A SUSTAINABILITY ASSESSMENT
OF THE SOLARIZE PHILLY PROGRAM

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Abstract

Solar energy is known as a green and clean source of energy and programs such as the *Solarize Philly* promote its use so people can enjoy its benefits. However, one cannot overlook the fact that producing electricity via solar panels produces emissions at various stages along the life cycle. In this paper, a sustainability analysis of the *Solarize Philly* program was carried out with aims to quantify and depict the environmental and monetary costs and benefits of the program as a whole and to its individual customers. The analysis includes a Life Cycle Assessment (LCA) to estimate the environmental impact in terms of Carbon Dioxide equivalent (CO_2e) emissions produced per kWh of electricity generated. The analysis is further followed by a Cost Benefit Analysis (CBA) of five households that participated in the program representing a range of installation costs.

The LCA showed that the average life cycle emissions of a panel used in the program is 99.8 gCO_2e/kWh and can offset up to 395 gCO_2e/kWh of emissions coming from conventional grid electricity.

The CBA was conducted for five installations with system sizes ranging from 5kW to 8kW and installation prices ranging from $16,000 to $28,000. All these projects were observed to be cost – effective. The average Net Present Value (NPV) for all projects was $11,941and the average Discounted Payback Time (DPT) was 8.26 years which is well within the project duration of 25 years.

As of April 2020, *Solarize Philly* has enabled 654 homeowners in Philadelphia install solar on their rooftops with additional projects in the installation pipeline. This study quantifies the environmental impact that *Solarize Philly* participants have had over three phases of the program and highlights its benefits.

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1. Introduction

Energy influences our day-to-day lives in an inevitable manner. We are dependent on energy for lighting, heating, cooking, cleaning, transportation and more. The electric power sector is among the largest contributors of greenhouse gases in the United States, representing 28% of all emissions (SEIA, 2020). This means that our daily activities have a significant impact on climate change directly or indirectly.

If we switch our electricity source from carbon intensive fuels to cleaner and greener sources of renewable energy like solar, our carbon footprints will drastically decrease. The U.S. solar industry has reduced emissions equivalent to the amount of carbon stored in 1.3 billion trees (SEIA, 2020).

The City of Philadelphia is taking strides to achieve a carbon neutral future. The City aims to provide clean, efficient, resilient, affordable and equitable energy to all its residents. Two of the goals of the City's Clean Energy Vision are:

- Cut citywide carbon pollution 80 percent by 2050 from 2006 levels (Fig. 1) and
- Achieve a 100 percent carbon-free electricity grid by 2050

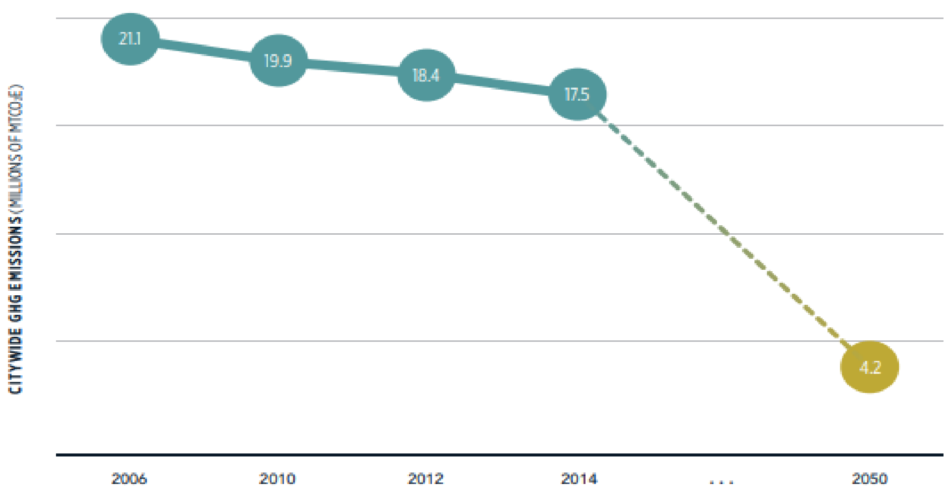

Figure 1. **Philadelphia's Carbon Trajectory**
Source: The City of Philadelphia Office of Sustainability. Powering Our Future: A Clean Energy Vision for Philadelphia. Retrieved from: https://www.phila.gov/media/20180821150658/Powering-Our-Future-Full-Report.pdf

In order to achieve this ambitious target, the city must add 15MW of solar each year and 80 percent of the Philadelphia rooftop space currently suitable for solar generation should have solar installations ("Powering Our Future," 2018).

1.1 Background

The *Solarize Philly* program administered by the Philadelphia Energy Authority (PEA) is one of many programs that is helping to power this transition. PEA is a government agency based in Philadelphia's City Hall that advises the City on energy affordability and sustainability. PEA's program, *Solarize Philly*, is a group buying program which encourages property owners in the city to go solar by providing a group buying discount. The program started in 2017 and has completed three phases as of January 2020.

The PEA partners with established solar installers based in the Philadelphia region that use equipment and modules from pre-vetted manufacturers to install solar panels on rooftops at discounted rates. To-date, 654 contracts have been signed amounting to 2.8 MW of solar electricity, and 89 new jobs have been created through the *Solarize Philly* program.

A product's life cycle spans above and beyond its 'Use' Phase. A product has environmental footprint from the extraction of raw materials to manufacture it up until its final disposal. A life cycle thinking approach takes a holistic view of the cradle to grave journey of a product by assessing the environmental impacts at every stage in order to measure and minimize its effect on the environment (Quantis, 2020).

Solar energy is widely touted as a carbon neutral source of energy, but it is not 100% clean, there are embedded Greenhouse Gas (GHG) emissions resulting from various activities along its lifecycle. However, these emissions are generally offset by a number of environmental benefits that result from the use of solar energy. In this study, the GHG emissions specific to solar electricity generated in the *Solarize Philly* program have been calculated to determine the exact amount of GHG emissions offset by the participants' reduced dependence on the electricity grid.

A life cycle approach helps identify life cycle stages that are major contributors to greenhouse gas emissions, in the verification of alleged climate benefits. This approach is also helpful in the analysis and development of options, policies, and innovations aimed at the mitigation of climate change (Reihnders, 2012). The Global Warming Potential (GWP) is the primary impact category analysed in this study. Global warming potential (GWP) is a reference measure of the kg or ton of carbon dioxide equivalent emissions of greenhouse gases (Ecochain, 2020) per functional unit-for example, 1kWh electricity produced by the solar panels in this study.

The GWP estimations in this study are expressed in terms of grams of carbon dioxide equivalents (gCO_2e) per kilowatt hour (kWh) which is a unit used to compare the emissions from different greenhouse gases to that of carbon dioxide. For example, the Life Cycle emissions from coal is 910 gCO_2e/kWh. (IPCC, 2013).

1.2 Problem Definition

This report is a Sustainability Assessment of the *Solarize Philly* program. The objectives of this study are to:

- Estimate life cycle global warming potential of the *Solarize Philly* Program for three different phases implemented from 2017 through 2019
- Estimate the payback time using a Cost – Benefit Analysis (CBA) method for households which participated in the program
- Assess the project densities across the three phases of the program using Geospatial Information System (GIS) method.

2.<u>Review of Literature</u>

This section presents a review of literature related to the life cycle stages of solar energy production, an overview of Solarize programs in the US and an overview of steps that *Solarize Philly* manufacturers are taking to reduce their carbon footprint.

2.1 Types of Solar panels

There are three main types of Solar panels available today, depicted in Fig. 2 and Table 1. These three types vary in how they are made, appearance, performance, costs, and the installations each are best suited for.

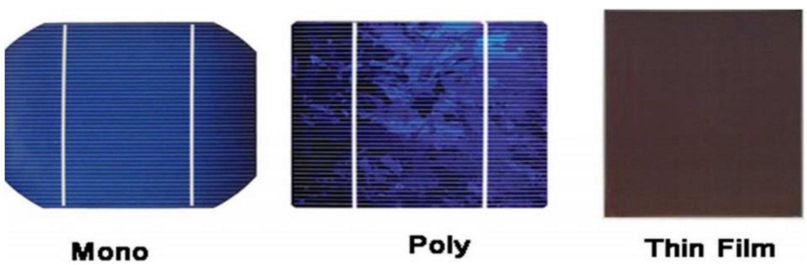

Figure 2. **Types of Solar panels** Askari Mohammad Bagher, Mirzaei Mahmoud Abadi Vahid, Mirhabibi Mohsen. Types of Solar Cells and Application. American Journal of Optics and Photonics, 3(5), 94. https://doi.org/10.11648/j.ajop.20150305.17

Table 1. Advantages and Disadvantages of Solar panel types

Solar panel type	Advantages	Disadvantages
Monocrystalline	• High efficiency/performance • Aesthetics	• Higher costs
Polycrystalline	• Low cost	• Lower efficiency/performance
Thin - film	• Portable and Flexible • Lightweight • Aesthetics	• Lowest efficiency/performance

Source: Energysage. (2020). Types of Solar Panels. Retrieved from: https://www.energysage.com/solar/101/types-solar-panels/

Monocrystalline silicon (Mono – Si) is one of the most important technological material of the last few decades - the "silicon era" – because it is available at an affordable cost and has been essential for the development of the electronic devices on which the present day electronic and informatic revolution is based (Bagher, 2015). All of the modules used in the *Solarize Philly* program are monocrystalline.

Monocrystalline silicon cells are made of a single continuous crystal lattice structure with almost no impurities. The main advantage of these cells is their relatively high efficiency, which is typically around 15%. However, they require a complicated manufacturing process to be produced and therefore have a higher cost (Bayod-Rújula, 2019).

Polycrystalline Silicon (Poly – Si) solar cells are the most common type of solar cells in the fast-growing PV market and consume most of the polysilicon produced worldwide. About 5 tons of polysilicon are required to manufacture 1 megawatt (MW) of conventional solar modules (Bagher, 2015).

Thin Film cells include Amorphous Silicon (A- Si), Cadmium Telluride (CdTe) and Copper Indium Gallium Selenide Solar Cells (CIGS) cells. They are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics or in small standalone power system.

A-Si is the most well-developed of the thin film technologies. It has been on the market for more than 15 years. It is widely used in pocket calculators, but it also powers some private homes, buildings, and remote facilities.

CdTe PV has the smallest carbon footprint, lowest water use and shortest energy payback time of all solar technologies. However, Cadmium is a heavy metal that's quite toxic and must be recycled efficiently at the end of its life.

CIGS panels are manufactured by depositing a thin layer of copper, indium, gallium and selenide on glass or plastic backing, along with electrodes on the front and back to collect current. CIGS has the advantage of being able to be deposited on flexible substrate materials, producing highly flexible, lightweight solar panels (Bagher, 2015).

2.2 Life Cycle Stages of solar energy production

All stages in the lifecycle influence economic and environmental aspects of a product or a process. In this study, four life cycle stages for solar energy production are presented and include manufacturing of solar panels, transportation of solar panels from factory to location, use phase and end of life management of the solar panels. This section discusses these stages in detail in the context of life cycle assessment.

2.2.1 Manufacturing of Solar Panels

All panels used in the *Solarize Philly* program are monocrystalline silicon panels. They are manufactured in different locations all over the world, but the method used to manufacture (Fig. 3) them is reasonably consistent at each location.

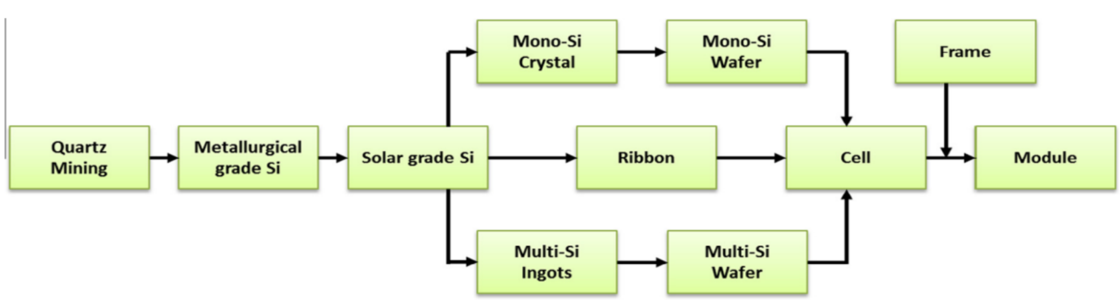

Figure 3. **System diagram for Solar Panel Manufacturing**
Source: Yue et.al. (2014). Domestic and overseas manufacturing scenarios of silicon-based photovoltaics: Life cycle energy and environmental comparative analysis. Retrieved from: https://doi.org/10.1016/j.solener.2014.04.008

The very first step in the monocrystalline silicon panels manufacturing process is extracting Silicon from sand. The Silicon is then refined to produce monocrystalline ingots, which are then sliced into wafers, fabricated into cells, and finally manufactured into completed panels (Woodhouse et al., 2017).

During the cutting processes of silicon, a large amount of material is wasted (40%–50%) as a large amount of it is cut off to get it into a rectangular shape (Bayod-Rújula, 2019).The wafers are refined by removing impurities. This is followed by steps which ensure enhanced sunlight conversion efficiencies and then cells are produced. The cells are electrically connected using metallic ribbons, mounted on a glass sheet, connected to a junction box which serves as the point of contact between the cells and finally encased within an aluminium frame to produce the ready panel (Woodhouse et al., 2017).

2.2.2 Use Phase (Solar Electricity Production Phase)

Solar cells are photovoltaics, which implies that they are devices that convert sun light into electricity. They work based on the principle of the photoelectric effect. Most solar cells are made up of semiconductors like Silicon. When a photon of light hits an atom of Silicon, it absorbs energy and releases electrons which are allowed to flow freely.

The panels usually have another electric field which forces the electrons freed by light to move in a specific direction, which creates a current. There are metal contacts on the top and bottom of the cell which collect and transport the current and make it available for external use (Toothman and Aldous, 2000).

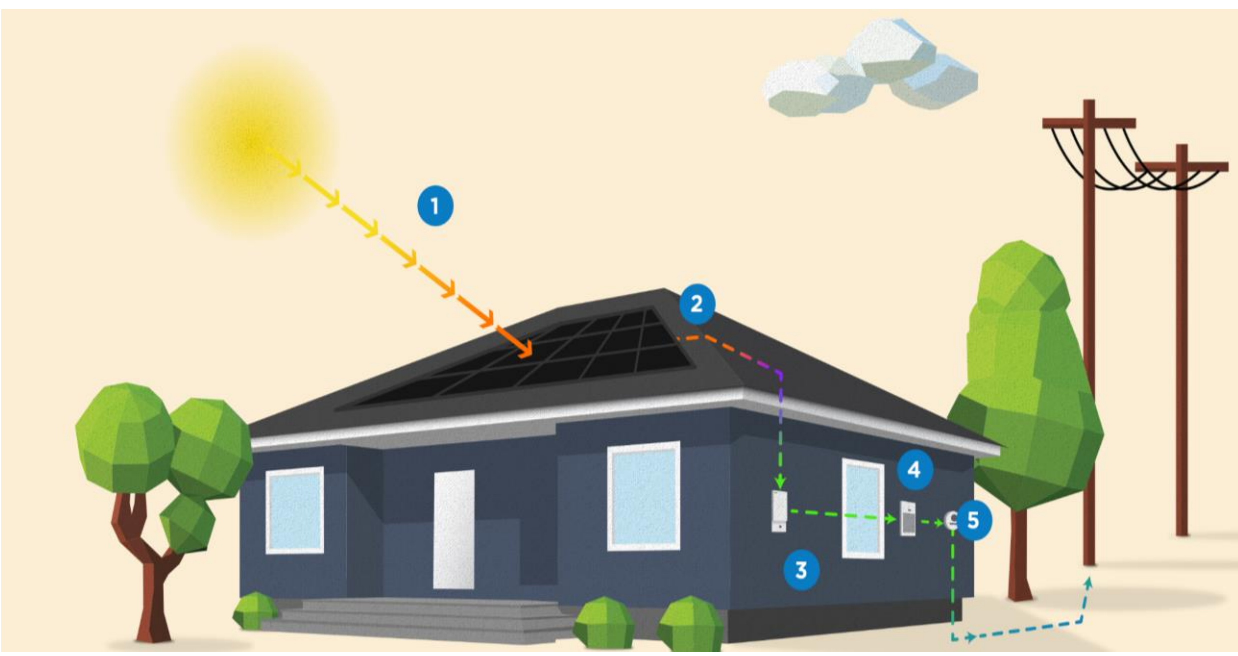

Figure 4. **Electricity generation by panels and net metering**
Source: CertainTeed. (2020). Solar 101: how solar energy works (step by step). Retrieved from: **https://www.certainteed.com/solar/solar-101-abcs-solar-power/**

2.2.2.1 Net metering

Net metering is a billing mechanism which enables residential and commercial users of solar panels to be credited for the electricity they send back to the grid (SEIA,2020).

