PHOTOVOLTAIZATION OF WPI

An Interactive Qualifying Project Report
Submitted to the Faculty of
WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science
by

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Abstract

Our campus has approximately 60,000 ft^2 available roof space for photovoltaic (PV) installations. This condition translates in availability of a total maximum power of 426kW and the potential to generate an impressive 500MWh/year. By producing this, we will be reducing the amount of CO2 by 400 tons/year which is the equivalent to planting about 1900 trees. This study helped determined the feasibility of "Photovoltization" of the WPI campus.

Executive Summary

This Interactive Qualifying Project, Photovoltization of WPI Campus, explores many different options available to WPI for investing in photovoltaic technology. The goal was to design an investment plan whose execution would benefit the WPI community as well as provide the institute with monetary savings.

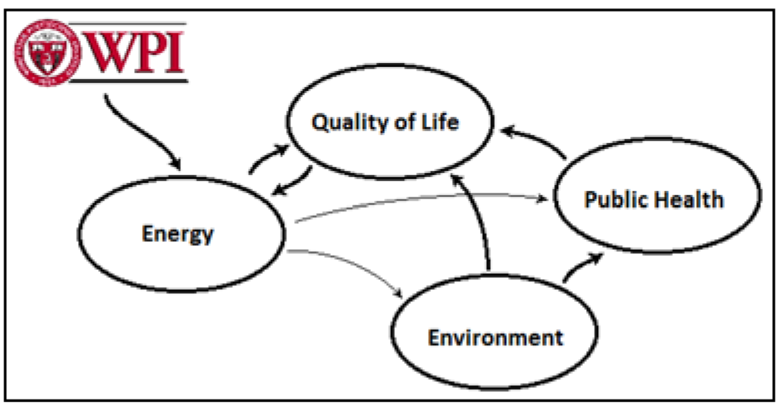


Figure A: Social interactions between energy and quality of life

It is generally accepted that in today's world the basic quality of life is greatly affected by access to energy resources. Residents of United States are privileged with the availability of cheap energy which greatly improves the society's productivity, and can be linked to US's status of being a first-world country. However, most of the harnessed energy is generated from non-renewable fossil fuels. In Massachusetts, over 50% of all supplied electricity comes from the combustion of natural gas, coal, and oil. The harmful byproducts of fossil fuel combustion worsen the quality of life of the general population by exposing them to smog and CO_2 pollution. These emissions are strongly linked to deteriorating human health as well as causing global climate change, and are one of the reasons why our society should gradually transition to cleaner energy technology. Photovoltaic technology has made major advancements in the past few decades, and has shaped into a prominent player in the energy market. Today, solar panels come with 25 year warranties, and record energy yield efficiencies. Being an engineering-driven school, Worcester Polytechnic Institute should strongly encourage responsible technological development by demonstrating a greater commitment to clean renewable energy. According to a survey conducted on campus, 82% of the WPI community thinks WPI should be making a stronger effort in promoting green renewable energy, and 51% would not mind if a percentage of their tuition were to go into funding these efforts. By investing in solar technology, WPI will help offset the demand for fossil fuels, and contribute to improving the quality of life of WPI community.

Federal and many state governments acknowledge the harmful byproducts of conventional energy generation and have passed incentive programs geared towards the promotion of green energy. The state of Massachusetts is especially committed to this goal: earlier this year, the state's Department of Energy Resources (DOER) implemented a market-driven SREC program, drastically shortening the break-even point for investments in solar panels. Prior to this program, there was no real incentive for WPI to invest in solar systems because most other incentives are tax-based and being a non-profit organization, WPI is not eligible for them. A monetary gain WPI would have previously seen would come from having to buy less electricity from utilities and because WPI already pays a very small electricity price, these savings would not be enough to account for the expensive initial costs of solar panels. However with this new SREC program, WPI will be eligible to sell the greenness attribute of solar electricity generation to utilities around the state. The program will increase the current value of the electricity (generated by the solar system) by 30-60 cents per kWh for the next 10 years. With this added incentive, the break-even point is drastically reduced to between 7 to 10 years. Past this point, the solar panels will supply the campus with free electricity until the end of their lifespan.

In developing the business proposal, details of every roof on campus were analyzed, and a list of potential hosts for the solar systems was created. The eligibility of each building was based on the condition, orientation, and tilt of the roof, as well as minor factors such as roof accessibility and historic integrity of the buildings. The list was ranked according to how soon installations should be done on each building and depends on factors such as roof-conditions, warranties, and repair schedules.

					Savings after 25 years			
Rank	Building	Size (kW)	Installation Costs	Production (kWh/year)	SREC 300	SREC 600	Pay-back period	Carbon Footprint Offset (metric tons of CO2/year)
1	**Admissions Office**	18.5	$120,250	23,413	$13,108	$61,990	6 to 9 years	17.6
2	**Morgan Hall**	43.7	$284,050	52,848	$20,705	$131,039	7 to 10 years	39.6
3	**Salisbury Labs**	42.4	$275,600	51,276	$20,000	$127,052	7 to 10 years	38.5
4	**Daniels Hall**	32.1	$208,650	38,820	$14,419	$95,465	7 to 10 years	29.1
5	**Atwater Kent**	24.5	$159,250	28,251	$2,276	$61,256	8 to 10 years	21.2
6	**Alumni**	42	$273,000	50,792	$19,784	$125,825	7 to 10 years	38.1
7	**Institute Hall**	19.1	$124,150	23,098	$7,374	$55,598	7 to 10 years	17.3
8	**Stoddard Complexes**	46.2	$300,300	55,872	$22,060	$138,705	7 to 10 years	41.9
9	**Library**	48.3	$313,950	58,411	$23,198	$145,146	7 to 10 years	43.8
10	**Fuller Labs**	35.5	$230,750	42,932	$16,261	$105,892	7 to 10 years	32.2
11	**Stratton Hall**	25.3	$164,450	30,596	$10,734	$74,611	7 to 10 years	22.9
	Total	**377.6**	**$2,454,400**	**456,310**	**$169,918**	**$1,122,579**		**342.2**

Table A: Detailed list of potential hosts of PV systems

Figure B summarizes the results of this study, showing each building's potential to host a photovoltaic system. The savings and pay-back period were calculated using two different economic models. Both of these models take into account factors including initial costs of installations, changing electricity costs, and degrading performance of solar panels. To predict the pay-back period we used a straight-forward payback period model which estimates the time it would take for the investment to generate enough savings to cover its initial costs. However, this model does not factor in the effect time may have on the value of currency. As a result, a cash-flow model was also used. It weighs in the depreciation of currency over time caused by inflation and rather than providing a payback period for the investment this model predicts the savings that are made in the solar system's life span. 3% electricity price growth rate and 3% currency depreciation rate were used in calculating the prediction of the above chart.

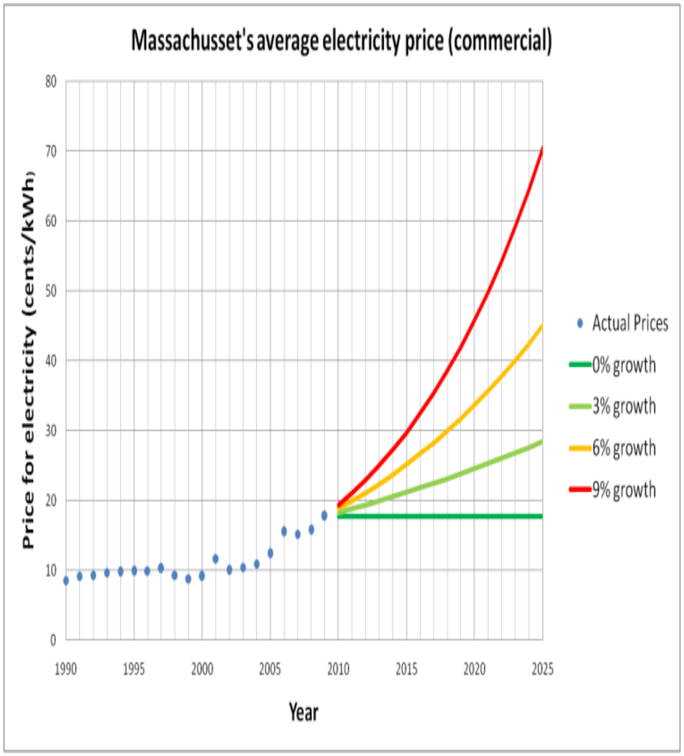


Figure B: Massachusetts's electricity price trend

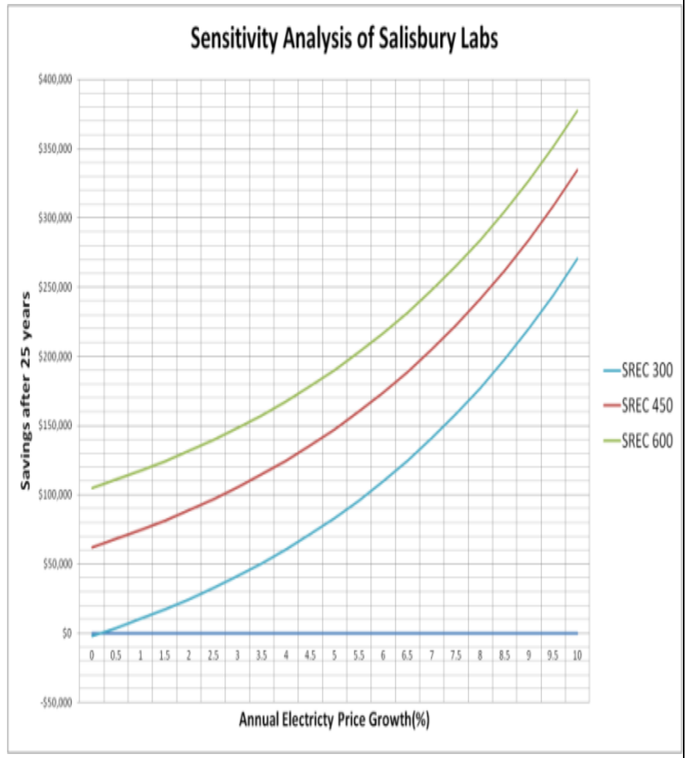


Figure C: Sensitivity analysis of electricity prices versus total savings for a solar system on roof of Salisbury Labs

More detailed sensitivity analyses were also done, showing how different rates for electricity price growth and depreciation of currency may affect the total savings. It is very possible that electricity prices will grow at a much greater rate than 3% as fossil fuel resources deplete and the demand for energy increases. Also electrical utilities in Massachusetts will be pressured to charge higher prices as they will be paying higher operation costs due to the new SREC regulations. Figure C displays how savings from installation on Salisbury labs will be much greater if higher electricity price growth rates persist. More importantly it shows that the savings remain positive even with a 0% electricity price growth rate.

Now is a great time for WPI to invest in solar power and benefit from the many long term rewards this technology has to offer. Such an investment will supply the school with clean renewable electricity and ultimately provide monetary savings. It will serve as an inspiration to the many young students who will witnesses these major steps towards a transition to clean renewable energy, and encourage them to be responsible contributors to society.

-1- Introduction

To this day, the cheap energy generated from fossil fuels has driven the biggest technological revolution of human history. While these energy sources have helped make positive contributions to our society, they have also brought with them many negative side effects. Many scientists fear that conventional energy contributes to global climate change and threatens the near future of our fragile ecosystem. Many political analysts also argue that as fossil fuel reserves deplete, humans will see increased geopolitical conflicts, and countries will fiercely compete for the remaining resources. It is thus important for the present communities to transition from fossil fuel energy to clean renewable technology.

