requiring the need for combined or alternative water heating solutions. Availability of better data can enable this analysis.

It should be noted that, the cumulative first cost of adoption of roof-top solar water heating is quite high using these adoption scenarios. Installation cost is the biggest barrier in implementation of SHWS. As the initial cost of these systems reduces, an improvement in adoption can be expected. However, it is to be noted that the lifetime cashflow NPV is negative in all scenarios. This is because of the assumptions of this scenario where the conventional technology would be required as back up to solar thermal heaters and that solar water heaters would not replace them. A conventional first cost of 0 is assumed, and energy savings don’t seem to be sufficient to payback the first cost. This is a scenario that makes sense on a global scale. However, this assumption needs to be interrogated in each region. Indeed, a wide range of operating costs of this technology were included. For some regions, the operating costs are very low, and it would be interesting to see what a weighted operating cost calculation yields.

## Limitations

DSWHS can be a valuable technology in reducing the carbon footprint of domestic water heating, however, are limited in their adoption due to their high first cost. More recent adoption projections are required to better estimate the adoption of this technology over time. More data on potential fuel replacement or reduction using solar water heaters will help with better estimates of CO2 reduction, in addition to considering various regional factors that impact solar energy received and its demand. Lifetime cashflow savings may improve if fuel prices increase.

## Benchmarks

This report uses IEA ETP 2016 and 2017 data to estimate TAM projections. IEA ETP 2016 has 3 scenarios 6 Degree Scenario (6DS), 4 Degree Scenario (4DS) and 2 Degree Scenario (2DS). IEA ETP 2016 also has 3 scenarios World Reference Technology Scenario or 4 Degree Scenario (4DS) and 2 Degree Scenario (2DS) and Beyond 2 Degree Scenario (B2DS). Table 4.1 presents the total water heating demand estimated by each IEA scenario along with Drawdown SHW adoption. Adoption in Drawdown scenarios are generally lower as expected since the total hot water produced by solar water heaters is modeled to not exceed a certain threshold since it’s a supplementary technology with a backup provided by another source.

Table 4.2 compares emission reductions between reference technology and projected adoption scenarios. To get the ETP estimates, emission differences between the two published scenarios were interpolated for missing years and summed over the desired period. The reductions projected by ETP are lower compared to Drawdown PDS2 and PDS3 scenarios. This is partly due to the reference scenarios of Drawdown being more defined differently. Also the adoptions of those two scenarios are much more aggressive than Reductions from PDS 3 are closer to reductions from the B2DS scenario which is the most aggressive adoption scenario for emissions reduction.

Table 4.1 Benchmarks (Heat produced)

| **Source and Scenario** | **HEAT produced 2050 (TWh (th))** | **HEAT produced 2030 (TWh (th))** | **Market Share in 2050 (%)** |
| --- | --- | --- | --- |
| IEA ETP 2017 (RTS) | 6,025 | 5,945 | - |
| IEA ETP 2017 (2DS) | 5,571 | 5,785 | - |
| IEA ETP 2017 (B2DS) | 4,742 | 5,501 | - |
| Project Drawdown – Plausible Scenario (PDS1) | 822 | 608 | 15% |
| Project Drawdown – Drawdown Scenario (PDS2) | 1,947 | 1,093 | 30% |
| Project Drawdown – Optimum Scenario (PDS3) | 2,642 | 1,968 | 50% |

Table 4.2 Emissions Benchmarks

| **Source and Scenario** | **GHG reduced 2020-2050 (GT CO2)** |
| --- | --- |
| IEA ETP 2017 (RTS-B2DS) (interpolated from published data) | 8.86 |
| IEA ETP 2016 (6DS-2DS) (interpolated from published data) | 7.40 |
| Project Drawdown – Plausible Scenario (PDS1) | 3.64 |
| Project Drawdown – Drawdown Scenario (PDS2) | 14.29 |
| Project Drawdown – Optimum Scenario (PDS3) | 27.58 |

# References

Bessa, V. M. T., & Prado, R. T. A. (2015). Reduction of carbon dioxide emissions by solar water heating systems and passive technologies in social housing. *Energy Policy*, *83*, 138–150.