Solar projects are typically designed to offset the property's usage on an annual basis. There will be times when the panels generate more electricity than the property uses. If the array is producing more electricity than the property is consuming, the excess solar electricity will flow onto the grid. There will also be times (such as at night or on a particularly cloudy day) when the property is consuming more electricity than the solar panels are generating, and electricity will need to be drawn from the grid. All homes which take part in the *Solarize Philly* program remain connected to the electricity grid and are taking advantage of net metering. They are provided with two-way meters by PECO. These meters measure the amount of electricity coming in from the grid as well as the amount going back out (NREL, n.d).

A solar customer who is taking advantage of net metering in Pennsylvania receives a credit for each kilowatt hour that they send out onto the grid. These credits are issued on a one-to-one basis, meaning that for each excess kilowatt hour generated on a sunny day the customer receives one kilowatt hour credit that they can use to offset future usage that they draw from the grid. They are charged for the difference between these two numbers on a monthly basis. Excess kilowatt hours are banked and can roll on to the next month. If there are any kilowatt hours remaining in a customer's account at the end of the energy year, which is on May 31st, customers are reimbursed for this amount at the price to compare which is $0.071/kWh (PECO, 2019).

This method of compensation is based on net metering legislations put forth by Pennsylvania Act 213, The Alternative Energy Portfolio Standards Act of 2004 (AEPS) which states that 'a customer must be reimbursed at retail rate for up to their annual usage and that excess can be reimbursed at generation price to compare'. Solar customers are credited only for the energy left in their bank as of May 31st of each year, which they generally do due to higher production during spring months. They are reimbursed for this amount even if their annual production is lower than their annual consumption. This means that solar customers are not reimbursed for the total excess energy their panels produce annually. This is an important point to consider while calculating savings during the 'Use' phase of panels.

2.2.3 End of Life Phase

The End of Life Phase of panels is often ignored or forgotten due to the present bias and lack of awareness. It is an issue customer do not need to worry about until at least 25 years after they purchase their panels. Panel disposal and reuse programs are still in the early stages of development since the industry is relatively new and modules have a relatively long life span.

The International Renewable Energy Agency (IRENA) estimated that at the end of 2016, there was around 250,000 metric tonnes of solar panel waste globally.

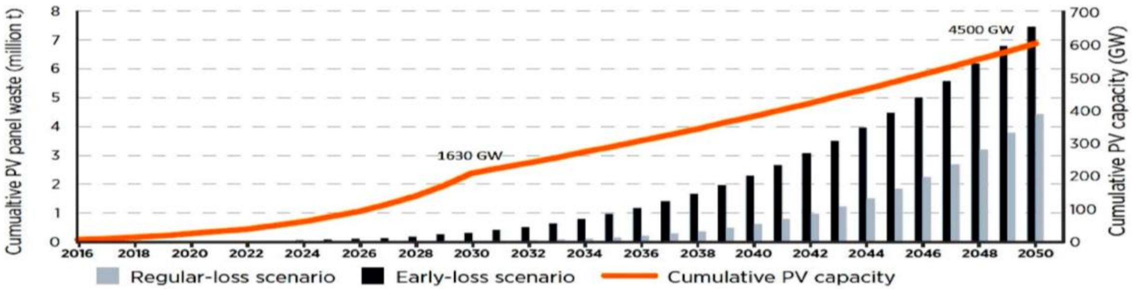

Figure 5. **Estimated cumulative worldwide PV module waste (tonnes) 2016-2015**
Source: Chowdhury et.al. (2020). An overview of solar photovoltaic panels' end-of-life material recycling. In *Energy Strategy Reviews* (Vol. 27, p. 100431). Elsevier Ltd. https://doi.org/10.1016/j.esr.2019.100431

Disposal of panels into landfills is not advisable because the modules can degrade, and harmful chemicals can leach into the ground causing drinking water contamination.

A framework for recycling panels needs to be established before we start experiencing the ill effects of disposed panels. Low-cost recycling technologies for the evolving PV industry need to be established along with the rapid commercialization of these new technologies. Many governments haven't taken steps to limit waste from solar panels. Japan, China and California, which are leading producers and users of solar, have no plan of action to manage their solar waste. Europe is the only place that requires manufacturers to collect and dispose solar waste (Chowdhury et.al, 2020).

2.2.3.1 Current state of End of Life of panels

Currently, most of these panels are stock piled, sent to landfills or donated to charities like Habitat for Humanity to be reused or repurposed. A majority of the solar panels are disposed off into electronic waste (E-waste) collection bins. Some of the reasons why solar panels are disposed include reaching the end of their lives; damage due to hail storms, fires, tree branches, animals tampering with them, water entering electric systems as well as the desire to upgrade to newer and more efficient versions. However, solar panels are often too big for e-waste collection bins and therefore are crushed before disposal.

There is also a significant secondary market for used solar panels in the form of off–grid applications. Solar panels at the end of their lives have a reduced wattage because of degraded efficiency; however, they are still capable of producing electricity that can be used for secondary applications such as powering irrigation or providing energy during disaster relief (California Product Stewardship Council,2020). Some installers and manufacturers manage take-back programs to reuse or refurbish panels and their parts. They are used for off-grid purposes or exported outside the US (SEIA, 2020).

The main step in recycling panels is to separate the layers, which necessitates dismantling the panel and separating each of the cellsto recover metals. Chemical and mechanical methods can be employed for this:

- **Chemical methods** recapture metals from Silicon cells. The substrate glass and the metals in the semiconductors are separated, recovered and can be isolated and purified.

- For **mechanical separation,** panels are primarily dismantled by removing the surrounded Al frame, as well as the junction-boxes and embedded cables. The panel, junction-box and cables are shredded and crushed to inspect the individual toxicity of each part and total toxicity of the module for disposal (Chowdhury et.al, 2020).

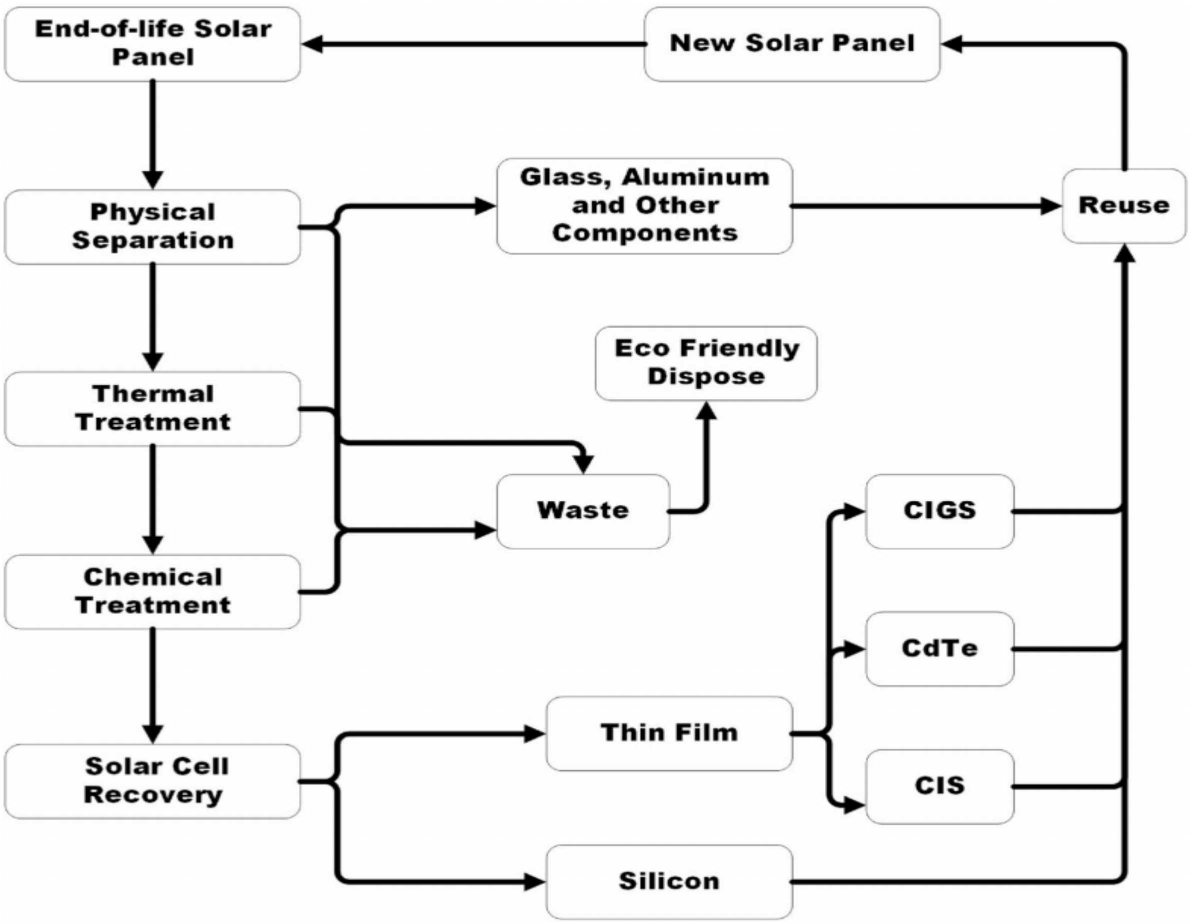

Figure 6. **End Of life management of a solar panel through chemical or mechanical treatment**
Source: Chowdhury et.al. (2020). An overview of solar photovoltaic panels' end-of-life material recycling. In *Energy Strategy Reviews* (Vol. 27, p. 100431). Elsevier Ltd. https://doi.org/10.1016/j.esr.2019.100431

2.2.4 Review of other Solar Life Cycle Assessment Studies

Most of the Life cycle Assessment of solar energy that were reviewed employed a cradle to grave approach. The Manufacturing Phase and Use Phase are well documented but the Transport and End of Life Phases are often omitted.

A study by Yue et. al. studies panels manufactured in China, Europe and US which represent three of the manufacturing locations of panels used in the *Solarize Philly* program. Most of the reviewed LCA studies are limited to the US and Europe even though Asia has become a big hub for solar panel manufacturing. These three regions have significantly different environmental restrictions and electricity grids which greatly affect a panel's life cycle. Yue et. al. conducted a comparative life cycle analysis of panels manufactured in these three locations. They found that compared to the domestic manufacturing scenario, the energy efficiency is generally 30% lower and the carbon footprint is almost doubled in the Chinese manufacturing scenario. In this study, the high - endscenario of panels manufactured in China and releasing 72.2 gCO2-eq./kWh has been considered (Yue, et.al.,2014).

It is challenging to obtain life cycle inventory data. Many manufacturers are unwilling to disclose this information or require you to sign Non – Disclosure Agreements. There are a few inventories that several studies have made use of. One such inventory was collected by Alsema and Wild-Scholten for crystalline silicon modules (mono-Si, poly-Si and ribbon-Si) from a number of PV manufacturers. They pointed out many gaps in manufacturing data.

Another inventory was published by Dones and Frischknecht. They performed the LCA studies on mono-Si andpoly-Si panel technologies in Switzerland. This study presented useful information about energy requirements and GHG emissions in PV manufacturing chains and provided a solid foundation for future LCA research.

One commonly used study was by Jungbluth et al. This inventory is available on the Ecoinvent Life Cycle Inventory database. This inventory is also based on panels produced in Switzerland. Sixteen different, grid-connected PV systems were analyzed (J. Peng et al., 2012). Amongst existing Life Cycle Studies, most focus on Silicon panels rather than thin layer panels.

The most commonly studied indicators are related to energy, such as the Energy Payback Time (EPBT) and indicators relative to climate change such as CO_2 emissions. When impact assessment methodologies are used, the databases which are generally utilized are Eco-Indicator99 and sometimes CML (Gerbinet et. al., 2014).

Over the past couple of years many Life Cycle Assessments have been carried out but they have wide – ranging results. This could be due to differences in system boundaries, types of systems analyzed, location, time, etc. NREL's Life Cycle Assessment (LCA) Harmonization Project and other harmonization studies aim to clarify inconsistent and conflicting life cycle GHG emission estimates in the published literature and provide more precise estimates of life cycle GHG emissions from PV systems.

The NREL analysts developed and applied a systematic approach to review LCA literature, identify primary sources of variability and, where possible, reduce variability in life cycle GHG emissions estimates through a process called "harmonization". Published results from 400 studies of PV were reviewed and screened. Primary sources of variability were identified and reduced where possible. A system lifetime of 30 years was considered. GHG emission estimates were harmonized to a consistent system boundary, as well as global warming potentials for methane and nitrous oxide. Only seventeen out of the four hundred studies passed the screening . The study yielded an emission of 40 gCO2 eq/kWh over a panel's life cycle with ~60% - 70% of these emissions come from upstream processes, ~21% - 26% come from operational processes and ~5% - 20% come from downstream processes. Other harmonization studies followed similar procedures.

The Transportation Phase of panels was omitted from many studies. Impacts can be negligible if the sites for manufacturing, collection, use, treatment and disposal of PV panels are assumed to be in the same vicinity, but, in most cases, the data for transport mode and distance are difficult to assess for the general case. Even if included, data for this stage was not displayed. This may be because it is highly variable, different modes of transport may be used to reach different locations. Only those which followed the life of a particular panel from its manufacturing to it's end of life analyzed the Transportation Phase and displayed this data.

One important take away is that all studies showed that mainstream photovoltaic power in all its forms has significantly lower life cycle greenhouse gas emissions than fossil power.

2.3 Initiatives being taken by *Solarize Philly* manufacturers to reduce GHG emissions

The following section contains information about the sustainability and greenhouse gas reduction initiatives being taken by manufacturers whose panels have been used in the *Solarize Philly* program. Steps being taken by manufacturers will ensure that the program is more sustainable overall and will ensure that panels which cause minimum harm to the environment are used.

Table 2: Initiatives of *Solarize Philly* manufacturers to reduce GHG emissions

Manufacturer	Initiatives
Q cells	Q cells has an aggressive corporate sustainability policy. They believe that a sustainable product requires a sustainable company policy. They state that in order to conserve natural resources they systematically evaluate and improve their environmental and energy performance. A crucial aspect is the efficient use of energy as well as the purchase of energy – efficient products. They undertake yearly audits to ensure that company processes and corporate standards are implemented effectively. They also have a sustainable purchasing strategy; all their suppliers are chosen based on financial and ecological criteria. Q cells also conduct life cycle assessments which calculate their panels' energy payback time and carbon footprint (Q cells, 2020).
Jinko:	Jinko calculates their product carbon footprint, water footprint, or other environmental impact footprints as they are important indicators in the environmental performance of products. This helps them create and manage hazardous substance management, pollution prevention, energy saving, waste reduction and other clean production measures in their factories. They also require and assist their suppliers in taking similar actions and hence creating a green supply chain. Jinko Solar creates GHG inventories which allows them to set priorities and reduction goals, raise the efficiency of the greenhouse gas reduction processes and confirm reduction results. Jinko Solar has adopted energy-conserving designs for new facility construction, purchased energy-efficient equipment by adjusting procurement specifications and optimized manufacturing processes to increase unit productivity per machine and per hour to reduce energy consumption. They shifted from manual soldering to fully automatic to avoid emissions from soldering tools. They installed inverters to the optimize cooling tower fan speed and replaced low-efficiency water pumps with high efficiency pumps (Jinko, 2018).
Longi	Longi factories have passed the ISO 14001 system certification. All factories have Environmental monitoring management systems and conduct internal audits every year or every six months.