Solar radiation is one of the most readily available and renewable source of energy that is generally taken for granted is solar energy. The sun showers the earth with more energy in 8-10 hours than what is used on a daily basis. In less than three days the solar energy that reaches Earth more than matches the estimated total energy of all the fossil fuels on Earth [3]. The yearly average power density of sun's irradiance at the Earth's atmosphere is approximately 1366 W/m^2 according to the information from National Institute of Standards and Technology (NIST) [26]. Solar energy is hazardless and pollution free and contributes to the continuity of life on earth.

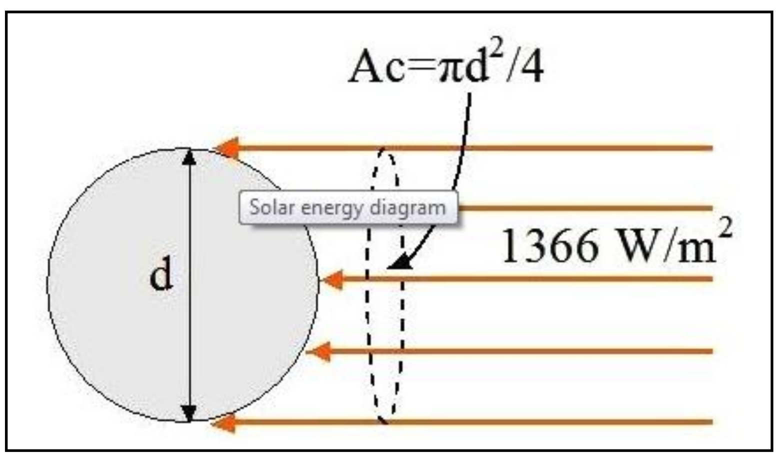


Figure 1: NIST description of W/m2 of solar irradiance [26]

-2- Background Information

Now the logical question that one might pose is "Why are we not making more use of solar energy?" The answer, of course, is that we have been using it since the beginning of human life on Earth. All our energy, for the exception of nuclear power, can be traced back to the sun. A gasoline fueled automobile also uses solar energy indirectly as sun energy is a major factor for fossil fuels formation. The challenge is to make use of solar energy directly and in a non-polluting fashion. A solution can be found in the form of a photovoltaic (PV) array system.

The history of photovoltaics dates back to 1839 when a French physicist Alexandre Edmond Becquerel discovered a certain phenomenon when he was conducting experiments with electrolytes and electrodes. During his experiments, he discovered that conductance in electrodes rises with illumination [1]. About 37 years later in 1876, William Grylls Adams, Professor of Natural Philosophy at King's College London, along with his student R. E. Day discovered that illuminating a junction between selenium and platinum leads to a PV effect. These findings became the basis for the first selenium solar cell constructed in 1877 [1]. A significant amount of work on photovoltaic was also done by Albert Einstein. He is credited for the discovery of the law of the photoelectric effect, which became the basis for future advancements in the photovoltaic cells. His contributions led him to earn a Nobel Prize in 1921. Later, Robert Milkan conducted experiments on Einstein's theories and validated them [1].

By the 1950's interest began to pick up via intensive laboratory research, particularly for utilization in satellites. On March 17^{th} 1955 the first satellite powered by solar cells, Vanguard I, was launched which ran continuously for 8 years. Now almost all of power operations on satellites run off of solar energy. In 1961 the United Nations held its first conference regarding solar energy applications in developing countries [1]. Subsequently, the importance of solar energy started to become popular in many countries around the world.

During the past 40 years, the advancements in technology have improved the efficiency of photovoltaics from a mere 2% up to 36 %, as shown in Figure 2 below [19]. The recent improvements have been made by the Boeing Spectrolab and National Renewable Energy Laboratory on three-junction concentrators design. People may think after observing the trend of high priced computers becoming obsolete in a few years time, that PVs bought today will have the same fate. However, the solar cells have less efficiency growth rate on technical grounds, thus expanding the lifetime of a PV panel purchased today.

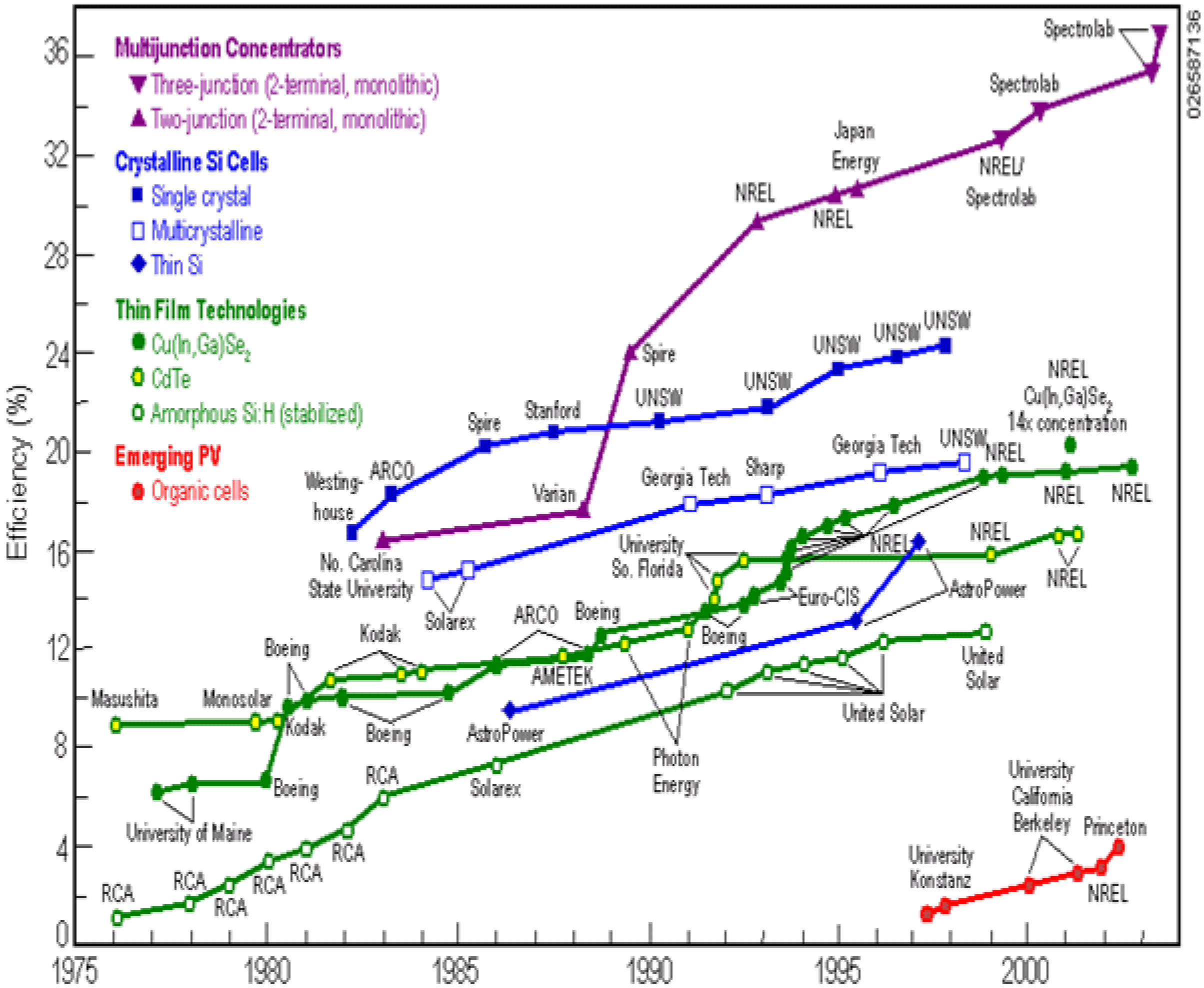


Figure 2: PV Efficiency vs. Time [19]

2.1-Historical Analysis of Cost Trends in Photovoltaic Panels

The historical cost trend of solar panel is fascinating. The following figure shows the historical cost trend in the PV module prices. Figure 3 encompasses from the year 1976 to 1994 and Figure 4 from 1998 to 2005.

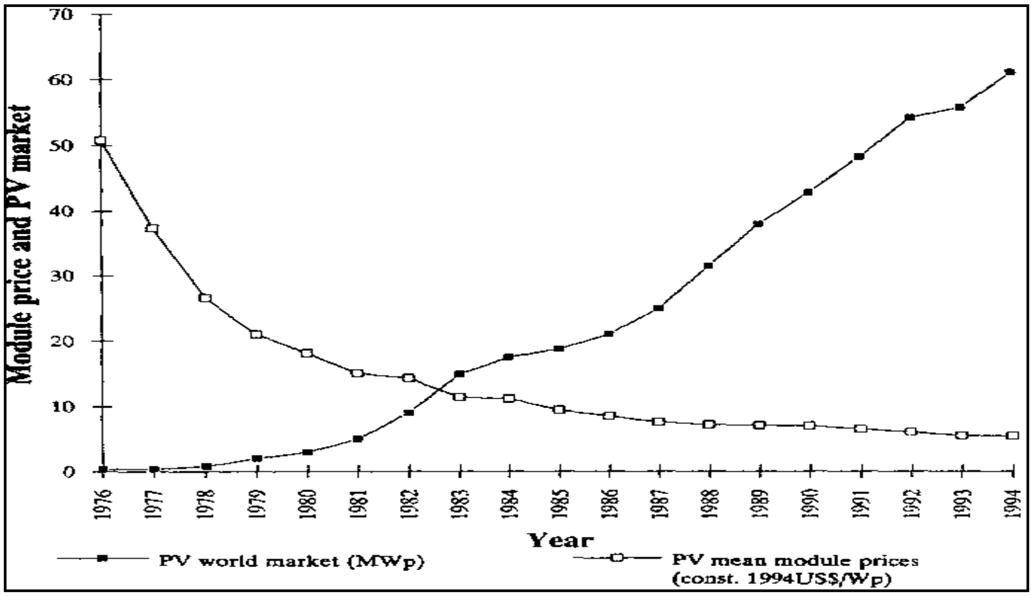


Figure 3: PV module price vs. time: 1976-1994

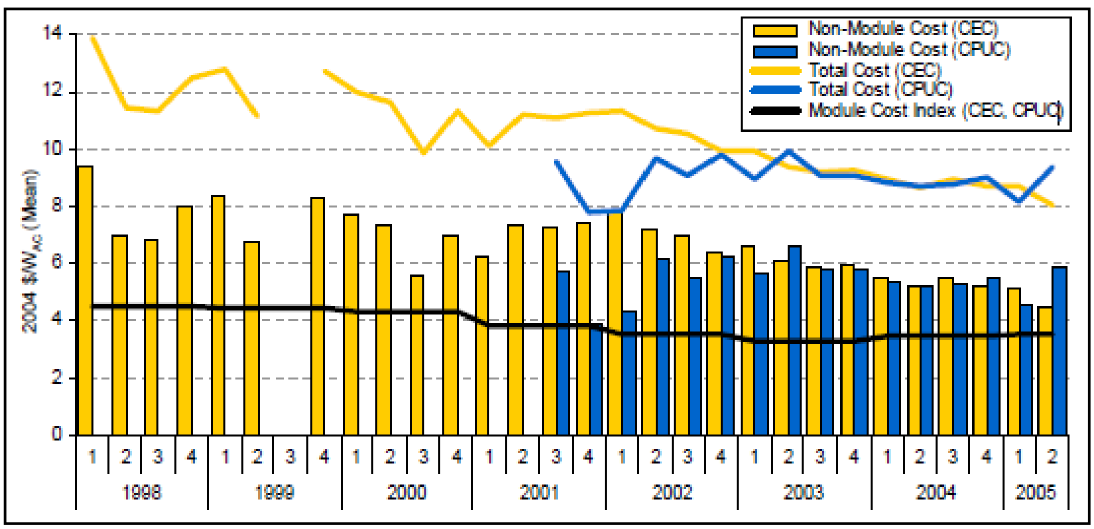


Figure 4: Costs trend over time [21]

The two figures shown above indicate that there is a decreasing trend in the cost of PV modules. There are many factors that affect this trend. One of the most important factors is the improvement in the efficiency of PV panels over time. The jump from 2% to 36% indicates that the returns from a PV system increases over time and they have kept on becoming more economically attractive [19].