Butler, B., Merry, L., & Young, D. (n.d.). Solar Hot Water Heating. *American Solar Energy Society*. Retrieved from https://www.ases.org/resources/solar-home-basics/solar-hot-water-heating/

ClimateTechWiki, n.d. Solar Thermal Hot Water, <http://www.climatetechwiki.org/technology/solar-thermal-hot-water>

Gautam, A., Chamoli, S., Kumar, A., & Singh, S. (2017). A review on technical improvements, economic feasibility and world scenario of solar water heating system. *Renewable and Sustainable Energy Reviews*, *68*. https://doi.org/10.1016/j.rser.2016.09.104

Hamola, C. (n.d.). *Solar Domestic Hot Water Heating Systems Design, Installation and Maintenance*. ASSE International. Retrieved from http://www.asse-plumbing.org/chapters/NOH%20SolarWtrHtg%20Pres.pdf

Hoogwijk, M., Graus, W., 2008. Global Potential of Renewable Energy sources: A literature assessment. Ren 21- Renewable Energy Policy Network for the 21st Century, <https://www.ecofys.com/files/files/report_global_potential_of_renewable_energy_sources_a_literature_assessment.pdf>

International Energy Agency (IEA), (n.d.). Solar, <https://www.iea.org/topics/renewables/subtopics/solar/>, Accessed 11.14.16.

International Energy Agency (IEA), 2012. Technology Roadmap: Solar Heating and Cooling, <http://www.iea.org/publications/freepublications/publication/technology-roadmap-solar-heating-and-cooling.html>, Accessed 11.14.16.

International Energy Agency (IEA), 2014. SHC || Solar Heat Worldwide Markets and Contribution to the Energy Supply, URL <http://www.iea-shc.org/solar-heat-worldwide>, Accessed 11.14.16.

International Energy Agency (IEA), 2016. Energy Technology Perspectives, http://www.iea.org/etp/ Accessed 11.14.16.

International Energy Agency. (2017a). Energy Technology Perspectives 2017. Retrieved December 2, 2018, from https://www.iea.org/etp2017/summary/

International Energy Agency. (2017b). *Tracking Clean Energy Progress 2017* (Excerpt Informing Energy Sector Transformations). International Energy Agency (IEA). Retrieved from https://www.iea.org/publications/freepublications/publication/TrackingCleanEnergyProgress2017.pdf

International Renewable Energy Agency. (2015). Solar Heating and Cooling for Residential Applications. IEA-ETSAP and IRENA.

Maguire, J., Fang, X., & Wilson, E. (2013). *Comparison of Advanced Residential Water Heating Technologies in the United States* (Technical report No. NREL/TP-5500-55475). Retrieved from https://www.nrel.gov/docs/fy13osti/55475.pdf

Mordor Intelligence. (2018). Solar Water Heater Market - Segmented by End-user, Collector, and Geography - Growth, Trends, and Forecast (2018 - 2023).

Natural Resources Canada. (2012). Water Heater Guide. Retrieved from https://www.nrcan.gc.ca/sites/oee.nrcan.gc.ca/files/files/pdf/equipment/WaterHeaterGuide\_e.pdf

REN21. (2018). *Renewables 2018 Global Status Report* (A comprehensive annual overview of the state of renewable energy). REN21. Retrieved from http://www.ren21.net/wp-content/uploads/2018/06/17-8652\_GSR2018\_FullReport\_web\_final\_.pdf

Residential Guide to Solar Hot Water. (n.d.). Massachusetts Clean Energy Center. Retrieved from http://files.masscec.com/uploads/attachments/SolarHotWaterResidentialGuidebook.pdf