	Longi launched the ‘Carbon Footprint’ project in 2017 through which they promoted the certification of their products based on carbon footprints. Through this, they integrate greenhouse gas emissions into the decision-making of their supply chain, manufacturing and other processes. In this way they meet customer demand for a lower product carbon footprint and build a green supply chain which enhances their brand influence (Longi, 2019).
LG	LG Electronics’ environmental policy is centered on its ‘Life’s Good when it’s green’ program. LG’s reduction of greenhouse gases emitted during a product’s life cycle including raw materials used in production, distribution, usage and disposal is carried out in stages. LG has voluntarily established greenhouse gas emissions reduction targets and is carrying out various initiatives to achieve these targets. They aim to reduce greenhouse gas emissions by 150,000 tons during the product manufacturing stage and by 30,000,000 tons during the product usage stage by the end of 2020 from 2009 standards (LG, 2009).
Panasonic	Panasonic formulated the ‘Panasonic Environment Vision 2050’ in 2017 to put forth initiatives to respond to the expectations and requests of their stakeholders. The Environment Vision 2050 means to work towards more efficient utilization of energy. Currently, the amount of energy created by their products is just one-tenth the amount of energy used in the manufacturing and consumption stage of the products. Panasonic aimsto make the "energy created" exceed the "energy used" toward the year 2050. In order to do this, they will develop technologies for enhancing the energy-saving performances of their products and innovate manufacturing processes to reduce the amount of energy consumption. For the energy created, they will expand energy-creation and storage businesses to increase the use of clean energy (Panasonic, 2020).
Yingli	Environmental impact of their product life cycles is one of Yingli’s three sustainability focus areas. They want to reduce the amount of resources needed for production of each panel and reduce the waste it produces. Yingli has invested in PV power generation projects at several of their facilities which generate 39.3 GWh of electricity annually, equivalent to 4.05% of their total power consumption in 2013. Yingli is committed to monitoring and reducing the emissions created by their manufacturing processes, including GHGs, PFCs, and other air emissions. They track all of their waste streams and strive to reduce their negative impact on the environment (Yingli, 2015).

2.4 Other Solar Cost – Benefit Analyses

Most CBAs calculate Net Present Value (NPV), Discounted Payback Time (DPT) and Internal Rate of Return (IRR). These values are calculated for either a 25 year period (the warranty period of most solar panels) or a 30 year period (the estimated lifetime of a solar panel) (Wampler, 2011 and Boro et.al., 2015).

Amongst the benefits which are often analyzed are net metering, avoided energy costs and other financial incentives which are available depending on the region. Other financial benefits which have been assessed include:

- Reduced financial risks with stable electricity prices: The cost of energy from fossil fuels can be very volatile and the cost of grid electricity varies accordingly. .Solar energy users pay an upfront cost for installation and hence protects the offset portion of their electricity bill from future price fluctuation of grid electricity.
- Avoided environmental compliance cost: Use of solar energy helps avoid emissions from conventional sources of energy and can save the cost of emission allowance in places where pollution is capped.

Environmental and societal benefits that have been analyzed include:

- Job creation: As the solar industry grows it is generating more green jobs, which as of 2015 helped 208,000 people earn a living.
- Avoided environmental costs of externalities from greenhouse gas emissions: Increasing the use of solar decreases dependence on fossil fuels, avoiding the emission of tons of greenhouse gases with high global warming potentials. It also decreases air pollution that result from fossil fuel combustion and the resulting health effects. The value of this benefit was calculated by incorporating the social cost of relevant greenhouse gases into their analysis (Fanshaw and Weissman, 2015).

The costs that have been analyzed in various papers include installation costs, cost of integration with the grid and maintenance costs (Beach and McGuire, 2013).

The studies conducted by both Fanshaw and Weissman as well as Beach and McGuire used a discount rate of 7.21% which was a value obtained from the Arizona Public Service (APS) commission. Wampler used a discount rate of 6%, which was the loan rate for a project they analyzed in California. The NREL study used in this analysis used a discount rate of 6.9%, which was a national average for residential rooftop PV power.

2.5 Other Solarize Programs in the US

There are many programs administered by US government agencies like the Environment Protection Agency (EPA) and Department of Energy (DOE) as well as by many state organizations which promote the use of renewable energy. Many of them provide loans and grants to promote research in the use of renewable energy. Some programs like those administered by the Loans Guarantee Office of the DOE promote the commercial use of new technologies. Programs like the Rural Communities program administered by the USDA provides financial assistance to communities with high energy costs. Some grants like the Sun Grant Program, administered by the National Institute of Food and Agriculture and the Inventions and Innovations programs offer competitive grants to small businesses and research institutions with innovative energy ideas (CRS, 2019).

In contrast to these programs, 'Solarize' programs make renewable energy like solar power accessible to homeowners and small commercial establishments through a simple and streamlined process. They aren't always administered by government agencies and enable the participation of many private entities.

Solarize programs tackle three major market barriers:

- **High Upfront costs**: Solar systems can have very high upfront costs going up to even $35,000. This prevents many people from adopting solar. Solarize programs present much lower upfront costs by bundling in federal, state and local tax credits and incentives as well as providing group buying discounts. Some programs even offer solar loans where customers can pay for the installation over a period of time through fixed instalments. The loans can be priced in many cases equal to their initial electricity bills so customers can get solar installed at no added price to them.
- **Complexity**: The entire process of installing solar may seem like a complicated task. The system involves many components including racking, inverters, meters, etc. There are many licenses and permits which needs to be obtained and it involves coordination with many agencies. Solarize programs make the entire process of going solar easier by working with pre – vetted installers and manufacturers which meet certain criteria. Customers can expect the best quality equipment and services. They are also provided with FAQs and other resources and the program coordinators are always available to answer any questions. They also streamline the entire installation process and work with different entities to obtain all the licenses and permits necessary.
- **Customer Inertia**: Sales cycles for solar are usually more than two years from first inquiry to installation (Irvine et.al, 2012). Solarize projects overcome this inertia to get installations in three to six months. This is done by presenting a highly competitive price in a limited-time offering, the campaign motivates customers to act. Additionally, group buying provided safety in numbers, so that participants didn't feel that they were making the decision on their own.

2.5.1 Case Studies

Solarize Southeast:

This program took place between 2009 and 2011 and was one of the first solarize programs in the nation. It was initiated by a group of Portland residents with the assistance of Southeast Uplift and the Energy Trust of Oregon. Within six months of starting their campaign, Solarize Southeast had signed up more than 300 residents and installed solar on 130 homes. The 130 installations added 350 kilowatts of new PV capacity to Portland and created 18 professional-wage jobs for site assessors, engineers, project managers, journeyman electricians, and roofers.

Solarize Washington:

This program was started in 2011 by a non – profit, Northwest Sustainable Energy for Economic Development (Northwest SEED) in the state of Washington. The first campaign was quite successful so they ended up running two additional campaigns, this made contractors confident enough to offer low flat prices for the first sale rather than having participation-based tiers which existed originally. As demand for Solarize campaigns has grown, Northwest SEED has begun to issue a Call for Partners to competitively select neighborhoods as hosts for upcoming Solarize campaigns. In addition, several local utilities have seen the success of Solarize Washington campaigns and are now offering support to expand the program.

One major difficulty in running this NGO lead Solarize campaign, was funding. Initially the organization relied heavily on foundation grants to support the program. Then they started working with local utilities and then started charging a lead generation fee to create a more stable and predictable funding mechanism.

Solarize Massachusetts (Solarize Mass):

This program was administered by the Massachusetts Clean Energy Center (MassCEC) along with the with the Massachusetts Department of Energy Resources, in 2011. They identified four neighborhoods called "Green Communities" which had to compete with one another. They provided each community with an outreach toolkit which contained a banner, yard signs, bumper stickers, templates, and other marketing materials. The community with the most widespread solar adoption won. Participants could either directly own or lease panels, both with four tiers of pricing based on the number of people who contract to install solar. The town of Harvard ultimately won, solarizing 4% of total residences [add numbers] (Irvine et.al, 2012).

Milwaukee Shines:

This was started in 2008 by the Environmental Collaboration Office (ECO) with many community partners funded by the U.S. Department of Energy. This program has enabled Milwaukee to streamline the permitting process, create a solar zoning ordinance and begin providing financing resources for home and business owners. As of January 2017, there are more than 2.2 MW of solar energy being produced in Milwaukee, which has exceeded the City's goal of 1 MW of solar capacity (*Perma | Milwaukee Shines (Solar)*, n.d.).

3. Methodology

3.1 Life Cycle Assessment

A life cycle approach was used to calculate total greenhouse gas emissions from all life cycle stages including ‘Manufacturing’, ‘Transport’, ‘Use’ and ‘End of Life’.

3.1.1 Goal and Scope

The goal of this study is to estimate CO_2e emissions over the entire Life Cycle and determine the greenhouse gases offset using these panels.

The functional unit is 1 kWh. In the analysis Carbon dioxide equivalent per kWh (CO_2e/kWh) is calculated and then used to determine the environmental impact of producing 1kWh electricity using solar panels used in the three phases of the *Solarize Philly* program and calculate the greenhouse gas emissions offset by their use.

The Global Warming Potential (GWP) of the panels across their Use Phase was analyzed. GWP is measured in terms of Carbon dioxide equivalent per kilo watt hour (CO_2e/kWh). The data can be used by the Philadelphia Energy Authority to understand the impact of their past phases and in the selection of modules for future phases. This is the main impact which is calculated, other impacts such as ozone layer depletion, ecotoxicity, cumulative energy demand, etc. were not analyzed.

Assumptions:

- The manufacturing of only panels has been accounted for in the calculation of GWP in this study. The manufacturing of inverters and racking and other Balance of System components which are also a part of rooftop solar systems were not included in the analysis.
- The panels used in the program are manufactured in China, Malaysia, Vietnam, Germany and the US. They are transported via ocean freighter and freight truck. The distances travelled were calculated using the distance and time calculator on: https://www.searates.com/services/distances-time/. Further details on transportation data are summarized in the data inventory (Appendix A).
- The analysis will be conducted for a 25-year timeframe, which is the warranty period of the panels.

The system diagram which clearly defines the scope of this study is on the next page.

System Diagram:

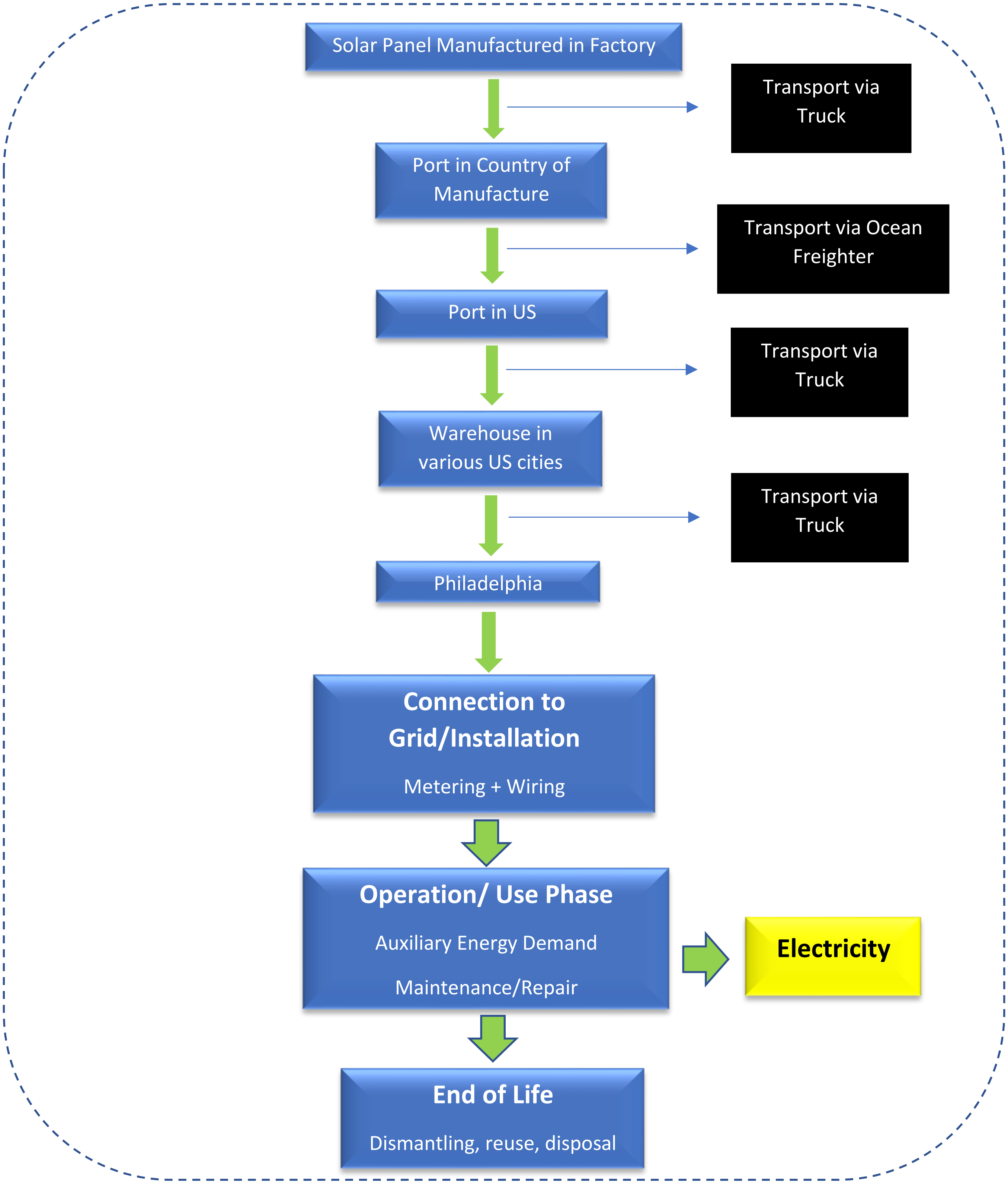

Figure 7. **System Diagram**

Solar panels from 8 manufacturers were used in the *Solarize Philly* program. They were:

- Jinko
- Q Cells
- Yingli Solar
- CertainTeed Solar
- LG
- Axitec Solar
- Longi
- Panasonic

3.1.2 Manufacturing Phase

All panels were Crystalline Silicon (C – Si) monocrystalline modules with a 25-year performance warranty.

The process of manufacturing each of these panels is very similar so data on global warming potential of monocrystalline panels from a study by Yue et. al. Data was obtained for panels manufactured in both China and Europe from this study. The manufacturing process has been elaborated in the Review of Literature.

- In the study they used country-specific data for the Life Cycle Inventory (LCI). Ecoinvent data was used for the European scenario. Data from the Chinese Life Cycle Database (CLCD) was used for the Chinese scenario. The LCI data derived from CLCD are considered comparable with those from the Ecoinvent database asthe up-to-date Ecoinvent database is integrated in and compatible with CLCD.
- The weighted GHG emissions are calculated based on the annual generation of electricity. The analysis resulted in 37.3 gCO2-eq./kWh for Europe and 72.2 gCO2-eq./kWh for China (Yue et.al., 2014).

3.1.3 Transportation Phase

The manufacturers were contacted to obtain the manufacturing locations of the panels and their possible routes to Philadelphia.

Freight trucks are used to transport panels from factories to the nearest port. Ocean freighters are used to transport them from ports to the US. In the US, panels reach different ports and are stored in different warehouses. Truck freight is used to transport them from these warehouses to Philadelphia.

The trucks which were assumed to be used were long-haul low Sulphur diesel trucks. Emission data for these trucks was obtained from the GREET database for Well to Wheel emissions. Trucks emit many greenhouse gases including CO_2, CH_4 and N_2O. The other greenhouse gases are present in very low quantities. To obtain the total CO_2e values we need to multiply the quantity of each greenhouse gas with their IPCC emission factors. The IPCC emission factors are used to compare the emissions from different greenhouse gases to that of carbon dioxide.

These values are expressed in terms of gCO_2e/tkm. 1-ton kilometre or tkm refers to the transportation of one metric ton of freight one kilometre

Table 3. Calculation of GWP of truck transport

Greenhouse gases emitted by trucks	**IPCC emission factors (according to Assessment Report (AR 5)**	**GREET values for HD - Long haul, Low Sulpher diesel truck, Well to Wheels (WTW) values (g/tkm)**	**GWP values gCO2e/tkm**
CO2	1	69.26	69.26
CH4	28	0.10	2.69
N2O	265	0.0025	0.66
Total GWP for Truck emissions			72.61

The final GWP of truck transport was found to be 72.61 gCO_2e/tkm.

The GWP for ocean freighters was found to be 30 gCO_2e/tkm. This value was obtained from a CLECLAT (the European association for forwarding, transport, logistic and Customs services) study. The study is titled 'Calculating GHG emissions for freight forwarders and logistics services.' It follows the new European standard EN 16258, this standard is specifically for transport. The guide helps companies calculate their greenhouse gas emissions according to this standard.

30 gCO_2e/tkm is a conversion factor mentioned in the report for Well-to-wheels greenhouse gas emissions per tonne kilometre for container ships which run on Heavy Fuel Oil (HFO). These are the types of trucks which are most likely used to transport the panels (Schmied and Knörr, 2012).