Over time, companies and entrepreneurs have realized the immense profit potential in the PV production. As a result, an increasing number of companies have started to move into the PV module production market. As more companies start producing photovoltaics in greater quantities, their unit cost of PV production is reduced because the average fixed costs (capital costs) decreased as production capacity increased. This concept is further highlighted in Figure 5 below. . Fixed costs do not change with output and they are usually associated with initial capital investment such as cost of machinery and insurance costs etc.

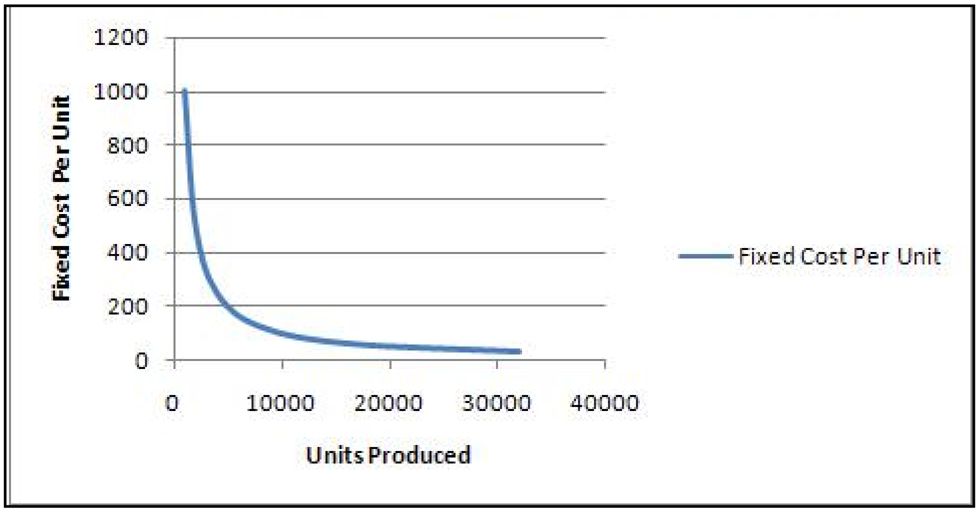


Figure 5b: Fixed costs Per Unit vs. unit produced

2.2-Current Issues with Conventional Energy

Granted there would be no reason to switch to photovoltaics unless there are driving issues that justify such trends. Each 'conventional' source of energy has one or two rather pertinent downsides, which when added up can lead to some rather grim outcomes.

2.2.1-Natural Gas

First off, natural gas has contains methane. Methane is a highly combustible gas. Thus, there is a high possibility of a natural gas explosion particularly at the time of extraction and transportation via pipes and trucks. Natural gas is colorless and so whenever there is a natural gas leakage through pipes, for example, it was very hard to detect it.

Secondly, there are huge costs in transporting natural gas through pipes. Pipes are usually used to transport natural gas from its extraction and processing sites to the users' ends. Pipes are usually laid underground and the construction is expensive. Also, the pipes need to be regularly checked for maintenance which adds to the administrative costs. If leakages do occur during natural gas transportation, methane can go into the surroundings. Inhaling methane is harmful to one's health as it can block the supply of oxygen to the body. So it is quite necessary to take strict safety measures during natural gas transportation which makes the process even more expensive.

2.2.2-Oil

Oil is a non-renewable energy source and thus if existing oil reserves get depleted, they cannot be regenerated. The recent oil crises which led to sudden rise in oil prices were not due to depletion of oil reserves but the increase in demand in America. The higher the degree of demand increases, the more barrels of oil are imported into the U.S.A. In the last couple of years Saudi Arabia reached its maximum capacity in terms of Crude Oil production. As demand further increased, they were unable to match it with supply and so the oil prices increased.

Oil is primarily transported through ships and massive trucks. Oil spillage is rare but incidents have happened in the past. Spillages can do tremendous damage to wildlife and the ecosystem. One such incident occurred in 2003 when the Tasmin Spirit, a 24-year-old Greek oil tanker, spilled 15,000 tons of crude oil across a 14 kilometer stretch of the coast Karachi, Pakistan. Much of the nearby forest was destroyed and marine life was severely affected.

Burning oil generates carbon dioxide, a 'greenhouse gas' – although to a slightly lesser extent than coal in terms of the energy extracted. Oil contains sulfur which when burnt forms sulfur dioxide and sulfur trioxide – these compounds combine with atmospheric moisture to form sulfuric acid, leading to 'acid rain'. This can lead to destruction of forests and the progressive erosion of rock and masonry structures, both natural and man-made. The use of low-sulfur fuels can help to reduce the impact of this. However, such treatments are expensive and not affordable by poor and developing countries.

2.2.3-Coal

World reserves of coal are very large and it is estimated that they will last for 200 years at the current rates of consumption. Moreover, these reserves are spread more equitably across the world than those of oil. United States, one of the largest consumers of energy also has one of the largest coal reserves in the world. And a final point: coal should remain a cheap energy source; it is not expensive to extract or to use to produce electricity.

However coal does have its disadvantages. Coal burning leads to ecological deterioration. Like oil, coal contains sulfur and emits sulfur dioxide when it is burned. The burning of coal also emits oxides of nitrogen (NOx). Several efficient processes exist for sulfur and nitrogen cleaning of gas emissions from the burning of coal. Action can be taken both upstream, before burning, or downstream, by treating the fumes. In the latter case, the proportion of SO2 can be reduced by 90% and that of nitrogen oxides by 80% [28]. However these procedures are expensive and realistically can only be used by developed countries. The burning of coal, like that of gas and oil, also produces carbon dioxide (CO_2), the prominent greenhouse gas. There is no current solution to deal with the carbon dioxide emissions apart from reducing coal consumption. The future of coal consumption is strongly linked to the commitment of each country, in order to reduce emissions of greenhouse gasses.

2.3-Population growth effect on current Energy situation

We may think that energy consumption is directly proportional to population, but it is not always true. The United States does not have the world's largest population; Americans make up only 5% of the world's population but consume 20% of its energy [2]. Figure 6 shows population and energy consumption by country.

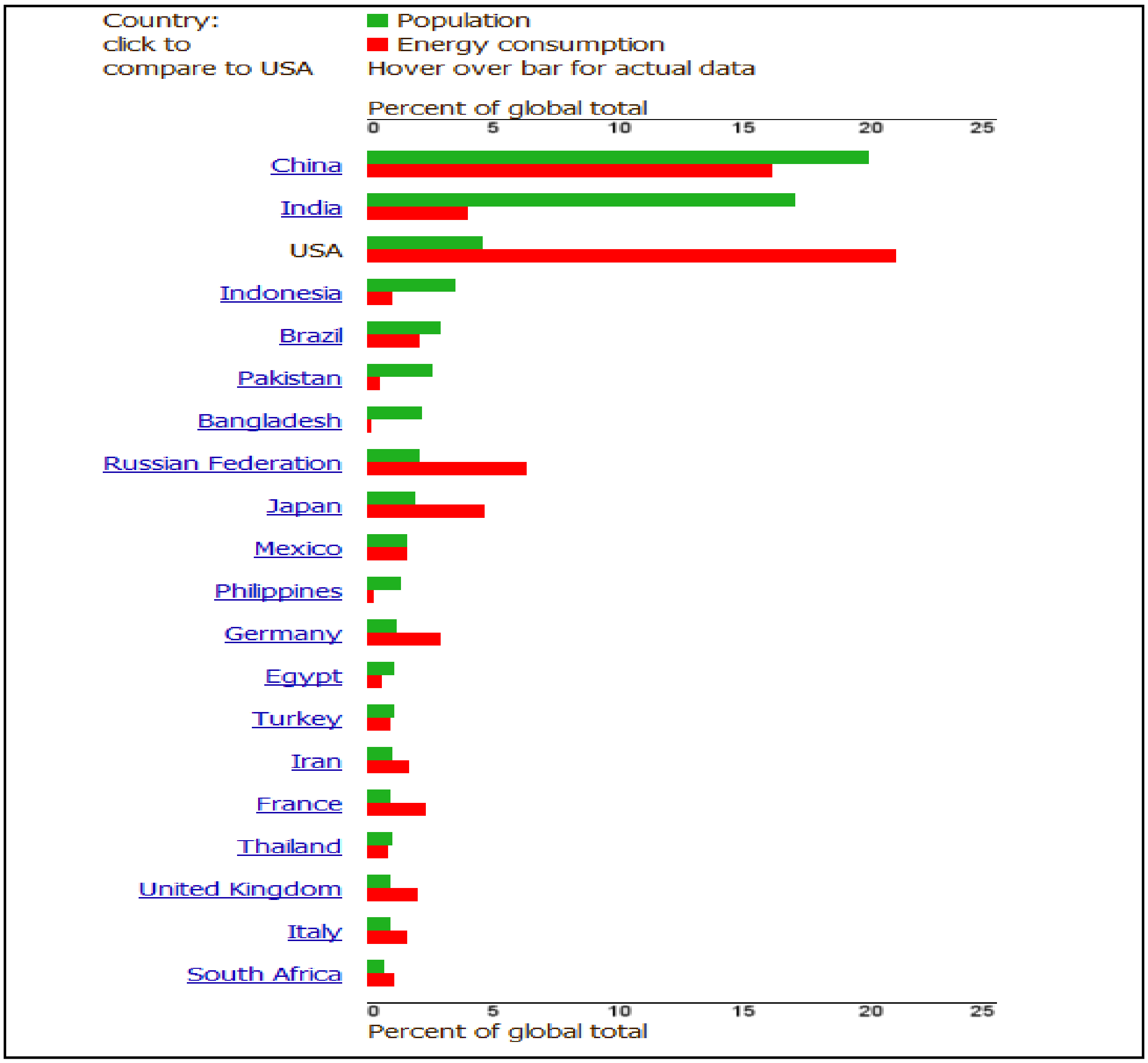


Figure 6: Population and Energy Consumption [2]

The per capita energy consumption of the United States is approximately 16 times greater than the India [2]. This shows that the United States is one of the leading contributors to the depletion of non-renewable sources of energy. One must also take into account that the population is constantly increasing. As Earth's population increases, the demand for energy increases which will force countries to increase their production capacity. Figure 7 illustrates this cycle more clearly.

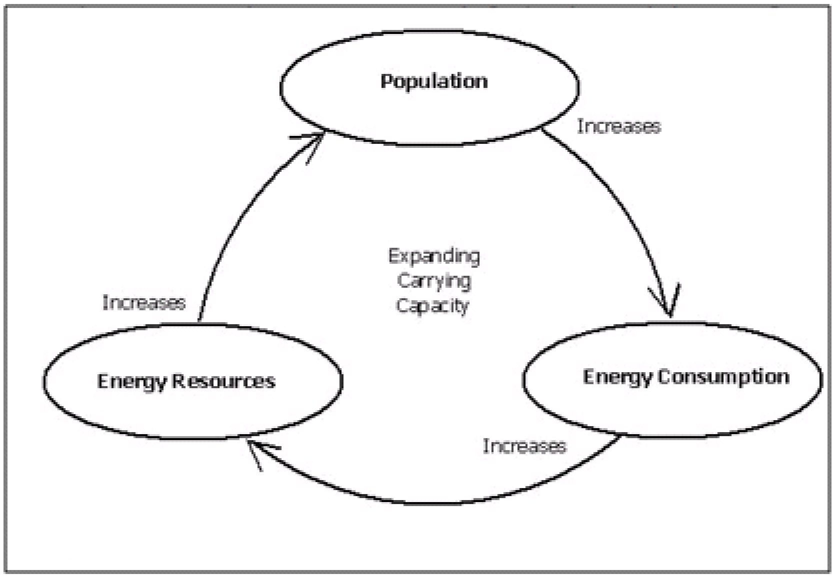


Figure 7: Population/ Energy Dependency [23]

However this trend can be sustained only if the supplies of resources also keep on matching the demand. This is possible only up to a certain point as the major energy resources come from non-renewable sources. In the near future, mankind will run out of oil, natural gas and coal reserves if a greater movement toward more renewable sources of energy such as energy produced from solar, wind and nuclear energy sources is not taken into effect as soon as possible.