ReVision Energy. (n.d.). Solar-powered water heating [Business]. Retrieved from https://www.revisionenergy.com/solar-power-for-your-home/solar-powered-water-heating/

Reynolds, M. (2018). Solar Water Heater With Overheating Protection [Business]. Retrieved from https://www.ecohome.net/guides/3297/product-of-the-month-solar-water-heater-with-overheating-protection/

Richardson, D. (2013). *Solar Heat - Sustainable Future: Clean Energy Solutions for Canada*. Retrieved from https://www.cansia.ca/uploads/7/2/5/1/72513707/20140129\_cansia\_solar\_heat\_sustainable\_future.pdf

Solahart. (2018). Gas Boosted Solar [https://www.solahart.com.au/info-pages/gas-water-heater/gas-boosted-solar/]. Retrieved from https://www.solahart.com.au/info-pages/gas-water-heater/gas-boosted-solar/

UN Environment and International Energy Agency (2017): Towards a zero-emission, efficient, and resilient buildings and construction sector. Global Status Report 2017.

United Nations Environment Programme. (2015). Solar Water Heating A Strategic Planning Guide for Cities In Developing Countries. Retrieved from <http://www.estif.org/fileadmin/estif/content/publications/downloads/UNEP_2015/unep_report_cities_lr.pdf>

Ürge-Vorsatz, D., Cabeza, L.F., Serrano, S., Barreneche, C., Petrichenko, K., 2015. Heating and cooling energy trends and drivers in buildings. Renew. Sustain. Energy Rev. 41, 85–98. doi:10.1016/j.rser.2014.08.039

US Department of Energy (DOE), (n.d.). Furnaces and Boilers, <http://energy.gov/energysaver/furnaces-and-boilers>, Accessed 11.15.16.

US Department of Energy (DOE), (n.d.). Solar Water Heaters, <http://energy.gov/energysaver/solar-water-heaters>, Accessed 11.14.16.

US Department of Energy. (2016). Integrated Collector Storage [Government]. Retrieved from https://basc.pnnl.gov/resource-guides/integrated-collector-storage#quicktabs-guides=1

Weil-McLain Canada. (2018). HYDRONIC HEATING 101. Retrieved from http://weil-mclain.ca/support/product-support/hydronic-heating-101/

Weiss, W., & Spörk-Dür, M. (2018). *Solar Heat Worldwide| Global Market Development and Trends in 2017| Detailed Market Figures 2016* (Solar Heating and Cooling Program No. Edition 2018). Austria: International Energy Agency (IEA). Retrieved from <https://www.iea-shc.org/Data/Sites/1/publications/Solar-Heat-Worldwide-2018.pdf>

# 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. Global weighted averages are taken 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.

**Insolation** – This is a measure of the exposure to the sun’s rays, not to be confused with ins***u***lation

**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 experience 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* drop by 2% every time total production doubles. Note that this assumes that the figure is in the form as an “Efficiency Rate” which is typically close to 0. Many sources express the Learning Rate as a number close to 100%. So, it’s more likely that the Learning Rate is 98% and the Efficiency Rate us 2%. The model accepts input of Efficiency Rates.

**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

**TWh (Therm)/ TWh (th)** – 1 TWh of thermal (heating) energy

1. Current adoption is defined as the amount of functional demand supplied by the solution in the base year of study. This study uses 2014 as the base year due to the availability of global adoption data for all Project Drawdown solutions evaluated. The ‘current’ adoption in the model is therefore for the year 2014. [↑](#footnote-ref-1)
2. Insolation is a measure of the exposure to the sun’s rays, not to be confused with insulation [↑](#footnote-ref-2)
3. 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-3)
4. This can be interpreted as a single building with multiple efficiency technologies. [↑](#footnote-ref-4)
5. Some solutions such as Electric Vehicles and High-Speed Rail increase the demand for electricity and reduce the demand for fuel. [↑](#footnote-ref-5)