The method of calculating emissions from transportation has been depicted below using the following example:

Table 4. Transportation Phase emission calculation example

Brand	Starting point	Endpoint	Type of Transport	Distance (km)	Emission_Ocean (Distance x 30) (gCO2e/ton SP)	Emission_truck (Distance x 72.61) (gCO2e/ton SP)	Weight of 1 solar panel (kg)	Factor 1 (kg Sp/kWh)	Factor 2 (ton SP/kWh)	Emissions_trucks (gCO2e/kWh)	Emissions_ocean (gCO2e/kWh)	Total Emissions (gCO2e/kWH)	Emissions from each brand(gCO2e/kWH)
A	Point A, USA	Philadelphia	Truck Freight	1188.06		86265.04	18.7	0.042	4.16E-05	3.59	0	3.59	3.59
B													
Route 1	Point B, South Korea	Point C, South Korea	Truck Freight	108.23		7858.58	17.1	0.038	3.80E-05	0.30	0		
	Point C, South Korea	Point D, USA	Ocean freighter	18495.95	554878.5		17.1	0.038	3.80E-05	0.00	21.11	25.02	
	Point D, USA	Philadelphia	Truck Freight	10.07		731.18	17.1	0.038	3.80E-05	0.03	0		
													24.47
Route 2	Point E, China	Point F, Chir	Truck Freight	57.78		4195.41	19	0.042	4.23E-05	0.18	0		
	Point F, China	Point G, US/	Ocean freighter	18694.33	560829.9		19	0.042	4.23E-05	0.00	23.70	23.91	
	Point G, USA	Philadelphia	Truck Freight	10.07		731.18	19	0.042	4.23E-05	0.03	0		

The details for each brand are available in the data inventory in Appendix A.

First, the distances the panels travelled were calculated using Searates.com as mentioned in the assumptions. This was then multiplied with their emission factors to obtain the total emissions from truck and ocean transport expressed in terms of gCO_2e/ton. The nameplate capacity was assumed as 315 W (i.e., 0.315 kW) across all solar panels irrespective of the manufacturer. The nameplate capacity used in analyses is the average value obtained from specification sheets provided by the manufacturers for solar panels used in *Solarize Philly* program. The estimated average nameplate capacity of 315 W was used to calculate electricity generated by the solar panels for an entire year. The average peak sunlight hours for Pennsylvania is 3.91 hours per day (Turbine generator, 2020). Thus, the electricity generation by the panels per year was calculated as follows:

0.315 x 3.91 x 365 = 449.55 kWh

Emissions from trucks and ocean freighters need to be calculated in terms of gCO_2e/kWh. The following calculation need to be done to obtain these values:

1. Factor 1: kg Solar Panel /kWh = $\frac{\text{Weight of Solar panel (kg)}}{\text{449.55 kWh (Electricity produced per year)}}$
2. Factor 2: ton of Solar Panel/kWh = Factor 1 x 0.001 (ton/kWh)
3. Emission from trucks as gCO_2e/kWh = $\frac{\text{Total Emission from truck transport (gCO}_2\text{e/ton)}}{\text{Factor 2 (ton/kWh)}}$
4. Emission from ocean freight as gCO_2e/kWh = $\frac{\text{Total Emission from ocean transport (gCO}_2\text{e/ton)}}{\text{Factor 2 (ton/kWh)}}$

The emissions from Ocean freight and trucks i.e. the values obtained in steps 3 and 4 are then added up to obtain the total emissions from transportation for a panel following a particulartransport route. This value was averaged out for each route followed by a specific brand. In the above example the transport emissions for each brand were were 3.59 gCO_2e/kWh and 24.47 gCO_2e/kWh respectively.

The transportation emissions from panels of each brand were averaged out to get the average transportation emissions of a solar panel used in the *Solarize Philly* program. This averaged value was used in the analysis as emissions from the Transport Phase

3.1.4 Use Phase

During the Use Phase, solar panels don't have any emissions since they use sunlight to produce electricity through the photoelectric effect. Emissions obtained from grid electricity were calculated. These emissions were subtracted from those produced by all other phases as they are offset byusing solar panels.

Table 5. Calculation of grid emissions for Philadelphia, High – end scenario

Fuel	**Percentage contribution to Philadelphia's grid**	**Life Cycle Emissions from IPCC (gCO2e/kWh)**	**Emissions for Philadelphia (gCO2e/kWh)**
Coal	28.60%	910	260.26
Natural gas	30.30%	650	196.95
Nuclear	34.20%	110	37.62

The electricity grid mix data was obtained from PJM's 'State of the Market' report for 2018 data. PJM Interconnection is a regional transmission organization (RTO) that coordinates the movement of wholesale electricity in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia (PJM, 2020). Philadelphia obtains its energy from PJM's grid.

The contribution of coal, natural gas and nuclear fuel to the grid mix were recorded. The other energy sources are wind and hydroelectricity but their contribution and their emissions are very low so they were not included in the study. The Life Cycle emission data was for coal, natural gas and nuclear fuel per kWh was obtained from an IPCC report called 'Mitigation of Climate Change'. The highest emission values were used in order to compute values which represent the High – end emission scenario (Bruckner et.al., 2014). A weighted average for the emission from each of these fuels was calculated by multiplying their percentage contribution with their life cycle emissions per kWh. These were added up to get the total grid emissions by taking weighted averages.

3.1.5 End of Life Phase

The emissions for the End of Life Phase were obtained from an NREL study, part of their Life Cycle Assessment (LCA) Harmonization Project which has been elaborated on in the Review of Literature. The study provides a range of values for emissions from the End of Life Phase. The worst-case scenario for End of Life emissions is 20% of a panel's life cycle emissions which according to them is 40 gCO2e/kWh. Thus, the emissions which were considered for the High - end emissions for the End of Life Phase were 8 gCO2e/kWh. The study states that these emissions are generated by disposal and decommissioning activities but doesn't elaborate on what these activities are (NREL, 2012).

The emissions from the Manufacturing, Transport and End of Life Phase were added up to determine the overall life cycle emissions of solar panels and find out the emissions they offset by the use of grid electricity. Detailed tables of the data inventory are available in Appendix A. A sensitivity analysis was also conducted. Through this, impacts were analyzed for a Low – end emission scenario. The methodology presented above shows how to calculate emissions for a High – end emission scenario. When calculating emissions for a Low-end emission scenario, the following changes are made:

- Emissions from the manufacturing of panels in Europe replaces emissions from manufacturing in China. According to Yue et al, this value is 37.3 gco2e/kwh (Yue *et al*., 2014)
- The NREL study from which End of Life emissions were obtained stated that the best-case scenario End of Life emissions is 5% of a panel's life cycle emissions which according to them is 40 gCO2e/kWh. Thus, the emissions which were considered for the High -end emissions for the End of Life Phase were 2 gCO2e/kWh (NREL, 2012).
- Minimum emissions from Life Cycle emissions from coal, natural gas and nuclear fuels are 212 gco2e/kwh, 124 gco2e/kwh and 1.3 gco2e/kwh respectively according to the IPCC report called 'Mitigation of Climate Change' (Bruckner et.al., 2014).

Table 6. Calculation of grid emissions for Philadelphia, Low – end scenario

Fuel	**Percentage contribution to Philadelphia's grid**	**Life Cycle Emissions from IPCC (gCO2e/kWh))**	**Emissions for Philadelphia (gCO_2e/kWh)**
Coal	28.60%	740	211.64
Natural gas	30.30%	410	124.23
Nuclear	34.20%	3.7	1.26

The graphs for the analysis were developed in R and Excel. These have been displayed in the results section.

3.2 Cost Benefit Analysis

Solar Installations for five different households that went solar through the *Solarize Philly* program were analyzed. Households were selected to show a range of installation costs. The details of each system and the Cost Benefit Analysis calculations are in Appendix B.

3.2.1 Background

The **Net Present Value (NPV)** and **Discounted Payback Time (DPT)** were calculated for each system.

The Net Present Value is a method which helps bring all cashflows that are a part of a project, both present and future, to a fixed point in time.. It determines the current value of all future cashflows generated by a project, including initial capital investment (Seth, 2019).

It can be represented as:

NPV = (Today's value of the expected future cash flows) – (Today's value of invested cash)

This is based on the concept of the Time value of money which states that money available at present is worth more than the same amount of money available at some point in the future (Chen, 2019). The discount rate, *i* adjusts for the timing of cashflows.

The formula for calculating the Present Value (PV) of cashflows for a year is:

$$PV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

where:

Rt = net cash inflow – outflow during a single time period t

i = discount rate or return that could be earned in alternative investments

t = number of time periods

The discount rate used is 6.9%. It is the discount rate for residential or commercial PV published in an NREL study titled 'U.S. Solar Photovoltaic System Cost Benchmark: Q1 2018'. The report benchmarks costs of U.S. solar PV for residential, commercial, and utility-scale systems built in the first quarter of 2018 (Q1 2018) (Feldman and Margolis, 2018).

The following equation is used to calculate the NPV:

$$\text{NPV} = \sum(\text{PV}_t / (1 + i)_t) - \text{Capital Investment}$$

In this analysis, the time period being considered will be 25 which is the warranty period of the panels.

The PV is calculated for each year and *t* is replaced accordingly. The sum of the PV values for 25 years is added up and subtracted from the **Capital Investment (CI)** to get the NPV of the project. The rule of thumb is to compare the benefits and the costs. If the benefits are greater than the costs, i.e. if NPV is positive then the project is profitable and cost beneficial.

The payback period of a project is the number of periods before cash flows equal to the initial investment are earned. The discounted payback time is the same as the payback period but you replace the future cash flows with their present values (Diamond et.al., 2020). It gives the number of years it takes to break even from undertaking the initial expenditure considering the time value of money.

3.2.2 Defining Costs and Benefits

Capital Investment (CI)

There are six values needed to calculate the Capital Investment:

- **Cost of Installation:** This is determined by the installer serving each customer. It is presented to each customer by the installers after accounting for the *Solarize Philly* discount. This value was provided by PEA for each of the five sample customers.
- **Cost of adders**: Some installations may have added costs such as racking, extra costs for interconnection, lifting equipment, etc. The sum of all these costs is the cost of adders.
- **Solar loan interest:** Some customers use loans to pay for their systems. This is done in the form of monthly investments. They have a fixed interest rate for the entire loan term so they need to pay this extra amount as well.
- **Federal Investment tax credit (FITC)**: All customers which have been assessed in this analysis are assumed to install their system in the year 2020. The investment tax credit for renewable energy projects for this year is 26% of the cost of installation. This is shown as a reduction in the Capital Investment for this analysis, based on the assumption that all households included in the analysis will have adequate tax burden to take advantage of the FITC. It should be noted that the customer will not receive the benefit of the FITC until they file their taxes for the year in which the installation was completed.
- **Philadelphia Solar rebate**: Through this rebate, residential customers are credited 20 cents for every Watt of solar capacity that they install. The households will be eligible to apply for the Philadelphia Solar Rebate after their projects are completed. Rebates are issued based on available funds. In this analysis it is assumed that all of the households receive the Rebate.

The total CI was calculated by adding the cost of installation with the cost of adders and the solar loan interest if present (which was calculated for the entire loan term) and then subtracting it from the cost of the Federal Investment tax credit and the Philadelphia Solar rebate.

Variable costs

There are no variable costs for a solar project. Once the capital investment is paid to an installer, there are no recurring costs to a customer. The remaining annual electricity bill is not considered a cost for this project as the customer would have been paying this amount even in the absence of the solar installation.

Benefits

Three of the monetary benefits you can get from solar installations are:

- **Savings from annual electricity bill:** Customers don't have to pay as much as they did before they installed solar for electricity. The saving from decreased electricity bills was calculated by multiplying the annual consumption with the price per kilowatt hour.. These savings are made possible by net metering, which was explained in detail in the Review of Literature.
- **Solar Renewable Energy Certificates (SRECs):** SRECs are incentives to owners of solar systems which allow them to sell certificates which have a certain price. They exist due to a regulation called renewable portfolio standards (RPS) or Alternative Energy portfolio standards (AEPS) in Pennsylvania, which are adopted by states to make sure a certain amount of their energy is produced from renewable sources. A solar system owner earns an SREC for every 1 MWh (1000 kWh) (Energysage, 2019). The SREC price for Pennsylvania at the beginning of 2020 was $40 according to SRECtrade.com. The amount earned from SRECs by each customer was calculated by multiplying 40 with the number of MWh produced by the system per year.

The saving from decreased electricity bills and net metering were calculated for each year using the following equation:

$$\begin{aligned}&\text{Savings from decreased electricity bills and net metering (\$)}\\&= \left[\text{Annual Production } \times \text{unit price } \left(\frac{\$}{kWh}\right)\right]\\&- [(\text{Percentage undervaluation of solar } \times \text{ Annual Production } \times \text{unit price } \left(\frac{\$}{kWh}\right)]\end{aligned}$$

The percentage undervaluation of solar was obtained from data provided by PEA. This calculation takes net metering into consideration. This value was added to the SREC price per year to obtain the total benefits. The year 1 annual production was obtained from PEA and the production of every subsequent year was calculated based on a 0.8% degradation rate. This value was obtained from an NREL study titled 'Photovoltaic Degradation Rates- An Analytical Review' analyzed 2,000 degradation rates, measured on individual modules or entire systems, assembled from literature and showed a mean degradation rate of 0.8%/year (Jordan and Kurtz, 2012).

The price per kWh for the grid electricity offset by the solar enegy produced for year 1 for each household was obtained from PEA and the price per kWh of each subsequent year was calculated based on an escalation rate of 2.3%. This price was determined by the Federal Energy

Management Program in their report titled 'Energy Price Indices and Discount Factors for Life Cycle Cost Analysis 2019' (FEMP, 2019).

Another potential benefit is **increase in property value**. There are many studies which show that installing solar increases the value of a property. However, this value is realized only later when a customer sells their home or if they rent it, so it wasn't included in the analysis. The increase in property value was calculate for an average Philadelphia row home. The price per square foot of a residential property in Philadelphia for the year 2019 was obtained from various real estate websites and their average was calculated.

Table 7. Price per square foot of Philadelphia homes for 2019

Zillow	$180.00
Trulia	$166.00
Redfin	$161.00
Realtor	$165.00
Movoto	$192.00
Average	$172.80

According to the *Philadelphia Rowhouse Manual*, the size of an average row home is 1,500 sq. ft (Schade, 2008). Thus, the cost of an average row house in Philadelphia is 172.8 x 1,500 = $259,200

The increase in property value due to the addition of solar is 3.73% according to a study by the Lawrence Berkeley National Laboratory (LBNL). The study used an appraisal method to evaluate sale price premiums for owned PV systems on single unit detached houses across the country (Adomatis and Hoen, 2016).

The increase in property value with solar = 3.73% of $259,200 = $9,668.2

3.2.3 Calculating Discounted Payback Time and Net Present Value

Cash In is the initial capital Investment of the project. **Cash out** is the difference of the benefits and variable costs incurred by the project every year. This should be a positive value as the yearly benefits should be greater than the yearly costs to break even at some point. In this project, the Cash out is equal to only the value of the benefits as there are no variable costs.

$$\textbf{Simple Payback Time} = \frac{\text{Cash In}}{\text{Cash Out}}$$

The **Cash Flow (CF)** for the first year is calculated using the PV formula with Cash Out as R. The CF of each subsequent year is calculated using the CF of the preceding year as R.

The **Cumulative Cash Flow (CCF)** for the first year is calculated by adding the Cash In (which is given a negative value) with the present value of cashflows for that year. The cumulative cash flow for each subsequent year is calculated by adding the present value of cash flows for that year with the CCF of the previous year.

The DPT is determined by finding the point of time when the inflows are greater than or equal to the outflows, i.e. the first time in the 25 year period, the CCF turns positive (Kenton, 2019).It is calculated using the following formula:

$$\text{DPT} = \text{Year before CCF turns positive (year)} + \frac{\text{CCF in year before recovery (\$)}}{\text{CF in year after recovery (\$)}}$$

The NPV is calculated by subtracting the capital investment from the sum of the discounted cashflows for the 25 years.

3.3 GIS Analysis

The ArcMap and ArcScene software which are the main components of ESRI's GIS suite were used for this analysis. The addresses of all the solar installations across the three phases of the program were obtained from PEA. They were geocoded i.e. the latitude and longitude of these addresses were obtained from https://www.gpsvisualizer.com/geocoding.html and saved as csv files. These csv files were exported into ArcMap along with a shapefile of Philadelphia's boundary. The points were plotted on the Philadelphia boundary using the 'display XY data option' with the help of the latitude and longitude values obtained from the csv file. First, a point shapefiles were created. The colors of each point were adjusted according to respective phases. Point density maps were created from the point shapefiles and exported to ArcScene. In ArcScene, each point density map was given a different colour and extrapolated to the same extent with the same base height to create 2D and 3D maps of point distribution of solar panels in Philadelphia under the *Solarize Philly* program.

4. Results

4.4 Life Cycle Assessment Results

The Life Cycle emissions for each stage were computed according to the above methodology.