2.4-Energy Independence: It's Importance

The following in an excerpt from the State of the Union Address given by President Obama in January of 2009.

"At a time of such great challenge for America, no single issue is as fundamental to our future as energy. America's dependence on oil is one of the most serious threats that our nation has faced. It bankrolls dictators, pays for nuclear proliferation, and funds both sides of our struggle against

terrorism. It puts the American people at the mercy of shifting gas prices, stifles innovation and sets back our ability to compete." **President B.H Obama.**

Even the leader of the free world recognizes the need to break off from foreign fuels and that the best way to do so is to invest in renewable energy that can be produced on American soil. In the past 5 years the price of a barrel of oil has more than quadrupled as can be seen in Figure 8 below.

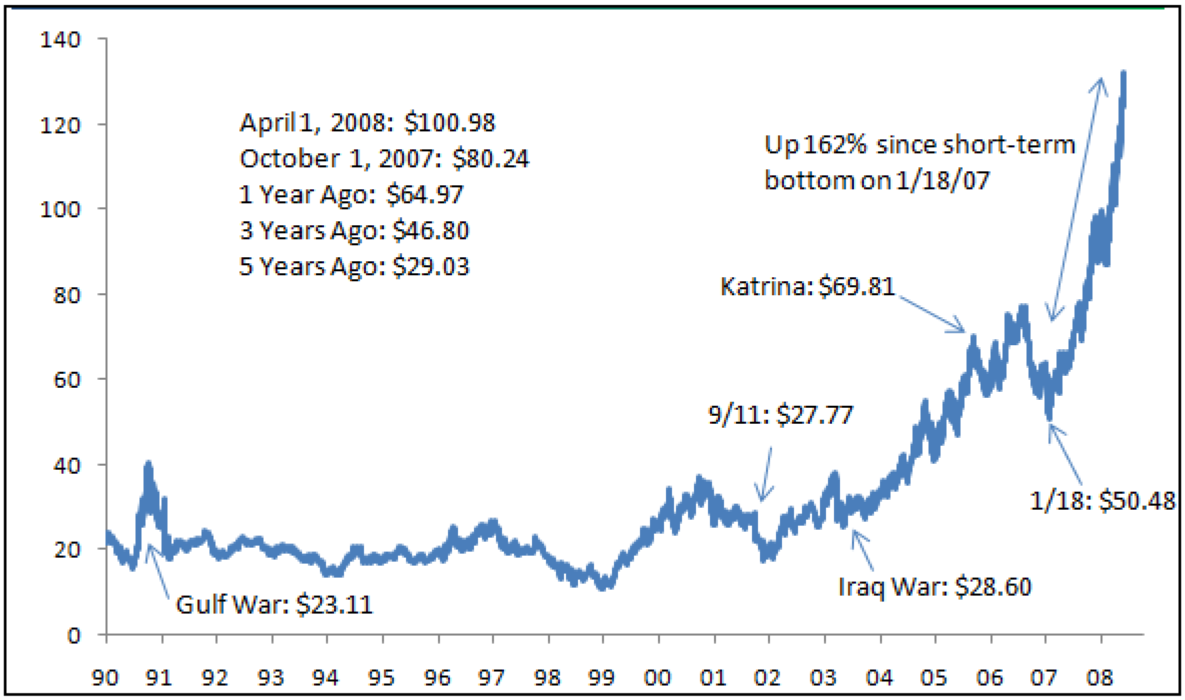


Figure 8: Oil prices over time [4]

Between the years 1950 and 1973, the United States increased its crude oil import from foreign countries from 0% to 32%. By 1994, the oil imported by the U.S. exceeded half of its crude oil consumption. And by June of 2010, America was importing approximately 362 million barrels of oil from other countries.

The ever growing energy dependence on foreign countries also came with an increased fear about an oil shortage. Since the 1973 Arab oil embargo, America has experienced many incidents of uncontrollable setbacks in oil prices. The initial embargo cut the flow of oil to USA which caused a severe oil shortage. In 1979, the Iranian Revolution interrupted the oil importation a second time. In 1991, the Persian Gulf War became the most urgent warning that America should become more energy independent. In July of 2008, the oil price ballooned up to $147/barrel. All this oil price uncertainty gives an added incentive for the promotion of the many renewable sources of energy.

2.4.1-Wind Power

Wind Power produces electricity through the use of wind turbines. Modern wind turbines can provide power output generally from a few Kilo watts to around 3 Mega watts. The wind power is best performed at high altitudes and off or near the coast, where the wind source is greatest. Wind power is a very promissing technology because the power generated is a function of the cube of the wind speed. That means a small amount of increase on wind speed can cause a dramatic increase on power output.

2.4.2-Hydropower

Hydropower uses turbines to convert the kinetic energy stored in flowing water into electric energy. Hydropower is renewable and will not produce any carbon dioxide. On average the electric generating capacity of a dam can reach up to 22 GW.

2.4.3-Biomass

Biomass is a reneable energy that use plants to store energy from the sun. The plants photosyntesize the energy from the sun and store the energy amongst themselves. When the plants are burned, the stored energy is released. This is a "long-term investment" and may cause pollution proper procedures arent followed.

2.4.4-Solar Energy

Solar energycan be generaly divided into passive solar energy and active solar energy. The passive solar technology concerns the design of buildings, the orientation to the sun, the material selection, and so on. These designs hope to find the best way to use the energy delivered from the sun to the building, and naturally circulate the air. The active solar technology harness the power from light by producing photovoltaic panels and solar thermal collectors.Compared with most of the current popular renewable energy, solar energy has its own advantages and disadvantages. Unlike wind power, hydropower, solar energy can be installed onsite of any household. They have reletively small size, and can help the owner to save money by producing their own energy. The solar energy is also clean, renewable, and sustainable. It doesn't produce significant carbon dioxide, nitrogen oxide, sulphur dioxide. It requires virtually no maintenance and once installed the owner can benefit from it for more than twenty years. However, there also has many limitations on solar energy. First of all, the efficiency is still very low, ranging from 14% to 20%. The performance of solar panel also depends on the weather condition, air pollution, and shadeing from nearby structures. During the night, the solar panels will no longer produce any energy, while biomass, hydropower don't have such limitations. However, the biofuel and biomass are still more expensive compared to solar power. And the hydropower is impossible for individual investor. Therefore investing in solar power seems to be WPI's best option.

-3- Policies and Incentives

While there are many benefits from producing electricity using photovoltaic technology, it is not yet marketable due to its high initial costs and relative low energy yield. Fossil fuels, such as oil and coal, remain the cheapest sources of energy, and make it very difficult for renewable green energy to compete in a free market. Fossil fuel technology has been around much longer and already benefit from having a well-established infrastructure. Green energy is often caught at a disadvantage because its greatest attributes, renewability and greenness, do not translate to appropriate costs in the minds of consumers. However, in the Unites States, both Federal and State governments acknowledge the long-term benefits of green energy and provide incentives and rebates aimed at boosting green sector's growth.

3.1-Federal Tax-based Incentives

Investors of photovoltaic technology can benefit from federal tax credits that cover 30% of the total expenses directly related to the system installations (including solar panels, invertors, racks, and labor). In order to collect this federal rebate in his tax return, the investor must report his expenditures as a "tax basis" using the Investment Credit form (IRS Form 3468 for commercial) [6]. At the time of tax-returns, 30% of this "tax basis" will be discounted from his taxes. If the investor receives additional grants or rebates from outside sources, he has to either file them as taxable income or subtract them from the tax basis. For example, if a taxpaying business receives a $2,000 grant through a state stimulus program for their $20,000 investment in a photovoltaic system, they can report it as taxable income and get a $6,000 (30%) rebate in their tax returns. Alternately, they can deduct that grant from the "tax basis", and receive $5,400 (30% of $18,000) in tax returns [5]. The latter option may be better suited for investors that are paying federal income taxes greater than 30%.

3.2-Solar Power Purchase Agreement

WPI is not eligible to receive tax based incentives because of its non-profit status. However, there is the option to enter a Solar Power Purchase Agreement (SPPA), which allows non-profit organizations to indirectly take advantage of tax rebates. SPPA is geared towards investors who desire clean electricity at agreed-upon rates for extended periods of time. It is a contract between a customer and a solar developer, allowing the developer to own, operate, and maintain a solar array on the customer's property. At the end of the contract, which typically last 6 to 25 years, the host can either keep the solar array or have it disposed [10]. This program is convenient because it lets non-profit organizations invest in photovoltaic technology, while still taking advantage of tax-driven incentives through private developers. However, those same developers act as middlemen and will seek to make an optimal profit. WPI may also encounter difficulty with finding an attractive PPA, since it already pays a low electricity cost of 12*cents/kWh*, while PPA rates typically range from 18-22*cents/kWh*.

3.3-Massachusetts Incentive Programs

3.3.1-Renewable Portfolio Standard

Many progressive states have issued additional incentive programs aimed to provide greater boost to the growth of green energy. In April 2002, the Department of Energy Resources of Massachusetts (DOER) set a noble goal to have 15% of the energy supplied by the utilities come from clean and renewable sources by 2020. To do this, Renewable Portfolio Standard (RPS) regulations were adopted, requiring all utility companies in the Commonwealth to supply a certain percentage of its energy from renewable-energy sources. If a utility is unable to meet the quota, they either have the option to purchase Renewable Energy Certificates from private investors, or pay an alternative compliance fee that currently stands at $60*/MWh.* The Renewable Energy Certificates are issued to private owners of green energy technology, at the rate at which it generates electricity. This program has done well in bringing up Massachusetts' clean energy market share from around 1% in 2002 to 5% today [7].

3.3.2-Solar Renewable Portfolio Standard, SRECs

In January, 2010 the DOER extended the RPS regulations in an effort to further promote photovoltaic energy expansion. Utilities are required to meet an additional solar requirement for which the compliance fee is much higher ($600). The goal of this incentive program is to expedite the pay-back rate of investments in photovoltaic systems, by augmenting the value of the generated electricity. Each SREC represents the renewability attribute associated with generation of 1MWh using solar panels. They are minted and issued by NESPOOL, and require that solar arrays are connected to power meters that can feed the electricity generation readings to ISO-NE. Investors are limited to using up to 2MW of system panels for generation of SRECs.

This SREC market-driven incentive for solar power is closely modeled after SREC programs that have existed in many other states like New Jersey. There are many improvements in the newer Massachusetts program making it easier for investors to predict long-term economical benefits from their investment. One difference is that the solar requirements for subsequent years are adjusted according to the actual solar growth of preceding years. In 2010, DOER set a goal to increase the statewide solar system capacity to 30MW, requiring electric utilities to account for 34,166MWh of solar electricity generation. If utilities succeed in meeting this goal, the solar requirement for 2011 will increase by 30%, adjusting the capacity cap to 69MW. This adjustment will occur until state wide solar system size reaches 400MW. If the market supply of SRECs is above the demand, certificate-holders can wait up to a year to sell them in an adjusted market with a potentially higher demand. Another improvement of Massachusetts SREC program is the implementation of Solar Credit

Clearinghouse Fixed-Price auction, which creates a bottom price cap for the price at which Solar Renewable Energy Certificates can be sold. Owners of PV systems have the option to sell any remaining certificates (not sold to utilities) at these auctions at a floor price of $300 for an opt-in period of 10 years.