For the high – end emission scenario, the emissions for each stage were:

Table 8. Emissions created per stage of a Solar panel used in the *Solarize Philly* program

Stage	**Emissions** (gCO_2e/kwh)
Manufacturing	72.2
Transport	19.6
End of Life	8
Total	99.8

Emissions offset during the Use Phase based on the gCO_2e/kwh of grid electricity = 495 gCO_2e/kwh

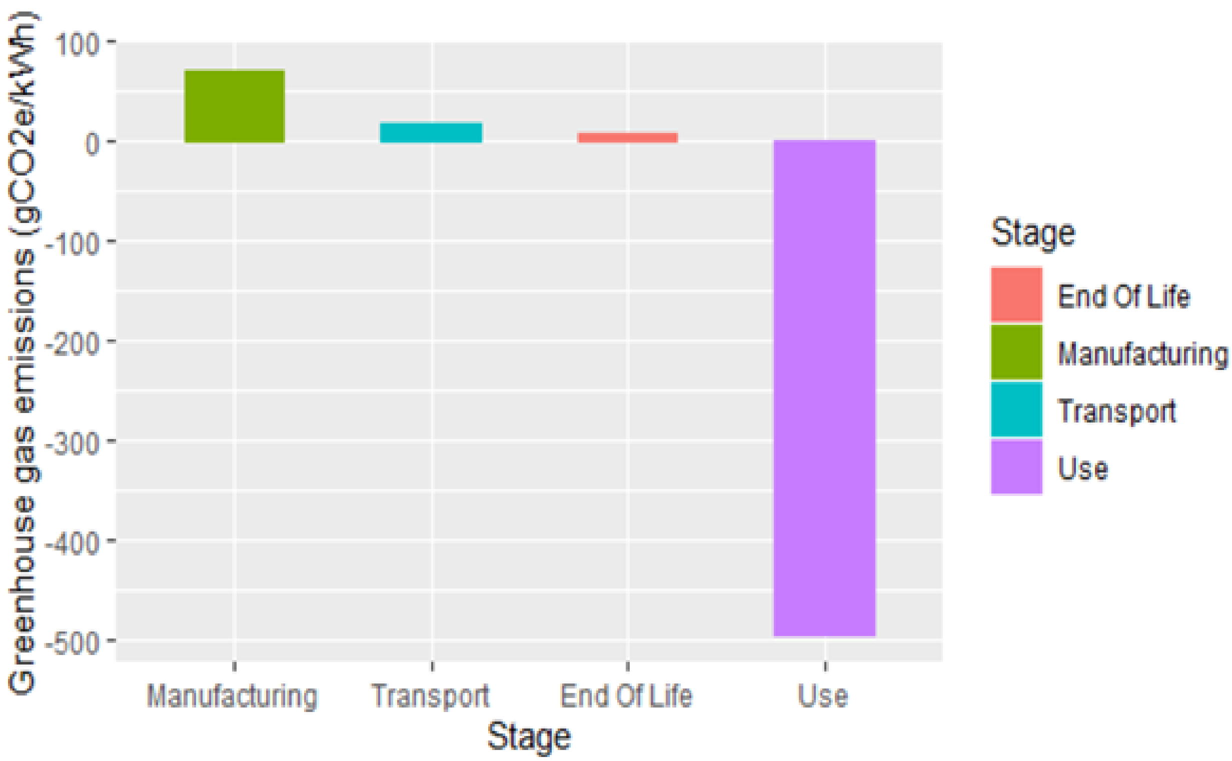

Figure 8. **Emissions created per stage in the Life Cycle of solar panels used in the *Solarize Philly* program under the High – end emission scenario**

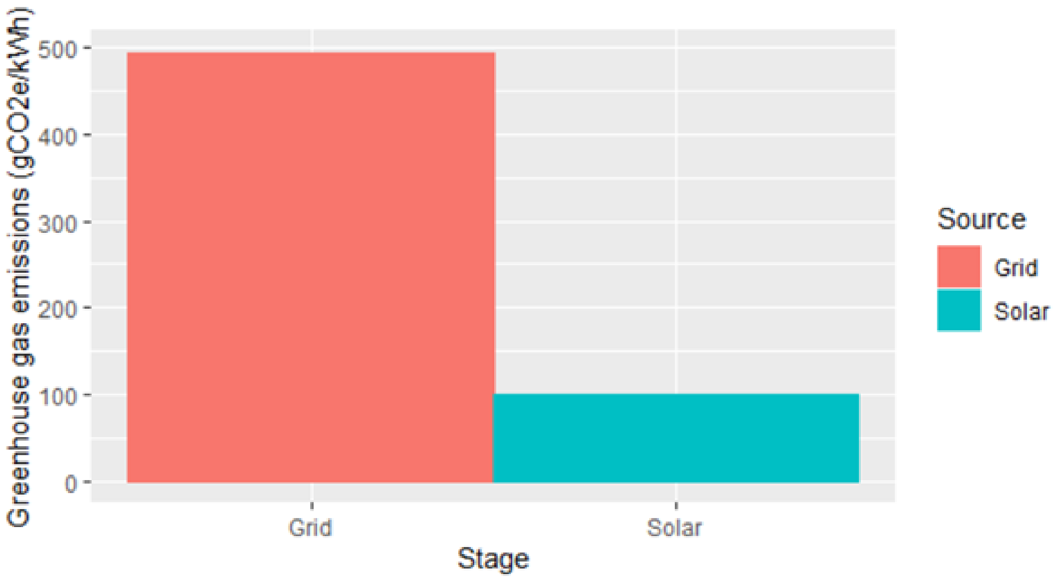

Figure 9. **Comparison of emissions created by grid electricity and solar panels under the High- end emission scenario**

- A single solar panel used in *Solarize Philly* produces 99.8 gCO_2e/kWh across the manufacturing, transport and end of life phases, most coming from manufacturing (72 gCO_2e/kWh).
- 495gCO_2e/kWh are produced by the PJM grid mix.
- Thus, using solar panels by *Solarize Philly* participants offsets 395 gCO_2e/kWh.

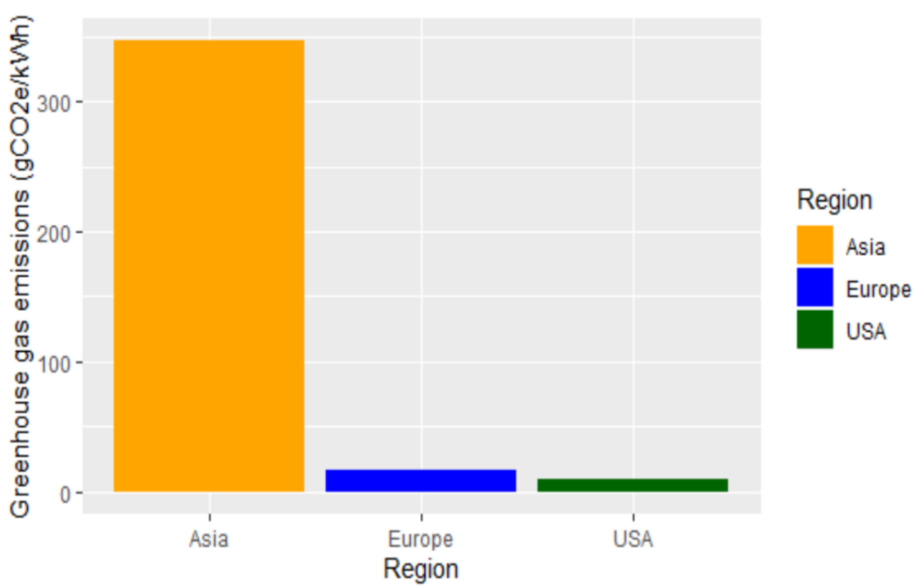

Figure 10. **Comparison of transportation emissions from different regions**

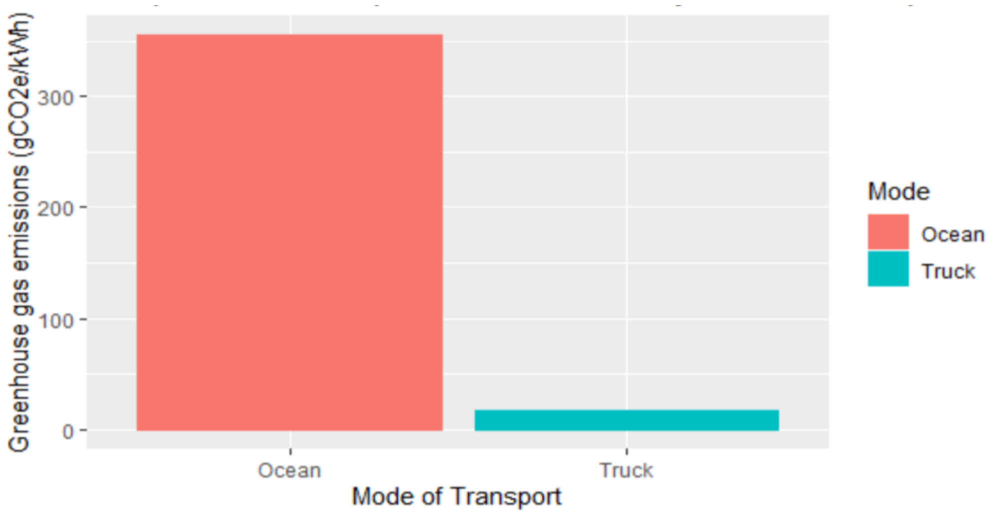

Figure 11. **Comparison of transportation emissions by mode of transport**

A majority of the transportation emissions are from panels manufactured in Asia (346 gCO_2e/kWh) because most of the panels used in the program are produced in Asia and they have to travel the longest distances. Emissions due to ocean freight are greater than truck freight due to the longer distances travelled.

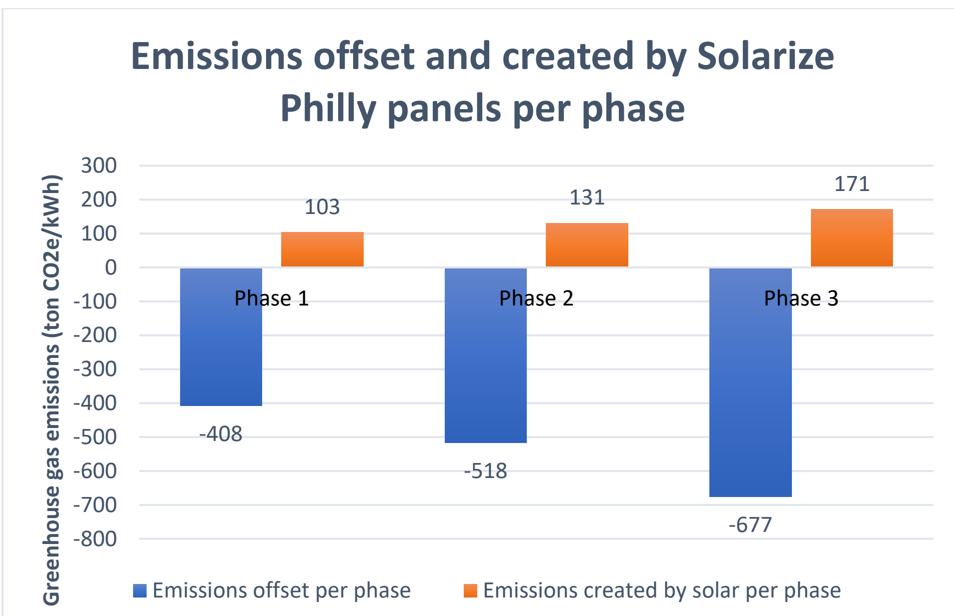

Figure 12. **Emissions offset and created by *Solarize Philly* panels per phase under the High – end emission scenario**

Phase 3 created and offset the most emissions as 1.2MW of solar was installed. This is followed by Phase 2, where 918 kW was installed and then Phase 1 where 724 kW of solar was installed.

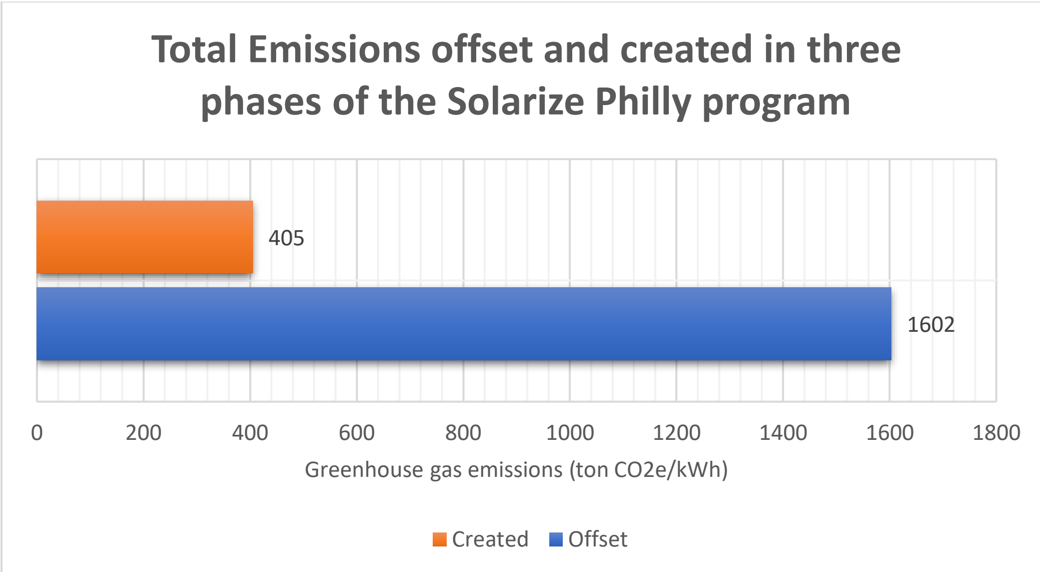

Figure 13. **Total Emissions offset and created in three phases of the *Solarize Philly* program under the High – end emission scenario**

A total of 405-ton CO_2e/kWh were generated by Solar panels and 1,602 ton CO_2e/kWh were offset by them across the three phases of the program.

4.1.1 Sensitivity Analysis

A sensitivity analysis reports other possible results which can occur from a different set of possible conditions. For this sensitivity analysis the Low – end emission scenario was analyzed to understand impacts which occur from the lowest possible emissions from various sources.

Table 9. Emissions created per stage of a Solar panel used in the *Solarize Philly* program under Low- end emission scenarios

Stage	**Emissions** (gCO_2e/kWh)
Manufacturing	37.3
Transport	19.6
End of Life	2
Total	58.9

Emissions produced by grid electricity during the Use Phase = 337.13 gCO_2e/kwh

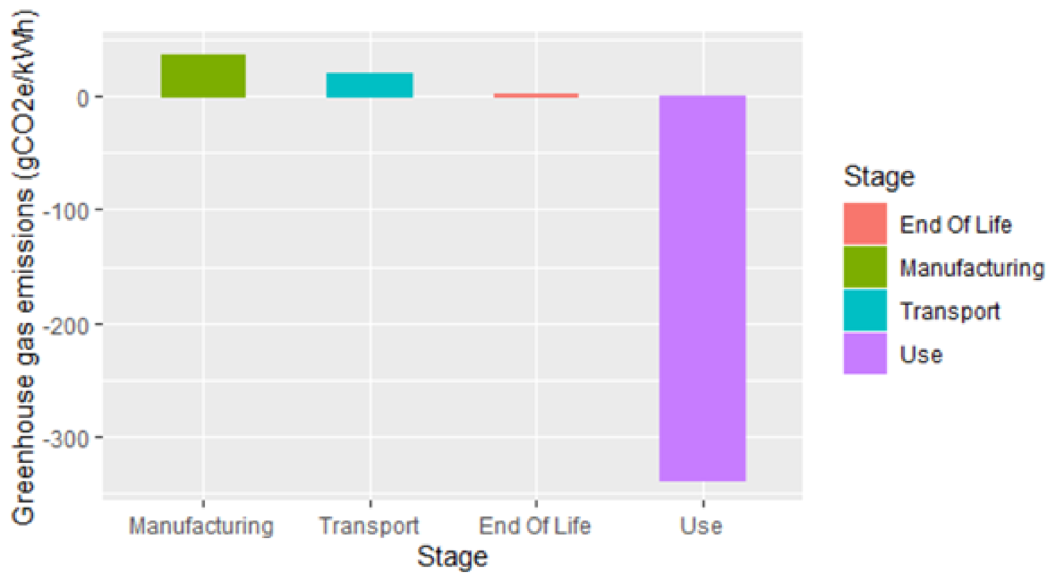

Figure 14. **Emissions created per stage in the Life Cycle of solar panels used in the *Solarize Philly* program under the Low – end emission scenario**

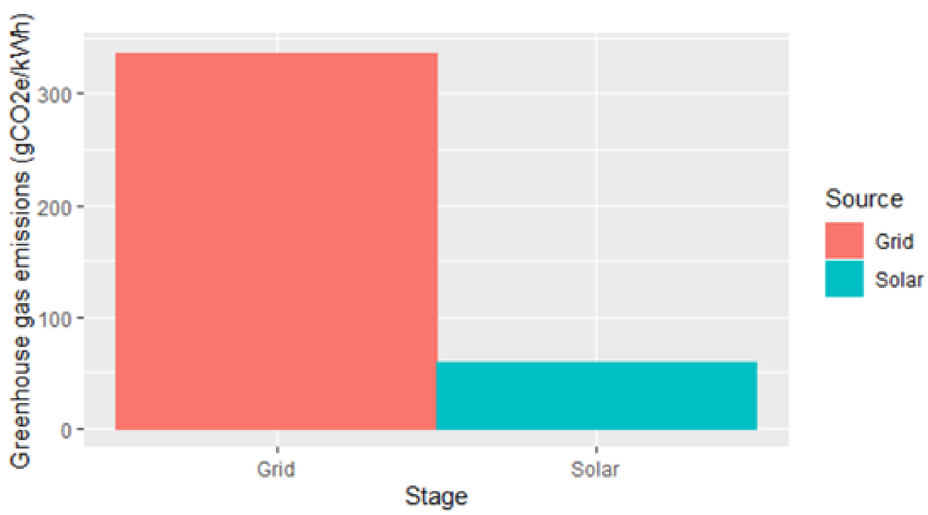

Figure 15. **Comparison of emissions created by grid electricity and solar panels under the Low- end emission scenario**

In this scenario:

- A single solar panel used in *Solarize Philly* produces 58.9 gCO_2e/kWh across the manufacturing, transport and end of life phases, which is significantly lower than the 99.8 gCO_2e/kWh GWP produced under the High – end emission scenario.
- 337 gCO_2e/kWh are produced by the PJM grid mix (495 gCO_2e/kWh under the High-end emission scenario).
- Thus, using solar panels by *Solarize Philly* participants offsets 278 gCO_2e/kWh.