The Massachusetts SREC program is the biggest incentive to investing in solar panels economically feasible for Worcester Polytechnic Institute. This program is planned to expire in a few years, so it is very important for WPI to act quickly to take the advantage of its benefits.

-4- Technology

4.1-Brief analysis of the manufacturing of Photovoltaic Cells

The construction of a solar panel is a delicate process. Crystalline Silicon is cut into tiny disks and then polished. The disks then go through a small repair process to counter the damage done during the slicing process. Some materials and metal conductors are spread across each disk. The conductors are aligned in a thin, grid-like matrix on the top of the solar panel. A thin layer of cover glass is then coated on top of the PV cells as a protective measure. The panel is then attached to a substrate by a thermally conductive element. The purpose of this thermally conductive element is to protect the solar panels from overheating which would cause the efficiency of the PV cells to deteriorate.

4.2-Solar cell Parameters

4.2.1-Guaranteed Power

The minimum guaranteed power is mentioned by the manufacture of PV modules so one never get less than he/she paid for. Most manufacturers of solar panels use the term kilowatt peak (kWp) to denote the rated amount power that the solar panels will produce. The kWp of a solar panel is determined by measuring the voltage and current across it by using a variable resister under defined illumination condition i.e. under standard testing conditions. The resistive load is varied on the module between open and closed circuit conditions to measure the power output for PV cells and the maximum power measure is called peak power. "The insolation level is 1,000W/m2, with a spectrum similar to sunlight hitting the earth's surface at latitude 35°N in the summer [14]. A standard air mass of 1.5 and temperature of the cells at 25°C is also assumed" [13] . Insolation level is a measure of solar radiation energy that a given surface area receives in a given time. Only about 74% of the solar energy of the radiation from the sun that reaches the top of Earth's atmosphere passes through to the surface [14].

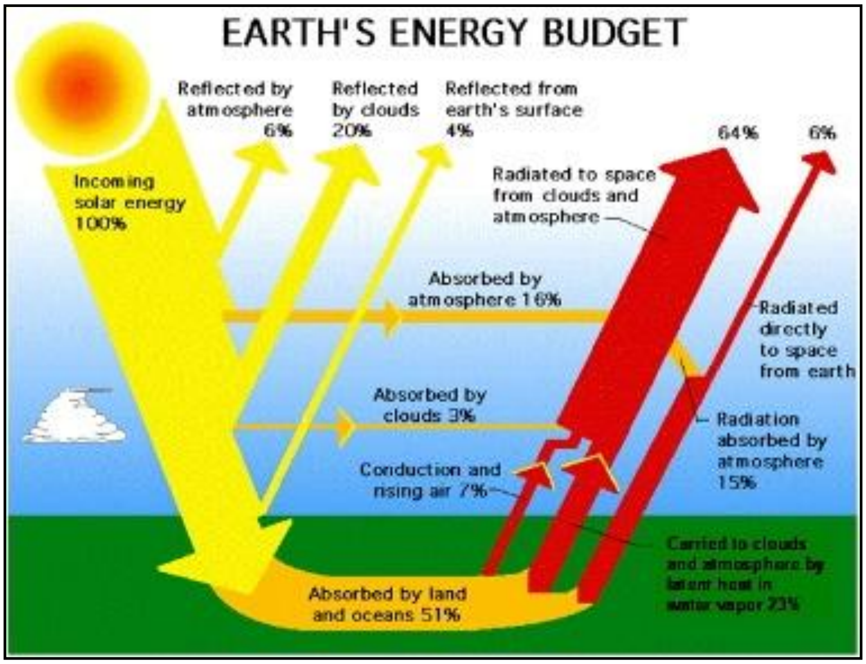


Figure 9: Solar Energy absorption analysis [14]

The total amount of sunlight that is received per square meter depends on the time of the day, latitude, the weather, the season of the year which, thus, would vary in different locations around the world. However, on a clear day, the earth receives about 1000W per perpendicular area of m^2 to sunlight [14].

4.2.2-Efficiency of PV panels

The efficiency factor is the ratio of peak power delivered by a PV panel to its dimensions as seen in Equation A below:

$$Efficiency\ Rating = \frac{kWp}{surface\ area\ in\ m^2}$$

Equation A: Efficiency Rating

Many manufactures provide accuracy figures with kWp values. The manufacturers have an accuracy boundary of approximately plus or minus 10% which suggests a greater variability in performance of Photovoltaic panels [15]. Using anti-reflective glass for PV can deliver 2-3% more electricity compared to panels made with standard glass [30].

The output of the PV modules is primarily dictated by the Sun's intensity. The load that is connected to the PV determines the voltage and current determination of the module [17]. There may be various options for the load; if the load happens to be a battery, then the internal resistance of the battery would determine the module's operating Voltage/Current (V/I) characteristic. A module rated at 20 volts would deliver less power than its specified one if it is connected to a battery. The reason for this phenomenon is that the actual working voltage, which would be less than the rated value, gets dissipated due to the internal resistance of the battery. Thus, if the working voltage of the PV decrease the power output, which is the product of voltage and current (V*I), would decrease.

Figure 10 shows the operating points of current and voltage at a given temperature and light intensity conditions. Even though an increment of temperature increases current it reduces the voltage at a greater rate.

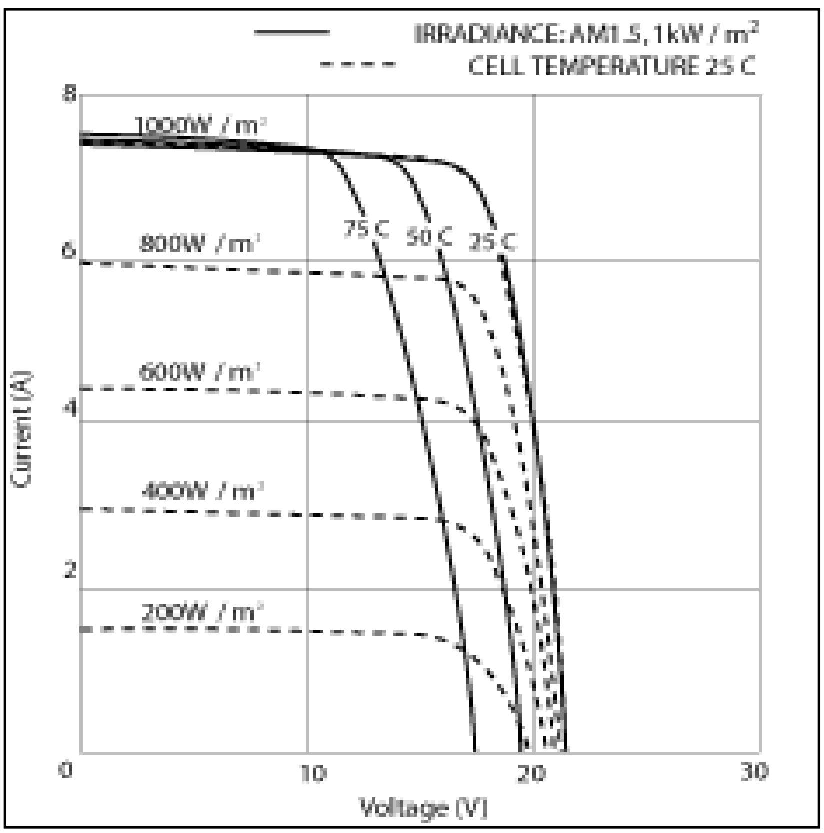


Figure 10: The V/I characteristic of PV module with respected to temperature and light intensity [17]

Maximum power can be derived at the knee of the curve. To better calculate the actual power, one should check the amperage generated by the solar array at the battery's current operating voltage.

4.2.3-Shading

Many photovoltaic panels are sensitive to the shading element. Shading can lower the efficiency of the PV array. Light shading can be in the form of obstacles that just cast dispersed and diffused shadow on the modules. This does not cause much effect to the efficiency, however intense shading can. Even if just a single solar cell is intensely shaded, the voltage of the module will drop down to half of its maximum voltage obtained under non-shadow conditions. If much of the module is under dense shade, the electrical energy generation will greatly reduce and more importantly it would consume energy to keep it functioning.

Due to the solar cells of a panel being connected in series, if even 1 cell is shaded the power generation capability of other solar panels will be reduced. Thus, if half of the row of cells is shaded or half of one cell is under shade, the reduction in the power generation of the panel would be decreased to 50% maximum [17].

However, a fully shaded cell will on the contrary consume energy produced by other cells of the panel which are not under shadow. Even a single cell is fully shaded will cause the power level of the module to drop to half of its full available power value. A complete full bottom row is under shade can reduce PV module power to zero [17]. This shows the significance of shading consideration when installing solar panels. The partial and full shading concepts can be seen in Figure 11 and 12 below.

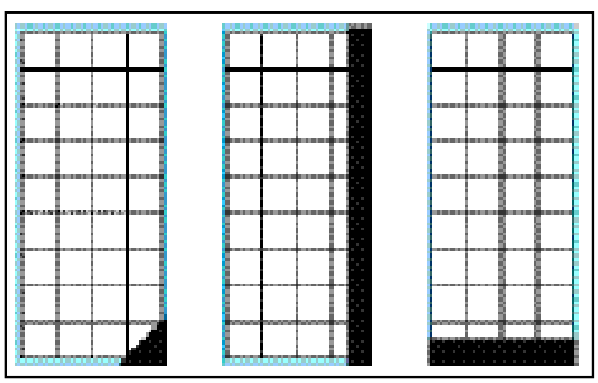


Figure 11: Partial shading phenomena [17]

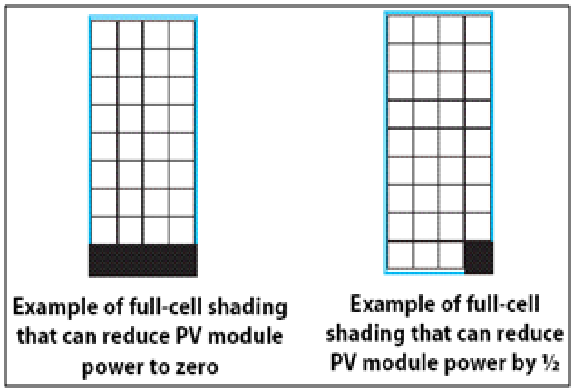


Figure 12: Full cell shading phenomena [17]

4.2.4-Orthogonal Analysis

The orientation of the module also plays a vital role for the efficiency of a PV module. The modules should be racked in a way that faces in a southerly direction if in the northern hemisphere. They should shy no more than 15 degrees away from south in order to capture maximum amount of sunlight per annum [17]. If the module is within 15 degrees of the latitude angle yearly then the annual production of electrical energy from module will approximately decrease by 5% from its peak value. The peak value can be obtained if the module is perpendicular to the solar radiation. If the tilt of the solar module system is more than 15 degrees of the latitude angle, than a 15% reduction in annual energy output can be expected [17]. Greater latitude tilt angles to perfect south will lead to a greater decrease in power generation capability during winter season.

4.3-Inverters

Solar panel inverters basically convert direct current (DC) into alternating current (AC). The electrical energy initially absorbed by the solar panel is in the form of direct current. However, the electrical energy through the grid is propagated as alternating current so the DC to AC converter is necessary at the output of solar panels.