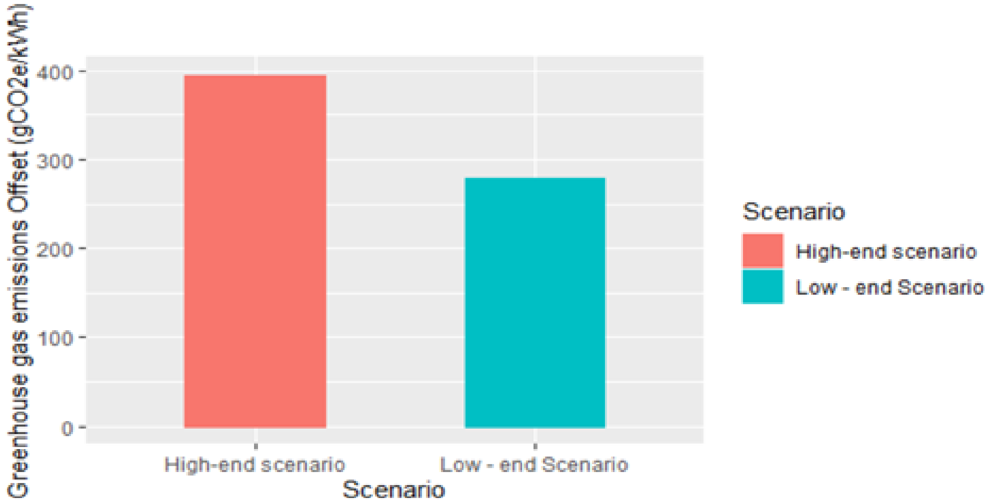

Figure 16. **Comparison of emissions offset under by solar panels under the High-end emission scenario and Low- end emission scenario**

4.1.2 Total Emissions which will be offset by the panels during its lifetime

The current installed capacity of panels used in the *Solarize Philly* program is 2,800 kW. The electricity they will generate in their 25-year warranty period = 2,800 x 3.9 x 365 x 25 = 99,645,000 kWh = 99,645 MWh

3.9 hours is the yearly average number of hours a solar panel in Pennsylvania produces electricity in a day.

The emissions they will offset under the High – end emission scenario conditions = 99,645,000 kWh x 395 gCO_2e/kWh = 39,359,775,000, gCO_2e = 39,359.77 $tonCO_2e$

Similarly, if we perform the same calculations for the 30-year lifespan of the panels, the emissions they will offset = 47,231.73 $tonCO_2e$

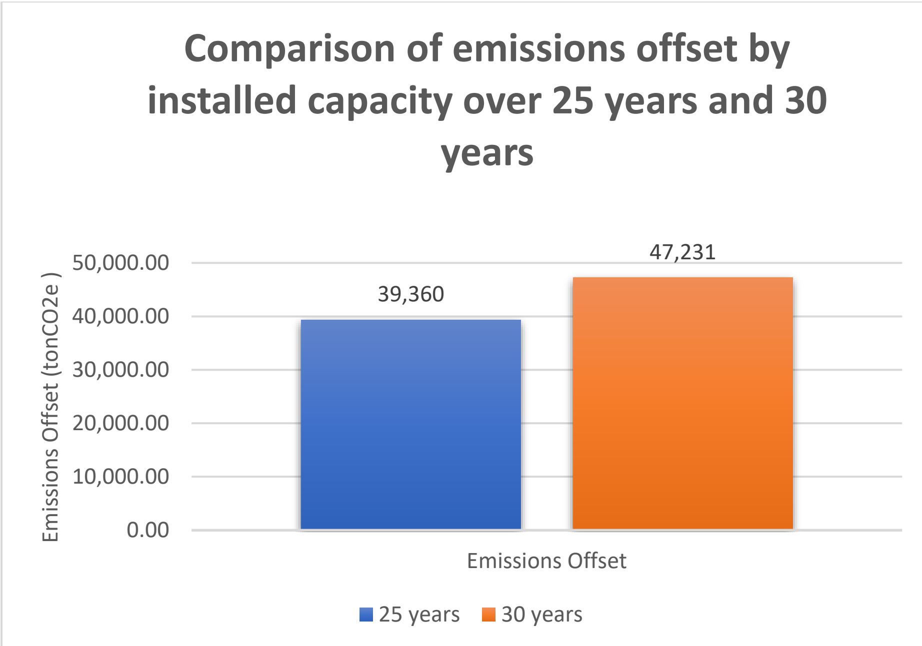

Figure 17. **Comparison of emissions offset by current installed capacity over 25 years and 30 years**

One important point to note is that the degradation rate of the panels has not been considered to calculate the electricity output. An NREL study titled ‘Photovoltaic Degradation Rates — An Analytical Review’ analyzed 2000 degradation rates, measured on individual modules or entire systems, assembled from literature and showed a mean degradation rate of 0·8%/year (Jordan and Kurtz, 2012).

4.2 CBA Results

All the *Solarize Philly* projects studied for this analysis have a discounted payback time that is within the 25 year warranty period of the panels. All of the discounted payback times for the sample five projects are within 16 years. The simple payback times are around 10 years or below. The NPVs of all projects are positive. Thus, every project is cost beneficial.

Table 10. Details of 5 customers considered in the Cost – Benefit Analysis

Customer	**System Size (kW)**	**Year 1 annual production (kWh)**	**Annual consumption (kwh)**	**$/kWh of electricity based on previous PECO bill**	**Installation Price**
A	8.820	10,920	12,754	$0.14	$28,753
B	5.120	6,618	9,431	$0.21	$16,384
C	5.00	5,928	8,109	$0.26	$18,395
D	7.00	6,720	6,145	$0.25	$22,623
E	6.00	7,353	7,205	$0.17	$24,575

Detailed spreadsheets with calculations are in Appendix B

Table 11. Results of CBA for a 25 year time period

Customer	Simple payback time (SBT)	Discounted Payback time (DPT)	Net Present Value (NPV)
A	10.1 years	15.8 years	$ 5,550
B	6.8 years	8.9 year	$ 10,250
C	7.2 years	9.6 years	$ 10,954
D	5.7 years	7.4 years	$ 18,879
E	7.1 years	9.6 years	$ 14,070

The NPV for customer A is the lowest and they also have the longest payback times. This could be due to the high cost of installation.

The average NPV for all projects was $11,941.

The average DPT was 8.26 years.

The average SBT is 7.38 years.

Over a 30 year time period the NPVs increase

Table 12. NPVs for a 30 year time period

Customer	Net Present Value
A	$ 7,589.62
B	$12,005.06
C	$12,926.41
D	$21,514.10
E	$16,581.73

If the amount earned from incentives like the Philadelphia rebate and the FITC were increased the overall CI would decrease and increase the NPV, making the projects have an even higher NPV.

The SREC price in New Jersey in the beginning of 2020 was $225 according to SRECtrade.com. When this value replaced $40 in the NPV calculation for customer A the NPV increased drastically to $26,524. This shows the tremendous influence of SREC prices. If Pennsylvania’s SREC prices come close to New Jersey’s, solar will be much more accessible and profitable to all.

When the increase in property value was considered in the calculation of NPV for customer E, it increased to $23,739. This represents benefits to customers interested in selling their homes.

This analysis highlights the importance of incentives like the Philadelphia solar rebate, the ITC and SRECs and showcases the great difference they can make. Increasing their values will result in higher NPVs. Thus, they are crucial to making rooftop solar installations accessible and affordable to all.

4.3 GIS Results

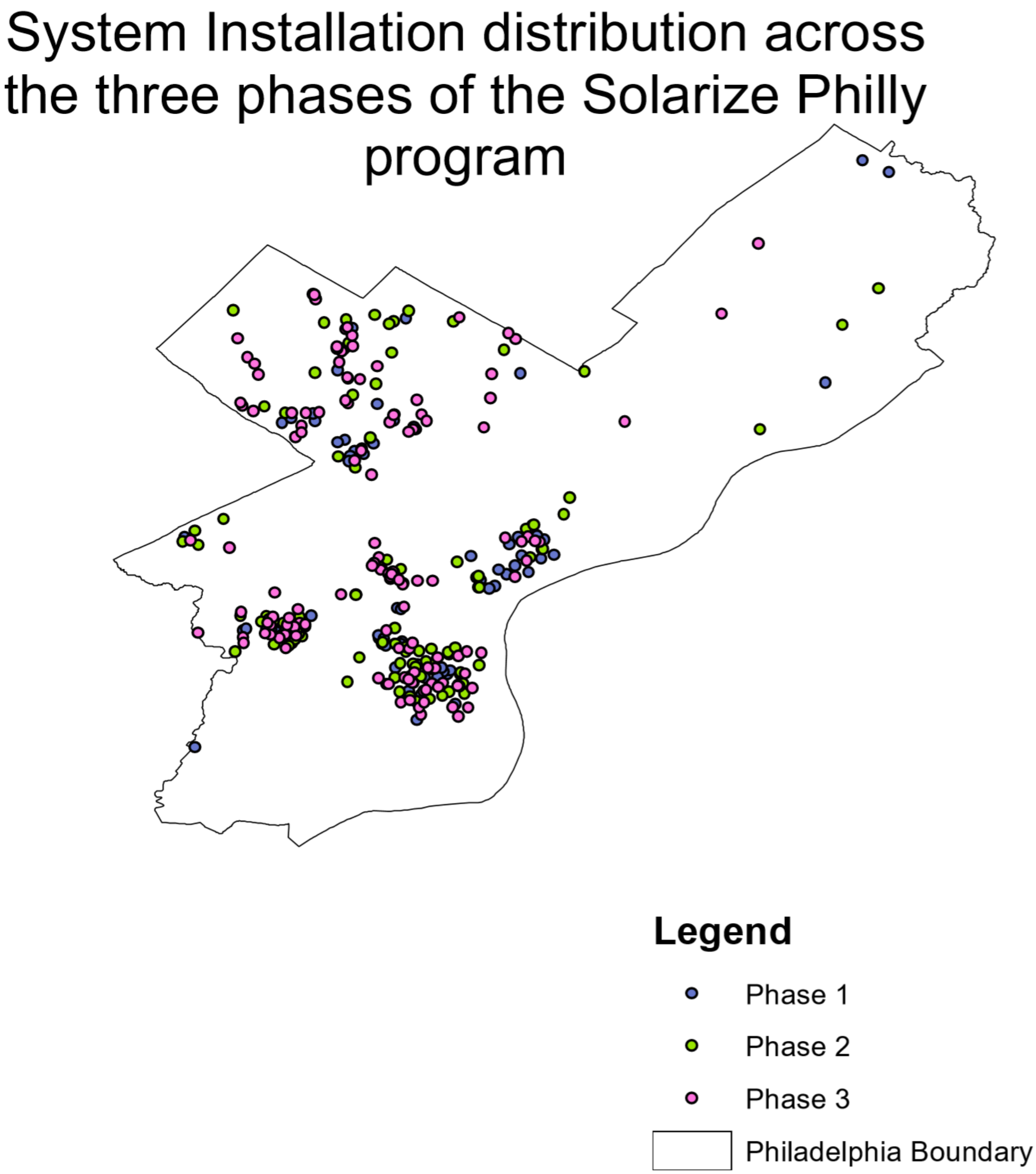

Figure 18. **Point distribution of Solar installations across three phases of the *Solarize Philly* program**

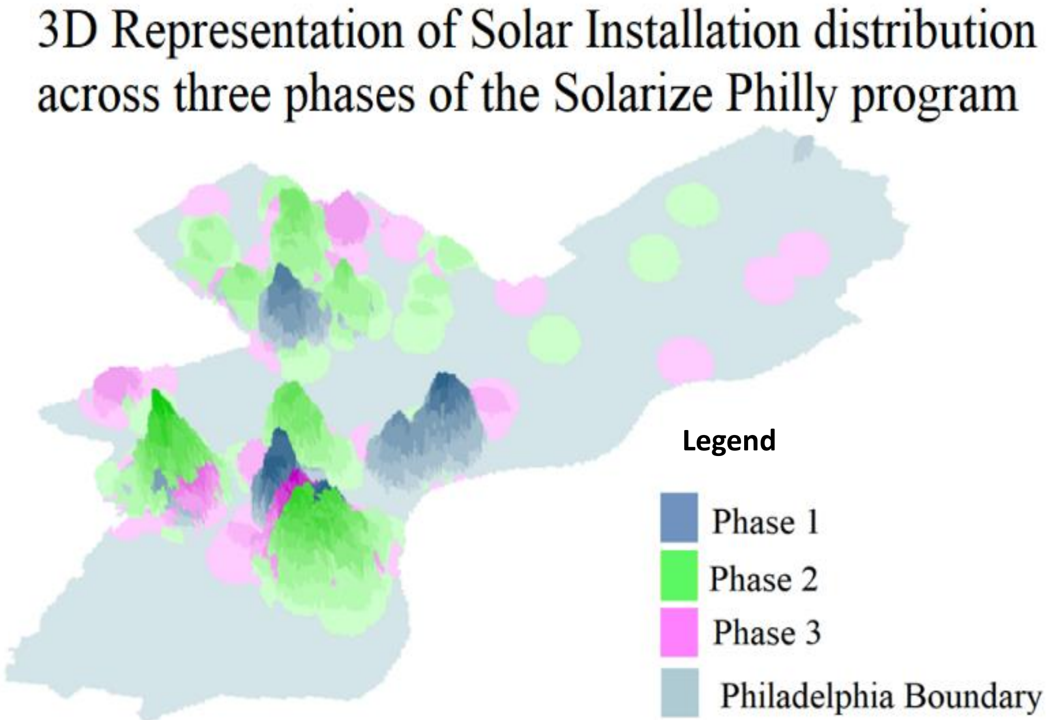

Figure 19. **Point distribution of Solar installations across three phases of the *Solarize Philly* program**

These two maps help in visualizing the distribution of solar installations across the three phases of the program. Clusters can be seen in the west and south of Philadelphia.

It is also observed that as more phases of the program were implemented, the installation locations started to become more dispersed. It can be seen that there are many areas in the city not covered by panels, showing that there is scope for expansion.

5. Discussion

Solarize Philly participants offset an average of 395 gCO_2e for every kWh of electricity they consume from their panels under the High – end emission scenario. Installation of a wide variety of systems with sizes ranging from 5kW to 8kW and installation prices ranging from $16,000 to $28,000 were observed to be cost – beneficial. The program is both environmentally and financially beneficial and GIS maps show us that there is a lot of scope for expansion.

5.1 GIS Analysis

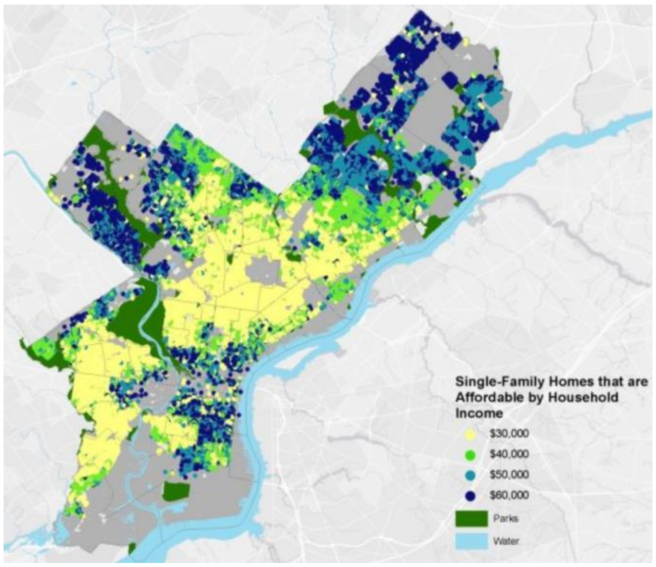

Figure 20. **Distribution of single-family homes in Philadelphia** Source: ESI, (2017). Mapping the Affordability of Philadelphia. Retrieved from: https://econsultsolutions.com /mapping-the-affordability-in-philadelphia/

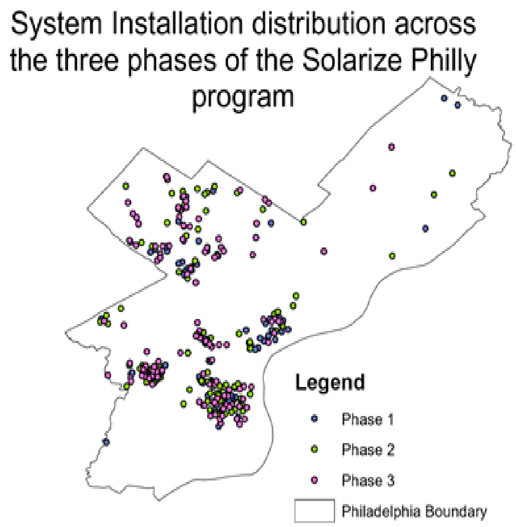

Figure 18. **Point distribution of Solar installations across three phases of the *Solarize Philly* program**

On comparing the above maps, it can be seen that there are many areas with homes that are lacking installations from *Solarize Philly*, especially in the north and southwest parts of the city, which are both lower-income sections of the city. Installations are scarce in the northeast Philadelphia, which according to figure 20 is occupied by higher-income households. There are both high – income and low – income areas in the city which lack installations so we can not confirm that there is a correlation between income and installations.

5.2 Life Cycle Assessment

Studies by Meijer et al. (2003) show that life cycle emissions for mono - Si PV panels range between 39–110 gCO2e/kWh. A study by Alsema and de Wild-Scholten in 2005 reported that this range was between 46 and 63 gCO2e/kWh and NREL's Life Cycle harmonization project reported that the average Life Cycle emissions of mono crystalline silicon solar panels is 40 gCO2e/kWh. The emissions calculated in this study for panels unique to the *Solarize Philly* program was found to range between 99.8 gCO_2e/kWh and 58.9 gCO_2e/kWh for High end and Low-end emission scenarios respectively. These values are close to those reported in other literature.

As discussed in the Review of Literature, most other studies do not consider emissions from the Transportation Phase of panels as they take a generalized view of a panel's Life Cycle and don't assess panels used in a specific geographic location. Since this study followed the Life Cycle of panels used in the *Solarize Philly* program, transportation emissions were calculated as 19.5 gCO2e/kWh. This value was obtained by taking an average of the emissions calculated for each route followed by panels used in the program. If the proportion of panels manufactured in each location was known, more accurate results could have been obtained by taking weighted averages.

From the LCA results, it is observed that the program yields large emission reductions and is beneficial for the environment. One of the observations shows that the solar panels imported from Asia (a majority of which have been from China) have the largest GWP because they travel the farthest distances and use a combination of ocean and road transport. The manufacturing emissions of panels produced in China are also much greater than those produced in Europe and the US due to the nature of the grid electricity in that region (the large proportion of coal-powered electricity in the grid mix).

If more panels that were manufactured locally were used in the program, the Life Cycle impact of the modules would be reduced.

The End of Life emissions which have been considered in this analysis are from NREL's Life Cycle harmonization study. They state that emissions at this stage are due to disposal and decommissioning activities but do not elaborate on what these activities are. It was also observed that there is limited data on the End of Life stage of panels since the industry is relatively new and the panels have a long life span

There are many options available to responsibly manage *Solarize Philly* panels when they reach their End of Life stage. According to a report by Community Energy, ninety-nine percent of the materials in solar panels are recyclable. 100% of the aluminum and 95% of the glass is recyclable. 85% of the silicon and 95% of the semiconductor materials are reusable. This makes it more recyclable than other common forms of E- waste. In the U.S., there are recycling programs like Green Century Recycling, Cleanlites, First Solar, Dynamic-Lifecycle Innovations, Echo Environment, Recycle PV and others, in place to recycle solar modules (Community Energy, 2019). Participants of the *Solarize Philly* program could possibly take part in these programs.

The *Solarize Philly* program started in 2017 and hence the maximum age of panels used in this program is three years. There's a long way to go for these panels to reach their End of Life Stage. Fortunately, many of the stakeholders in the program have started thinking ahead. Some of the manufacturers used in the *Solarize Philly* program including CertainTeed have takeback programs.

'We Recycle Solar' is a solar panel recycling company which can collect obsolete panels from Philadelphia and take it to their facility in New York. They have an efficient way of handling panels during their End of Life Phase, reducing the harmful effects of panels at this stage.

Heavy metals which come in during the mining stage of the manufacturing process can be harmful when panels are disposed into landfills as they can leach into soils and contaminate them (Chowdhury et.al, 2020). 'We Recycle' has a way to prevent them from leaching into the environment. Silver (Ag) and Lead (Pb) are the main heavy metals present in panels in quantities which can be considered hazardous. Sometimes Copper (Cu) and Zinc (Zn) are present in quantities which can be considered hazardous. We Recycle performs chemical analysis on modules they receive to determine the quantity of heavy metals. In their currently limited dataset, they've found a little more than two thirds of modules to be considered legally hazardous due to elevated levels of lead or silver. These elements are mechanically separated, and then chemically processed for transport to refineries for final disposition. Currently, California is the only state which has legislations that determine what quantities are hazardous and what are not (We Recycle, personal communication, March 2020).

5.3 Cost Benefit Analysis

All five projects which were analyzed were observed to be cost – beneficial. They all resulted in positive NPVs and had discounted payback times well within the 25 year warranty period of the panels.

One issue to be cautious about is the rebound effect. It is defined as the reduction in expected gains from new technologies that increase the efficiency of resource use, because of behavioral or other systemic responses (Grubb, 1990). A study by Qiu et. al. in 2019 on residents of Phoenix, Arizona who use solar panels showed that the solar rebound effects are estimated at 18%, i.e. residents used 18% more energy than they did before adopting solar as they believe they are saving more by adopting solar.

Solarize Philly customers need to be careful not to consume more electricity than they did before installing panels. This would result in decreased savings and hence reduce the profitability of their projects.

The CBA shows that incentives are extremely beneficial and their absence could have resulted in negative NPVs for some projects.

The **Federal Investment Tax** credit reduces the cost of a project significantly and enables certain customers to take up projects that they otherwise wouldn't have been able to afford.

According to Section 48 of the policy, the business that installs, develops and/or finances the project claims the credit. The tax credit is a dollar-for-dollar reduction in the income taxes that a person or company would otherwise pay the federal government. (SEIA, 2020).

Unfortunately, the investment tax credit is stepping down. It was initially 30% of the cost of a renewable energy project, from 2020 it's 26% of the cost of a project and will be stepping down to 22% in 2021 and 10% in 2022 for commercial users but 0% for residential customers.

This incentive has bolstered growth in the solar industry. Solar installations were projected to grow by 54% between 2015 and 2020 due to the ITC (Munsell, 2015). We would expect to see a drop in this growth as the ITC starts stepping down.

The **Philadelphia solar rebate program** was introduced to account for the stepping down of the ITC. The program will run from January 1, 2020 through December 31, 2024. It allows the City to allocate up to $500,000 per year for the Solar Incentive Program to be issued to solar customers on a first-come first-serve basis, with a potential prioritization of low-income households. A typical homeowner would receive an average rebate of $1,000 after installing solar on their home (Crump, 2019).

The rebate is definitely making solar energy cheaper than it would be in its absence but since it is distributed on a first come first serve basis there is no guarantee that every customer who applies for it will get it.

SRECs are another major benefit from solar. They aren't one – time payments and are received on a continuous basis so they remain a constant source of revenue over the life of the project. Since they increase property value, it is beneficial while selling a property with an installed solar system to someone. From the CBA it was seen that if Pennsylvania SREC prices reached the same value as those in New Jersey, NPV value for projects would greatly increase. Thus, if SREC prices increased many more Philadelphians would probably go solar.

Thus, PEA can target neighborhoods which currently have fewer installations to expand the program. Since incentives make projects more profitable, PEA can try to increase the value of incentives within their control such as their discount which decreases the overall cost of installation. They should choose domestically produced panels in their future phases as they will have lower Life Cycle emissions.

6. Conclusion

This paper analyzed the Life Cycle emissions of a solar panel used in the *Solarize Philly* program and calculated the emissions they offset from grid electricity. It was found that a large amount of emissions are offset, proving that the program is highly beneficial and should be expanded. The Cost Benefit Analysis assessed five installations which were all cost beneficial and had reasonable payback times.

Environmental impacts like ozone depletion, ecotoxicity, water pollution and air pollution were not assessed in the Life Cycle Assessment. Qualitative benefits such as avoided costs of environmental externalities such as decreased health costs from decreased air pollution and social benefits such as job creation were not assessed. These issues can be analyzed in future studies.

Forecasting the number of installations during future phases isn't feasible at present as the program has completed only three phases and there are only three data points available. As the program progresses and more data points are obtained, more accurate predictions can be made. Even five data points would yield better results than three. This data can be used to predict impacts and shape decisions.

The data collected and analyzed in this study can be used to plan future phases of the program. It can be used to choose panel manufacturers, quantify impacts and understand the value of incentives and identify areas in the city to target for future expansion.

Solarize Philly is making solar accessible to more Philadelphians at profitable rates and is avoiding tons of greenhouse gas emissions each year by decreasing dependence in grid electricity. The program is helping Philadelphia reach its climate targets.

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8.Appendices

8.1 Appendix A

Life Cycle Assessment Data Inventory

Manufacturing Phase

Manufacturing location	Emissions	Unit
Europe	37.3	gCO2e/kWh
China	72.2	gCO2e/kWh

Transport Phase

Brand	Starting point	Endpoint	Type of Transport	Distance (km)	Emission_ Ocean (Distance x 30) (gCO2e/ton SP)	Emission _truck (Distance x 72.61) (gCO2e/ton SP)	Weight of 1 solar panel (kg)	Factor 2 (ton SP/kWh)	Emissions_ trucks/ ocean (gCO2e/kWh)	Emissions from each brand(gCO2e/kWH)
Yingli	Point A	Point B	Truck Freight	256.78		18644.80	18.6	4.1375E-05	0.77	
	Point B	Point C	Ocean freighter	19841.01	595230.30		18.6	4.1375E-05	24.63	25.86
	Point C	Philadelphia, PA, USA	Truck Freight	152.18		11049.79	18.6	4.1375E-05	0.46	
CertainTeed	Point D	Point E	Truck Freight	50.01		3631.23	19.6	4.3599E-05	0.16	
	Point E	Point F	Ocean freighter	21474.07	644222.10		19.6	4.3599E-05	28.09	28.09
	Point F	Philadelphia, PA, USA	Truck Freight	10.07		731.18	19.6	4.3599E-05	0.03	
LG	Huntsville, AL, USA	Philadelphia, PA, USA	Truck Freight	1345.56		97701.11	17.1	3.8038E-05	3.72	3.72
	Gumi-si, South Korea	Pohang, South Korea	Truck Freight	108.23		7858.58	17.1	3.8038E-05	0.30	
	Pohang, South Korea	Camden, NJ, USA	Ocean freighter	18495.95	554878.50		17.1	3.8038E-05	21.11	21.11
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	17.1	3.8038E-05	0.03	
Q cells	Dalton, GA, USA	Philadelphia, PA, USA	Truck Freight	1188.06		86265.04	18.7	4.1597E-05	3.59	3.59
	Jincheon, South Korea	Pyeong Taek, South Korea	Truck Freight	63.49		4610.01	18.7	4.1597E-05	0.19	
	Pyeong Taek, South Korea	Camden, NJ, USA	Ocean freighter	19237.20	577116.00		18.7	4.1597E-05	24.01	24.01
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	18.7	4.1597E-05	0.03	
	Cyberjaya, Selangor, Malaysia	Port Kelang Malaysia	Truck Freight	57.78		4195.41	18.7	4.1597E-05	0.17	
	Port Kelang Malaysia	Camden, NJ, USA	Ocean freighter	18694.33	560829.90		18.7	4.1597E-05	23.33	23.33

	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	18.7	4.1597E-05	0.03	
Axitec	Vina Cell Technologies Van Trung,Vietnam	Hanoi, Vetnam	Truck Freight	50.01		3631.23	18.5	4.1152E-05	0.15	
	Hanoi, Vetnam	Camden, NJ, USA	Ocean freighter	21474.07	644222.10		18.5	4.1152E-05	26.51	26.51
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	18.5	4.1152E-05	0.03	
	Sun M technologies, Hyderabad, India	Krishnapatnam , India	Truck Freight	480.16		34864.42	18.5	4.1152E-05	1.43	
	Krishnapatnam , India	Camden, NJ, USA	Ocean freighter	16789.09	503672.70		18.5	4.1152E-05	20.73	20.73
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	18.5	4.1152E-05	0.03	
	Baoding, Heibei Province, China	Huanghua, China	Truck Freight	256.78		18644.80	18.5	4.1152E-05	0.77	
	Huanghua, China	Camden, NJ, USA	Ocean freighter	19788.85	593665.50		18.5	4.1152E-05	24.43	24.43
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	18.5	4.1152E-05	0.03	
	Heimsheimer Str. Weil der Stadt, Germany	Karlsruhe, Germany	Truck Freight	58.44		4243.33	18.5	4.1152E-05	0.17	
	Karlsruhe, Germany	Camden, NJ, USA	Ocean freighter	7007.43	210222.90		18.5	4.1152E-05	8.65	8.65
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	18.5	4.1152E-05	0.03	
Jinko										
pg 4	Shangrao, China	Jinhua, China	Truck Freight	205.98		14956.21	19	4.2264E-05	0.63	
	Jinhua, China	Camden, NJ, USA	Ocean freighter	19768.95	593068.50		19	4.2264E-05	25.07	25.07
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	19	4.2264E-05	0.03	
	Haining, China	Ranlishan, China	Truck Freight	25.99		1887.13	19	4.2264E-05	0.08	
	Ranlishan, China	Camden, NJ, USA	Ocean freighter	19514.43	585432.90		19	4.2264E-05	24.74	24.74
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	19	4.2264E-05	0.03	
	Portugal	Figueira Da Foz, Portugal	Truck Freight	144.59		10498.68	19	4.2264E-05	0.44	
	Figueira Da Foz, Portugal	Camden, NJ, USA	Ocean freighter	5704.42	171132.60		19	4.2264E-05	7.23	7.23
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	19	4.2264E-05	0.03	
	Perai, Malaysia	Penang, Malaysia	Truck Freight	15.40		1118.19	19	4.2264E-05	0.05	

	Penang, Malaysia	Camden, NJ, USA	Ocean freighter	18512.88	555386.40		19	4.2264E-05	23.47	23.47
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	19	4.2264E-05	0.03	
Longi	Xi'an, China	Wanxian, China	Truck Freight	631.58		45859.02	18.2	4.0485E-05	1.86	
	Wanxian, China	Camden, NJ, USA	Ocean freighter	21323.81	639714.30		18.2	4.0485E-05	25.90	25.90
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	18.2	4.0485E-05	0.03	
Panasonic	Osaka, Japan	Camden, NJ, USA	Ocean freighter	18354.29	550628.70		19	4.2264E-05	23.27	23.27
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	19	4.2264E-05	0.03	
	Selangor, Malaysia	Port Kelang, Malaysia	Truck Freight	28.21		2048.33	19	4.2264E-05	0.09	
	Port Kelang, Malaysia	Camden, NJ, USA	Ocean freighter	18694.33	560829.90		19	4.2264E-05	23.70	23.70
	Camden, NJ, USA	Philadelphia, PA, USA	Truck Freight	10.07		731.18	19	4.2264E-05	0.03	
	Buffalo, NY, USA	Philadelphia, PA, USA	Truck Freight	610.80		44350.19	19	4.2264E-05	1.87	1.87
Average										19.2249