There are three primary types of PV panel inverters, which are listed as follows:

4.3.1-Stand-Alone and Surge Solar Panel Inverters

These inverters change direct current from the battery to alternating current. They vary in their power capacity, usually ranging from as little as 100 watts to as much as 8000 watts [24]. The wattage you would need from your stand alone solar panel inverter depends on the AC load power rating of the devices you would be using.

There is another sub-type within this category which is called Surge Stand-Alone Panel Inverters. It is important to purchase a quality stand-alone inverter that has a built-in ability to surge if you are using heavy equipment such as power tools, automatic washers and dryers, and dishwashers. These appliances and equipment require a surge on startup, which your stand-alone inverter must be able to supply if you are planning to use these appliances.

4.3.2-Synchronous Solar Panel Inverters

The term Synchronous Solar Panel Inverters originates from the synchronous dynamic that such a system creates between the utility company and a personal solar-panel installation. Synchronous Solar Panel Inverters allow power generated by your solar panels to be stored in a battery cell. If there is an excess (meaning the power generated is greater than the power consumed), the excess energy is sold back to the utility company at the same rate at which it is usually sold.

On the other hand, if the solar panels are unable to provide enough power, the Synchronous Solar Panel Inverter will allow the utility company to supply the remaining power. This Synchronous Solar Panel Inverter system is quite useful - batteries will provide enough energy during a utility company's power outages and on bleak, rainy days, one won't have to worry about the solar panel's performance.

4.3.3-Multifunction Solar Panel Inverters

Multifunction Solar Panel Inverters combine the best of both of the previous inverters. As their name suggest, they perform similar function to the Stand-Alone and Synchronous Solar Panel Inverters. They are usually the best choice for a PV system; however they are the more expensive [24].

4.4-Types of Solar Panel

Just as with the inverters, there are different technologies regarding photovoltaics, which are discussed below.

4.4.1-Monocrystalline solar panels

Crystalline silicon is the basic material for conductivity. Monocrystal solar panels use a large, single crystal structure. Crystalline silicon cells are laid with metal strips. These metal strips acts as conductors that capture electrons. A monocrystalline panel's efficiency is around 15% [20]. They are a bit more expensive than other solar panels due to higher manufacturing costs. Monocrystalline silicon material is generally cut in larger sheets which gets the shape of large single cells.

4.4.2-Polycrystalline Solar panels

Unlike monocrystalline solar panels, polycrystalline silicon panels consist of multiple small silicon crystals. They are cheaper but less efficient than monocrystalline silicon solar cells.

4.4.3-Thin Film Panels

Thin film panels do not have crystalline structure so they can be applied as films directly to various materials. As these do not have crystalline structures, they don't have to be molded, drawn or sliced to fit into shape of solar cells. They have low manufacturing costs unlike mono- and polycrystalline panels. Being made of amorphous material, thin film panels can be quickly produced as it does not require silicon crystal creation. These can be made flexible as they can be used in thin layers to other materials. However, these panels have high impurity levels. This can lead to efficiency reduction within a short time period [20].

4.5-Racking Setups to Optimize Efficiency

There are multiple options available for installing a photovoltaic system based off of the type of roofs available. Due to the fact it is most efficient to install solar panels such that they directly face the sun, tilted roofs can be utilized to optimize solar exposure while requiring less material for a rack. In case of flat roofs, there are a couple of options that are available, in order to maximize the system's efficiency. It is possible to install one large rack on which all of the solar panels would be mounted. Another possibility is to have multiple racks, each able to mount one solar panel. Depending on which racking system is utilized will ultimately determine how well one can optimize the available roof space. Ultimately, it is desired to find a rack and orientation that would maximize kilowatt hours produced per meter squared (kWh/m^2).

4.5.1-One Large Rack

The first option for dealing with flat roofs is constructing one large rack on which all the solar panels would be mounted at a desired angle. The biggest benefit of this set-up is that it helps to avoid cross shading from other panels. Cross shading occurs when the sun is at a certain point in the sky where some panels can cast shadows over others, deteriorating the efficiency of the system. An example of this racking set up can be seen in Figure 12 below.

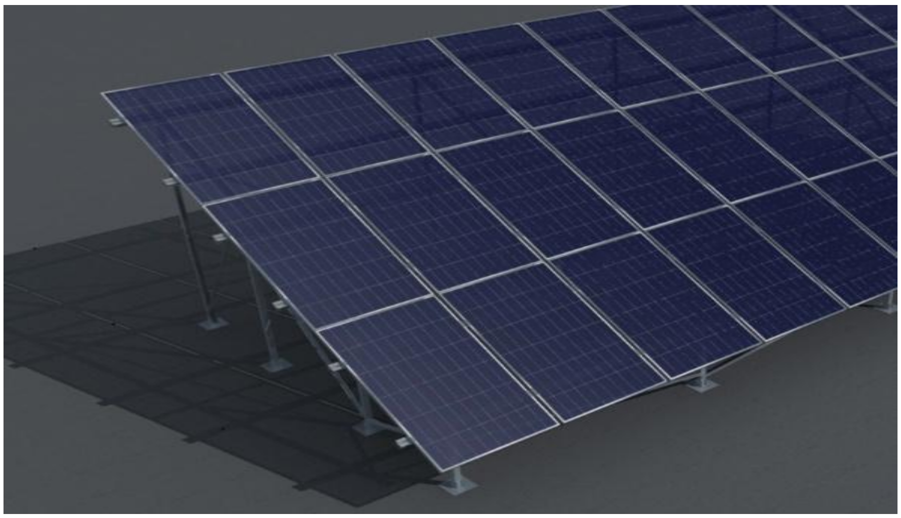


Figure 13: Having a bank of panels can be used to imitate the setup of panels on a slanted roof.

One of the downfalls of this option is that a large rack will be heavy in weight. Some buildings have limits on how high structures can be built on top of them. This can limit how many panels that could be utilized with this rack. Weather conditions such as wind, rain and snow can cause other problems as well.

4.5.2-Individual Racks

For the second option, the panels can be set up in their own individual racks. One advantage of individual racks is not having to worry about exceeding the buildings height requirement. This setup would also allow for a greater disbursement of the weight making it a more appealing option for roofs that might not be able to bear as much weight as the larger single rack. The main issue with this set up is the occurrence of shading which was discussed above. The only way to counteract this problem is to leave enough space between each rack to prevent any cross panel shading. In order to calculate the distance of this gap we found the angle at which the sun would be at its lowest in Worcester. Then, depending on the height of each row of panels, we could calculate the maximum distance at which the shadows would fall due to the sun's lowest position.

4.5.3-Orientation

The next step in determining the optimal setup for a PV array is to look at the different orientations one could place each individual panel, either horizontally or vertically. Considering the individual rack option from above and depending on the dimensions of the roof, one orientation might yield more overall kW/m^2 over another. With the horizontal orientation, the panels will be placed lengthwise. This reduces the amount of panels we would be able to fit in each row, but it also reduces the height. By reducing the height of each row, we can then install each row closer together for the shadows cast by them will not be as long. Inversely, if the panels are installed vertically in orientation, i.e. widthwise, there will be more panels per row, but there would need to be more space between each row to prevent cross shading. A more detailed explanation on the orientations can be viewed in Figure 13 below, where scenario A represents a horizontal orientation and scenario B represents a vertical one (the figures are not to scale).

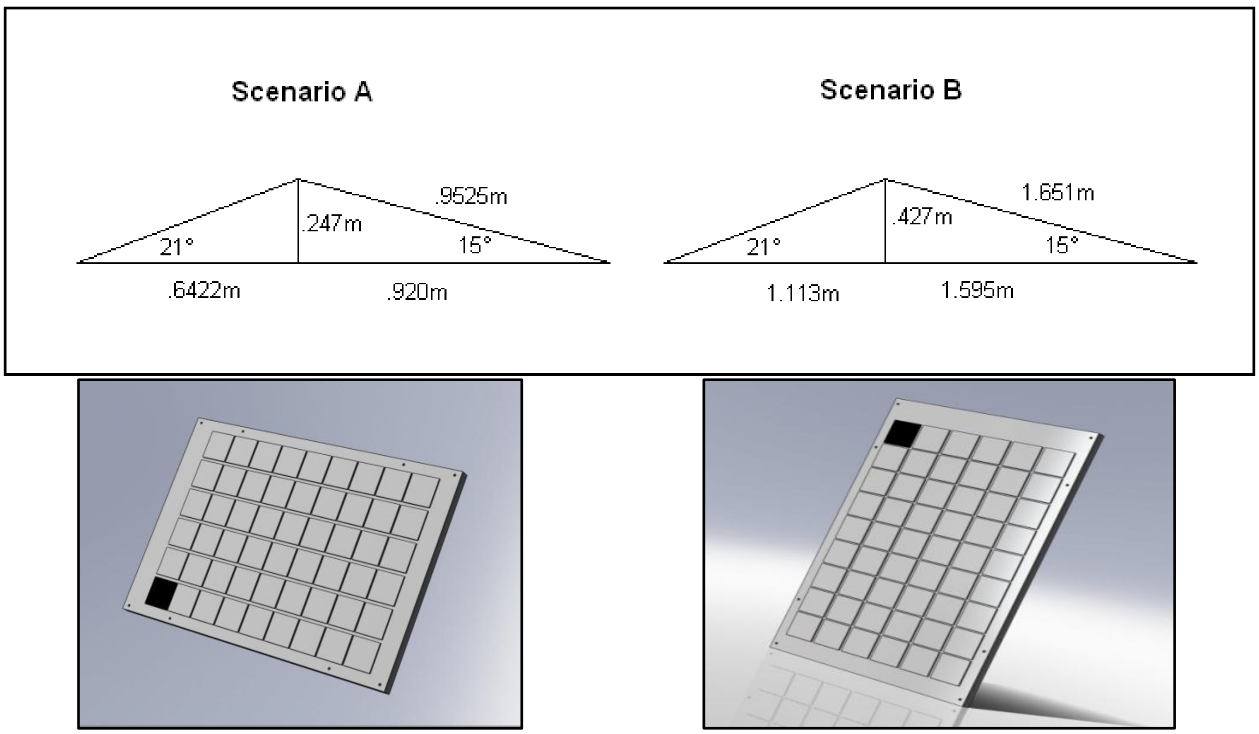


Figure 14: Two scenarios on the orientation of one PV Panel

The dimensions of the solar panels in the above figure are based off of the Evergreen 210 Watt ES-A Series Solar Panel whose details, along with the specifications of other commercial solar panels, can be seen in Appendix A and Appendix B respectively. The angle at which the panels are placed was determined based off of learning the minimum and maximum angles the sun would be located at for Worcester and going with a point that will allow for the most direct sun exposure. After our extensive research in this regard, it was found that an optimal tilt of 15 degrees would be appropriate option.

-5- Installers and Contractors

Many contractors were contacted in order to obtain information regarding pricing details for the purchase and installation of PV systems. We were able to contact the SunBug Solar Company and the president of Absolute Green Energy Corporation, Mike Ortolano. They all provided valuable information regarding planning installations as well as the overall price.

Ben Mayer and Cheney Brand from SunBug Solar Company came to Worcester Polytechnic Institute on February 25th 2010. Besides explaining the upcoming SREC market, Ben and Cheney also answered questions regarding the system installation, overall system price, and the system warranties. Below are quotes provided by both installers on the overall installation cost.

> *"So for a "small commercial" size system (10kW-25kW) you might be able get it done for less than $7/watt, but it is all in the specifics. For a rough budget, $7/watt is safe."*
>
> ---Ben Mayer, Sales at SunBug Solar Company

> *"Rough Estimate for Residential Installed Price per watt: $7.00/W*
> *Rough Estimate for Small Commercial installed price per watt: $6.00/W (up to 25kW)*
> *Rough Estimate for Medium Size Commercial Installed Price per watt: $5.50/W (up to 250kW)"*
>
> ---Mike Ortolano, president of Absolute Green Energy Corp.