8.2 Appendix B

Cost Benefit Analyses

Customer A

System Size (kW)	8.82							
System Size (W)	8820							
Year 1 annual production (kWh)	10920							
Year 1 Annual consumption (kwh)	12754							
SREC Cost	40.00							
COSTS AND BENEFITS								
Cash In								
FIXED COSTS								
Capital investment								
Cost of Installation after Solarize Pilly discount ($)	28,753.00							
Investment tax credit($)	-7475.78							
Philadelphia rebate($)	-1764							

Total CI	$ (19,513)							
Cash flow	**Annual production**	**Electricity rate ($)**	**Total Savings($)**	**SREC**	**Cash in (Total CI)**	**Cash out**	**CF, i=6.9%**	**CCF, i=6.9%**
1	10,920	0.14	1528.80	$ 400	-$ 19,513	$ 1,929	$ 1,804	$ (17,708.92)
2	10,833	0.14	1551.45	$ 400		$ 1,951	$ 1,708	$ (16,001.25)
3	10,746	0.15	1574.44	$ 400		$ 1,974	$ 1,616	$ (14,385.00)
4	10,660	0.15	1597.76	$ 400		$ 1,998	$ 1,530	$ (12,855.20)
5	10,575	0.15	1621.44	$ 400		$ 2,021	$ 1,448	$ (11,407.19)
6	10,490	0.16	1645.46	$ 400		$ 2,045	$ 1,371	$ (10,036.55)
7	10,406	0.16	1669.84	$ 400		$ 2,070	$ 1,297	$ (8,739.09)
8	10,323	0.16	1694.58	$ 400		$ 2,095	$ 1,228	$ (7,510.88)
9	10,240	0.17	1719.69	$ 400		$ 2,120	$ 1,163	$ (6,348.16)
10	10,158	0.17	1745.16	$ 400		$ 2,145	$ 1,101	$ (5,247.43)
11	10,077	0.18	1771.02	$ 400		$ 2,171	$ 1,042	$ (4,205.33)
12	9,997	0.18	1797.26	360		$ 2,157	$ 969	$ (3,236.67)
13	9,917	0.18	1823.89	360		$ 2,184	$ 917	$ (2,319.35)
14	9,837	0.19	1850.91	360		$ 2,211	$ 869	$ (1,450.62)
15	9,759	0.19	1878.33	360		$ 2,238	$ 823	$ (627.89)
16	9,680	0.20	1906.16	360		$ 2,266	$ 779	$ 151.31
17	9,603	0.20	1934.41	360		$ 2,294	$ 738	$ 889.30
18	9,526	0.21	1963.07	360		$ 2,323	$ 699	$ 1,588.27
19	9,450	0.21	1992.15	360		$ 2,352	$ 662	$ 2,250.32
20	9,374	0.22	2021.67	360		$ 2,382	$ 627	$ 2,877.41
21	9,299	0.22	2051.62	360		$ 2,412	$ 594	$ 3,471.39
22	9,225	0.23	2082.02	360		$ 2,442	$ 563	$ 4,034.04
23	9,151	0.23	2112.86	360		$ 2,473	$ 533	$ 4,567.03
24	9,078	0.24	2144.17	360		$ 2,504	$ 505	$ 5,071.92
25	9,005	0.24	2175.94	360		$ 2,536	$ 478	$ 5,550.21
Totals						$ 55,294.09	$ 25,063.43	$ (91,628.33)
Simple PBT, years	10.1	years						
Project duration	25	years						
NPV	$5,550							
Discounted pay back	15.8	years						

Customer B

System Size (kW)	5.12							
System Size (W)	5120.00							
Year 1 annual production (kWh)	6618.00							
Annual consumption (kwh)	9431.00							
$/kWh of electricity based on previous PECO bill	0.21							
SREC price	40.00	https://www.srectrade.com/markets/rps/srec/pennsylvania						
Cash In								
FIXED COSTS								
Capital investment	$							
Cost of Installation after Solarize Pilly discount	16384.00							
Investment tax credit	-4259.84							
Philadelphia rebate	-1024.00							
Total CI	-11100.16							
Cash Flow	**Annual production**	**Price/ kwh**	**Savings**	**SREC ($)**	**Total CI ($)**	**Cash out**	**CF, i=6.9%**	**CCF, i=6.9%**
1.00	6618.00	0.21	1389.78	240.00	-11100.16	1629.78	1524.58	-9575.58
2.00	6565.06	0.21	1410.37	240.00		1650.37	1543.85	-8031.73
3.00	6512.54	0.22	1431.27	240.00		1671.27	1462.48	-6569.25
4.00	6460.44	0.22	1452.47	240.00		1692.47	1385.44	-5183.81

5.00	6408.75	0.23	1473.99	240.00		1713.99	1312.50	-3871.31
6.00	6357.48	0.24	1495.83	240.00		1735.83	1243.42	-2627.89
7.00	6306.62	0.24	1517.99	240.00		1757.99	1178.02	-1449.87
8.00	6256.17	0.25	1540.48	240.00		1780.48	1116.08	-333.79
9.00	6206.12	0.25	1563.31	240.00		1803.31	1057.42	723.63
10.00	6156.47	0.26	1586.47	240.00		1826.47	1001.87	1725.50
11.00	6107.22	0.26	1609.97	240.00		1849.97	949.27	2674.77
12.00	6058.36	0.27	1633.83	240.00		1873.83	899.45	3574.22
13.00	6009.89	0.28	1658.04	240.00		1898.04	852.26	4426.47
14.00	5961.82	0.28	1682.60	200.00		1882.60	790.77	5217.24
15.00	5914.12	0.29	1707.53	200.00		1907.53	749.52	5966.76
16.00	5866.81	0.30	1732.83	200.00		1932.83	710.44	6677.20
17.00	5819.87	0.30	1758.50	200.00		1958.50	673.41	7350.61
18.00	5773.31	0.31	1784.56	200.00		1984.56	638.33	7988.94
19.00	5727.13	0.32	1811.00	200.00		2011.00	605.08	8594.02
20.00	5681.31	0.32	1837.83	200.00		2037.83	573.58	9167.60
21.00	5635.86	0.33	1865.06	200.00		2065.06	543.72	9711.32
22.00	5590.77	0.34	1892.69	200.00		2092.69	515.43	10226.75
23.00	5546.05	0.35	1920.73	200.00		2120.73	488.63	10715.38
24.00	5501.68	0.35	1949.19	200.00		2149.19	463.22	11178.60
25.00	5457.67	0.36	1978.07	200.00		2178.07	439.14	11617.74
Totals							**22717.90**	**79893.53**
Simple PBT, years	6.81	years						
Project duration	25.00	years						
NPV	10249.79	9M						

Discounted pay back	8.94	years						

Customer C

System Size (kW)	5.00							
System Size (W)	5000.00							
Year 1 annual production (kWh)	5928.00							
Annual consumption (kwh)	8109.00							
$/kWh of electricity based on previous PECO bill	0.26							
SREC trade shows that PA prices have been hovering around $40/kw for 2020	40.00	https://www.srectrade.com/markets/rps/srec/pennsylvania						
Cash In								
FIXED COSTS								
Capital investment	$							
Cost of Installation after Solarize Pilly discount	18395.00							
Investment tax credit	-4782.70							
Philadelphia rebate	-1000.00							
Adders	760.00							
Total CI	-13372.30							
Annual production (kWh)	**Price($)/ kwh**	**Savings**	**SREC price ($)**	**Cash flow**	**Cash in ($)**	**Cash out ($)**	**CF, i=6.9%**	**CCF, i=6.9%**

5928.00	0.26	1659.83	200.00	1.00	-13372.30	1859.83	1739.79	-11632.51
5880.58	0.27	1681.72	200.00	2.00		1881.72	1646.65	-9985.87
5833.53	0.27	1703.95	200.00	3.00		1903.95	1558.56	-8427.31
5786.86	0.28	1726.54	200.00	4.00		1926.54	1475.25	-6952.05
5740.57	0.28	1749.48	200.00	5.00		1949.48	1396.46	-5555.59
5694.64	0.29	1772.78	200.00	6.00		1972.78	1321.94	-4233.65
5649.09	0.30	1796.45	200.00	7.00		1996.45	1251.45	-2982.20
5603.89	0.30	1820.48	200.00	8.00		2020.48	1184.77	-1797.43
5559.06	0.31	1844.90	200.00	9.00		2044.90	1121.69	-675.74
5514.59	0.32	1869.70	200.00	10.00		2069.70	1062.01	386.28
5470.47	0.33	1894.88	200.00	11.00		2094.88	1005.55	1391.83
5426.71	0.33	1920.46	200.00	12.00		2120.46	952.13	2343.96
5383.30	0.34	1946.44	200.00	13.00		2146.44	901.59	3245.55
5340.23	0.35	1972.82	200.00	14.00		2172.82	853.76	4099.31
5297.51	0.36	1999.61	200.00	15.00		2199.61	808.50	4907.81
5255.13	0.37	2026.82	200.00	16.00		2226.82	765.67	5673.48
5213.09	0.37	2054.45	200.00	17.00		2254.45	725.14	6398.62
5171.38	0.38	2082.51	200.00	18.00		2282.51	686.77	7085.39
5130.01	0.39	2111.01	200.00	19.00		2311.01	650.47	7735.86
5088.97	0.40	2139.94	200.00	20.00		2339.94	616.10	8351.96
5048.26	0.41	2169.32	200.00	21.00		2369.32	583.57	8935.52
5007.87	0.42	2199.16	200.00	22.00		2399.16	552.78	9488.30
4967.81	0.43	2229.46	160.00	23.00		2389.46	515.01	10003.31
4928.07	0.44	2260.22	160.00	24.00		2420.22	487.97	10491.27
4888.64	0.45	2291.46	160.00	25.00		2451.46	462.36	10953.64
Totals							**24325.94**	
Simple PBT, years	7.20	years						

Project duration	25.00	years						
NPV	10954.00	9M						
Discounted pay back	9.60	years						

Customer D

Mode of financing - Solar loan	$155/month							
System Size (kW)	7							
System Size (W)	7000							
Cost of Installation after Solarize Pilly discount	32,332							
Year 1 annual production (kWh)	6720							
Annual consumption (kwh)	6145							
$/kWh of electricity based on previous PECO bill	0.25							
SREC trade shows that PA prices have been hovering around $40/kw for 2020	40.00	https://www.srectrade.com/markets/rps/srec/pennsylvania						
Cash In								
FIXED COSTS								
Capital investment	$22,623							
Adders	$2,500							
Investment tax credit	-8406.32							
Philadelphia rebate	-1400							

Interest on Loan price	676.42							
VARIABLE COSTS								
Total CI	$ (15,993)							
Annual production	**Price/kwh**	**Savings($)**	**SREC ($)**	**Cash flow**	**Cash in($)**	**Cash out($)**	**CF, i=6.9%**	**CCF, i=6.9%**
6720.00	0.25	2553.57	240.00	1	-15993.10	2793.57	2613.25	-13379.85
6666.24	0.26	2571.47	240.00	2		2811.47	2460.24	-10919.60
6612.91	0.26	2589.79	240.00	3		2829.79	2316.44	-8603.16
6560.01	0.27	2608.55	240.00	4		2848.55	2181.29	-6421.87
6507.53	0.27	2627.74	240.00	5		2867.74	2054.24	-4367.63
6455.47	0.28	2647.37	240.00	6		2887.37	1934.80	-2432.83
6403.82	0.29	2667.45	240.00	7		2907.45	1822.50	-610.33
6352.59	0.29	2687.97	240.00	8		2927.97	1716.90	1106.57
6301.77	0.30	2708.96	240.00	9		2948.96	1617.59	2724.17
6251.36	0.31	2730.40	240.00	10		2970.40	1524.19	4248.35
6201.35	0.31	2752.31	240.00	11		2992.31	1436.32	5684.67
6151.74	0.32	2774.70	240.00	12		3014.70	1353.66	7038.34
6102.52	0.33	2797.56	240.00	13		3037.56	1275.89	8314.23
6053.70	0.34	2820.91	240.00	14		3060.91	1202.71	9516.95
6005.27	0.34	2844.74	240.00	15		3084.74	1133.84	10650.79
5957.23	0.35	2869.08	200.00	16		3069.08	1055.27	11706.06
5909.57	0.36	2893.92	200.00	17		3093.92	995.15	12701.21
5862.30	0.37	2919.27	200.00	18		3119.27	938.54	13639.75
5815.40	0.38	2945.13	200.00	19		3145.13	885.24	14525.00
5768.87	0.39	2971.51	200.00	20		3171.51	835.05	15360.05
5722.72	0.39	2998.43	200.00	21		3198.43	787.78	16147.83
5676.94	0.40	3025.88	200.00	22		3225.88	743.26	16891.08

5631.53	0.41	3053.87	200.00	23		3253.87	701.32	17592.40
5586.47	0.42	3082.41	200.00	24		3282.41	661.80	18254.20
5541.78	0.43	3111.51	200.00	25		3311.51	624.57	18878.78
Totals							**34871.88**	
Simple PBT, years	5.7	years						
Project duration	25	years						
NPV	18,879	9M						
Discounted pay back	7.4	years						

Customer D

System Size (kW)	6							
System Size (W)	6000							
Year 1 annual production (kWh)	7353							
Annual consumption (kwh)	7205							
$/kWh of electricity based on previous PECO bill	0.17							
SREC price/MWh	40	https://www.srectrade.com/markets/rps/srec/pennsylvania						
Cash In								
FIXED COSTS								

Capital investment	$							
Cost of Installation after Solarize Pilly discount ($)	24575.00							
Investment tax credit ($)	-6389.50							
Philadelphia rebate ($)	-1200							
Adders	$500							
Total CI	-17485.50							
Annual production	**Price/kwh**	**Savings($)**	**SREC price ($)**	**Cash flow**	**Cash in ($)**	**Cash out ($)**	**CF, i=6.9%**	**CCF, i=6.9%**
7353.00	0.25	2426.47	280	1	-17485.50	2461.47	2302.59	-15182.91
7294.18	0.26	2449.00	280	2		2484.00	2173.68	-13009.23
7235.82	0.26	2471.97	280	3		2506.97	2052.18	-10957.04
7177.94	0.27	2495.39	280	4		2530.39	1937.65	-9019.39
7120.51	0.27	2519.26	280	5		2554.26	1829.68	-7189.71
7063.55	0.28	2543.58	280	6		2578.58	1727.89	-5461.82
7007.04	0.29	2568.38	280	7		2603.38	1631.90	-3829.92
6950.98	0.29	2593.64	240	8		2628.64	1541.38	-2288.54
6895.38	0.30	2619.38	240	9		2654.38	1456.01	-832.54
6840.21	0.31	2645.60	240	10		2680.60	1375.48	542.95
6785.49	0.31	2672.31	240	11		2707.31	1299.52	1842.47
6731.21	0.32	2699.52	240	12		2734.52	1227.86	3070.33
6677.36	0.33	2727.23	240	13		2762.23	1160.25	4230.58
6623.94	0.34	2755.45	240	14		2790.45	1096.44	5327.02
6570.95	0.34	2784.18	240	15		2819.18	1036.23	6363.25

6518.38	0.35	2813.44	240	16		2848.44	979.41	7342.66
6466.23	0.36	2843.23	240	17		2878.23	925.77	8268.43
6414.50	0.37	2873.55	240	18		2908.55	875.14	9143.57
6363.19	0.38	2904.41	240	19		2939.41	827.34	9970.91
6312.28	0.39	2935.83	240	20		2970.83	782.21	10753.12
6261.78	0.39	2967.81	240	21		3002.81	739.60	11492.72
6211.69	0.40	3000.35	240	22		3035.35	699.36	12192.08
6162.00	0.41	3033.46	240	23		3068.46	661.35	12853.43
6112.70	0.42	3067.16	240	24		3102.16	625.46	13478.89
6063.80	0.43	3101.44	240	25		3136.44	591.55	14070.45
Total							**31555.95**	
Simple PBT, years	7.10	years						
Project duration	25.00	years						
NPV	14070.45	9M						
Discounted pay back	9.61	years						