From the installers' evaluations, if only the installation of a PV system on Atwater Kent is considered the price would be $7.00/W. To finish the installation on the whole campus the project could be divided into 4 phases to reduce the cost of an initial investment. However, the overall system size at WPI campus can be up to 377kW, which meets the $5.50/W price range for 250kW system. If the systems are to be built in phases WPI would have to pay the price from $6.00/W to $7.00/W based on the system size in each phase.

Besides the initial investment price, WPI would also need to consider the cost of maintenance and replacement of broken components. SunBug Solar was able to verify our research on the solar panel warranties.

> *"Almost all panels now come with 25 year warranties, and most inverters are 10 years. But predicted system life of panels is much longer (almost forever... they degrade .5% annually) and inverters is 15 years. That 15 year number comes from historical data published by NREL, the National Renewable Energy Laboratory ...... This makes*

sense: a manufacturer is of course not going to warranty something for its predicted life - they are going to warranty it for 1/2 or 2/3rds of its predicted life..."

---Ben Mayer, Sales at SunBug Solar Company

The Installation is critical for the final user experience. There are construction codes, and different deigns available for different roof conditions as discussed in the technology section. Cheney Brand, the president and chief technician talked about the choices of installation.

*"……setting the panels up that way (line up on the floor) takes more room because you have the space between the rows, but it is better for the roof because you can use weight to hold the panels down instead of making penetrations in the roof. The other way to do it is to have a bank of panels (*See Figure 12 below*). But while the bank of panels allows you to fit more panels in a smaller area, it means you have to make more penetrations in the roof, which could leak."*

---Cheney Brand, President of SunBug Solar Company

Cheney also provided us an example of National Electric Code WPI would need to take into consideration in order to build the system.

"The racking for a solar system is technically part of the electrical system, which means it needs to be grounded according to NEC (national electric code…… so you have an electrical engineers stamp to satisfy the liability issues for the building department. If you use pre-build components, they have already done this, and have received listing (UL) saying that they have, so it's not a concern."

---Cheney Brand, President of SunBug Solar Company

-6- Case Studies

6.1-Boston Sand & Gravel

There are lots of contractors in the Massachusetts area that can provide services on selling and installing solar panels. Nexamp, as one of the leader in solar industry, installed a 109 kW DC solar project at Boston Sand & Gravel Company (BS&G) in 2008. BS&G is the first company installed a system over 100kW in Boston, and the solar project is visible from I-93 and the Orange Line. The estimated annual production is 120,000kWh. Figure 15 below shows the system's specifications:

PROJECT SPECIFICATIONS

Size	109 kW DC
Estimated annual production	120,000 kWh
Annual CO_2 reduction	188,255 lbs (based upon US EPA Nat'l average.)
Payback and Rate of Return	5.5 year payback and 11.4% after-tax rate of return
Incentives	Commonwealth Solar rebate Federal and State Tax Incentives
Components	Evergreen Solar panels Solectria Renewables Inverter PanelClaw mounting system
Turnkey installer	Nexamp, Inc.

Figure 15: BS&G PV System Specifications

6.2-Worcester State College

An example of an educational institution installing solar panels can be seen in Worcester State College's (WSC) 105.3 kW Grid-Tied PV System. The system was funded by IRS Clean Renewable Energy Bonds and a grant from Massachusetts Technology Collaborative. The 540-panel PV array generates over 140,000 kWh of electricity each year, which is equivalent to 20 homes of 2,800 square feet each. The system consists of 540 Evergreen ES-195 Modules, 1 Satcon 100 kW inverter, and each rack has 25° angle. Worcester State's array can be viewed in Figure 16 below.

Figure 16: WSC Learning Resource Center PV array

As can be seen, WSC opted to go with an individual racking setup with a horizontal orientation of each individual panel.

-7- Economics

Rather than spreading the costs over the system's lifetime, investments in solar technology are accounted for during the initial installations. This is its biggest downfall because this makes the savings, which are generated during the system's lifetime, very sensitive to the rates of inflation, electricity price growth, and the system's performance deterioration.

In estimating the economic feasibility, two different methods were used; a pay-back period model and a discounted cash-flow model. The pay-back period model follows a straight forward approach and is used for estimating the time it would take for the solar system to generate enough revenue to recover its initial costs. However, this model does not take into account the rate at which currency loses its value, and it may produce overly optimistic results. The discounted cash flow model does incorporate the discounting rate of currency, which it uses to convert the value of future cash-flows into present value.

With recent technological advancements in photovoltaic technology, solar panels' efficiency and durability have significantly improved. Most solar panels are now sold with 20-25 year warranties on power output, guaranteeing no more than 20% percent efficiency drop. Such warranties make it easier to calculate more precise economic predictions since it is possible to use them to get an accurate estimate of the worst-case performance deterioration rate. Unfortunately, other variables in our models are not as easy to derive. The rates of electricity price growth and inflation are extremely sensitive to the macroeconomics, and therefore are far less predictable.

7.1-Electricity Price:

Figure 17 below displays average electricity prices in Massachusetts for the last 20 years, and extrapolates future prices depending on different possible electricity price growth rates. The electricity price has steadily increased in the past twenty years, and the trend seems to suggest that it is very likely that it will grow even more in the future.

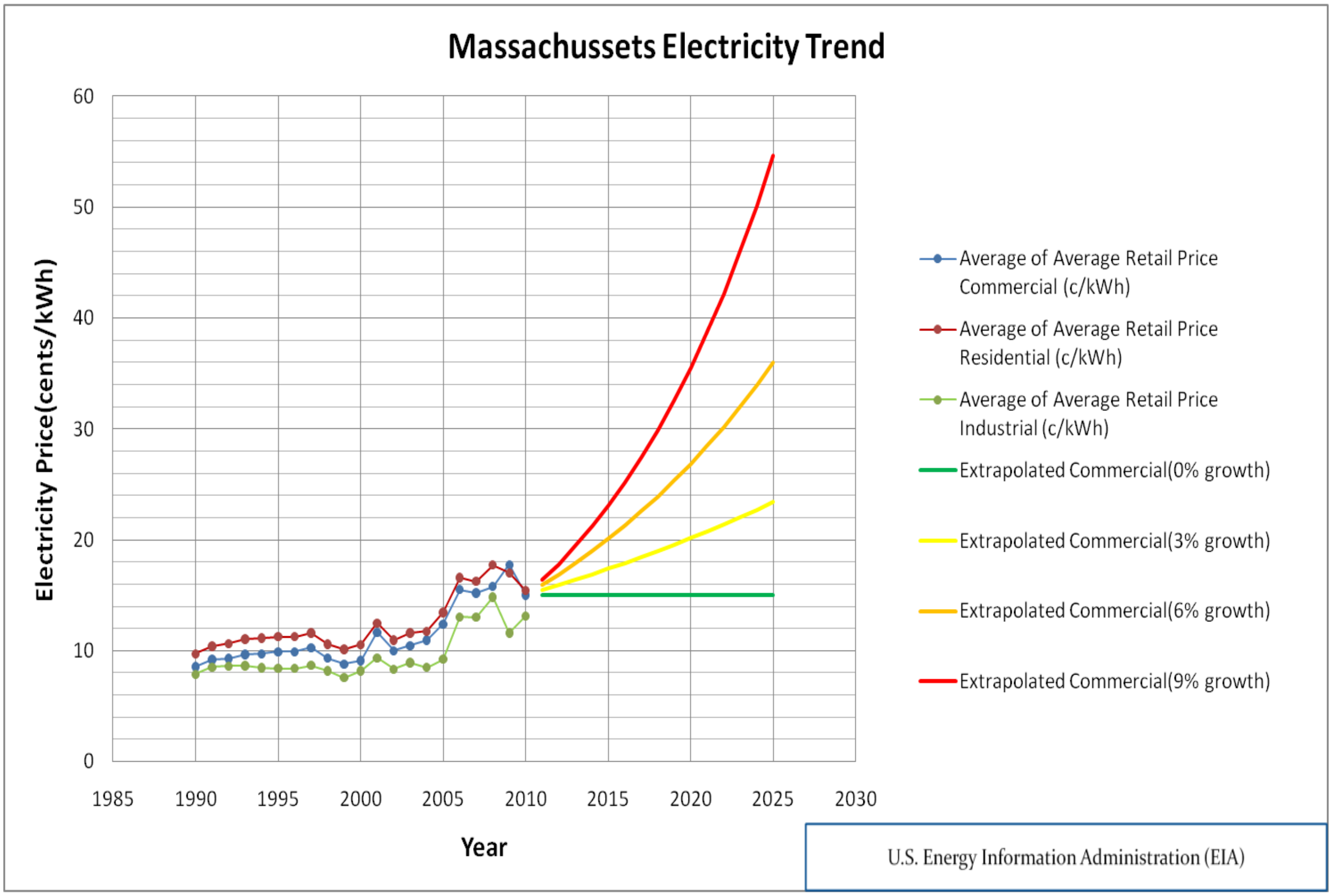


Figure 17: Estimated Electricity Growth Rate [29]

One of the reasons why these prices will increase in the long run is due to the dwindling supply of fossil fuels and an increasing demand for energy. It is also very likely that Massachusetts will see more rapid electricity price increases due to the implementation of the SREC program. These regulations will significantly increase operation costs of electrical utilities who will be pressured to charge higher prices.

7.2-Economic Models

7.2.1-Pay-back Period Model

In a pay-back period model, electricity price growth and PV panels' efficiency deterioration rates are the biggest factors in estimating the annual savings generated by the solar system. Figure 18 shows how this model can be applied to a photovoltaic system installed on the roof of Salisbury Labs. Salisbury Labs has the potential to host a 42.4kW solar array which would initially cost around $300,000 (with installation costs at $7 per watt). This system would generate around 51MWhs of electricity every year, saving WPI around $6,000. These saving will change annually as panels degrade, and electricity prices increase.

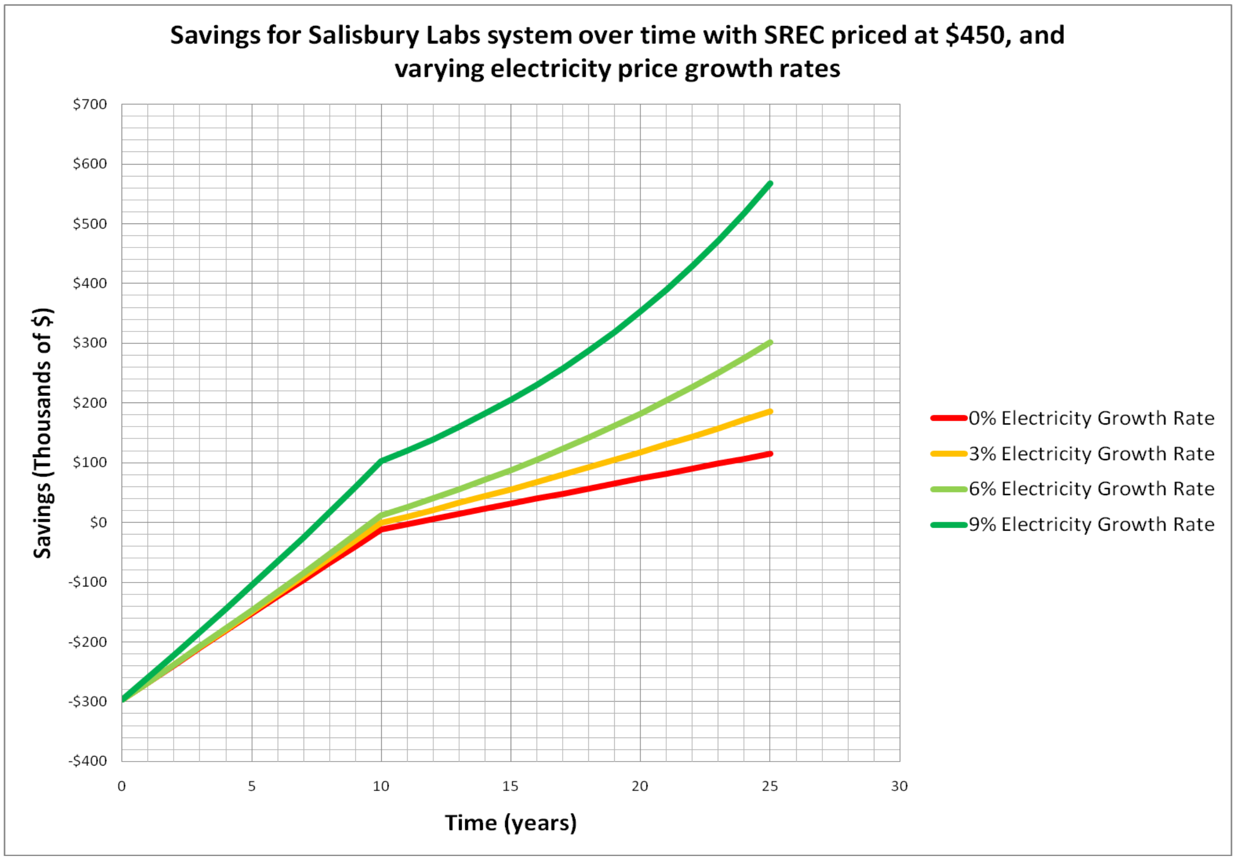


Figure 18: Estimated Savings with a PV System on Salisbury

For the first ten years, the graphs have much steeper slopes because of the Solar Renewable Energy Certificates market. For this model, the SREC are estimated to be value at an average of $450 per MWh. By selling these certificates, investors of solar technology will see shorter pay-back periods of around seven to ten years. This is a very favorable result considering that after the first ten years, the system will still have an additional ten to fifteen years to generate free clean electricity for the WPI campus.

7.2.2-Discounted Cash Flow Model

A discounted cash flow (DCF) model is the most widely used method for estimating the attractiveness of an investment opportunity. Its purpose is to provide an overly conservative estimate of the investment's net present value by discounting its future cash flows. For investments in solar panels, the discounting rate has a very significant impact. For it to be economically feasible, the future revenues, which are discounted over time, must sum up to be greater than the total costs of the investments. It is possible to derive the discounting rate needed for the DCF model from the inflation rate (seen in Figure 19). Inflation describes the rate at which currency loses its purchasing power as more of it is introduced into circulation. Discounting rate is also dependent on more arbitrary factors including risk of the investment and alternative investment opportunities.

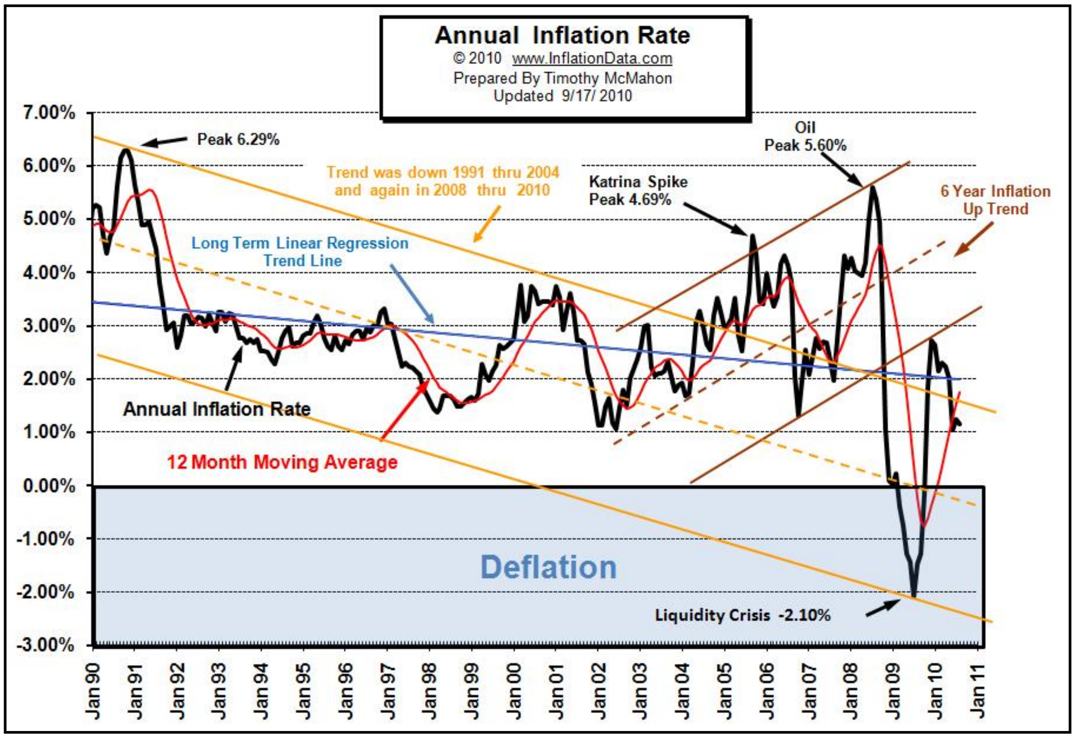


Figure 19: Annual Inflation Rate [18]

7.2.3-Detailed Description of DCF Model

For a photovoltaic system, the cost of the initial investment is dependent on the size of the project. Typical solar installations cost around $7 per Watt for residential systems (under 5kW in size). However for larger projects these costs may be reduced to $5.50 per Watt.

$$C_s = S * C_p$$

- **C_s**: Total initial cost of the photovoltaic system ($)
- **S**: Size of the system (watts)
- **C_p**: An estimate for initial installation ($/watt)

Because photovoltaic systems require very little maintenance, there are no annual costs that need to be considered in our model. However, there is one additional cost that needs to be considered: cost of replacing the inverters once they reach the end of their warranty. The cost of the inverter is discounted according to the time from now to when it needs to be replaced.

$$C_{i1} = \frac{1}{\left(1 + \frac{D}{100}\right)^t} * C_{i0}$$

- **C_{i1}**: cost of replacing an inverter in the future, in today's money ($)
- **C_{i0}**: current cost of replacing invertors ($)
- **D**: Discounting rate of currency (%/year)
- **t**: years in the future when the invertors need to be replaced (years)

After considering the costs associated with the investment, the next step is to estimate the revenue generated by the solar array. The following equation can be used to estimate the total savings from not having to pay for electricity produced by the solar system.

$$S_E = \sum_{t=0}^{25} \frac{1}{\left(1 + \frac{D}{100}\right)^t} * P * \left(1 - \frac{R_D}{100}\right)^t * P_E * \left(1 + \frac{R_E}{100}\right)^t$$

- **S_E**: net present value of the revenue created from not having to buy electricity which is alternatively produced by the PV system ($)
- **t**: Years following initial investment
- **D**: Discounting rate of currency (%/years)
- **P**: System's ideal production of electricity (kWh/year)
- **R_D**: Degradation rate of panels' efficiency (%/year)
- **P_E**: Current price of electricity ($/kWh)
- **R_E**: Growth rate in electricity prices (%/year)

Because of the Solar Renewable Energy Certificate incentives program, we would receive additional proceeds which may be calculated using the following equation. So far, the SREC program is designed to exist for the next ten years.

$$S_{SREC} = \sum_{t=0}^{t_0} \frac{1}{\left(1+\frac{D}{100}\right)^t} * P * \left(1-\frac{R_D}{100}\right)^t * \frac{SREC}{1000}$$

- **S_{SREC}**: Net present value of revenue received from selling SRECs ($)
- **t**: Years following initial investment
- **t_0**: The amount of years the incentive would last
- **D**: Discounting rate of currency (%/years)
- **P**: System's ideal production of electricity (kWh/year)
- **R_D**: Degradation rate of panels' efficiency (%/year)
- **SREC**: Price for which we would be able to sell the SRECs ($/MWh)

The total savings can then be estimated by subtracting the summed costs of the investment from the summed revenues. If total savings are greater than zero, then the investment in the solar system is economically feasible.

$$Savings = S_{SREC} + S_E - C_s - C_{i1}$$

7.3-Sensitivity analysis using discounted cash flow

One of the biggest advantages of the discounted cash flow approach is that it allows for sensitivity analysis which can provide a more detailed view on investment's feasibility. On the following page Figures 20 and 21 display the different electricity price growth rates, and discounting rates of currency, respectively, against the total returns of the investment (after 25 years of operation). For the electricity price sensitivity analysis, the discounting rate of currency is held at 3%. For the discounting rate of currency analysis the electricity price growth rate is also held at 3%. The three lines in each graph represent the projections at different prices for Solar Renewable Energy Certificates. These graphs indicate that as the electricity price growth rate increases, the returns grow exponentially. On the other hand, as the discounting rate of currency increases, the returns diminish.

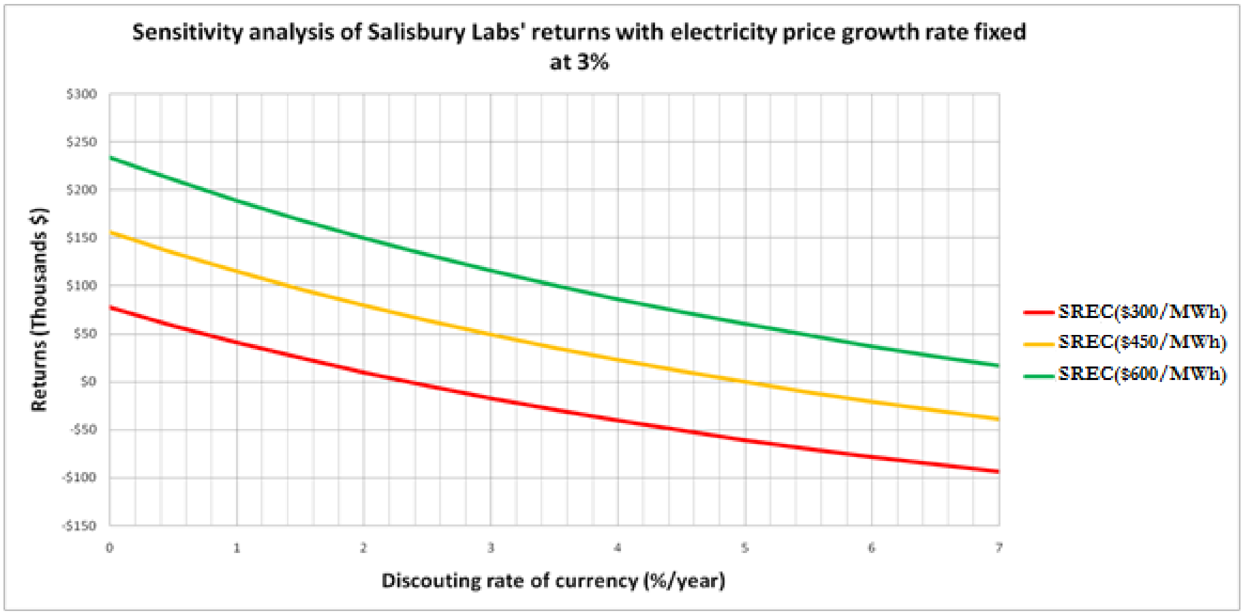


Figure 20: Sensitivity Analysis of Electricity Price Growth Rate vs. Returns

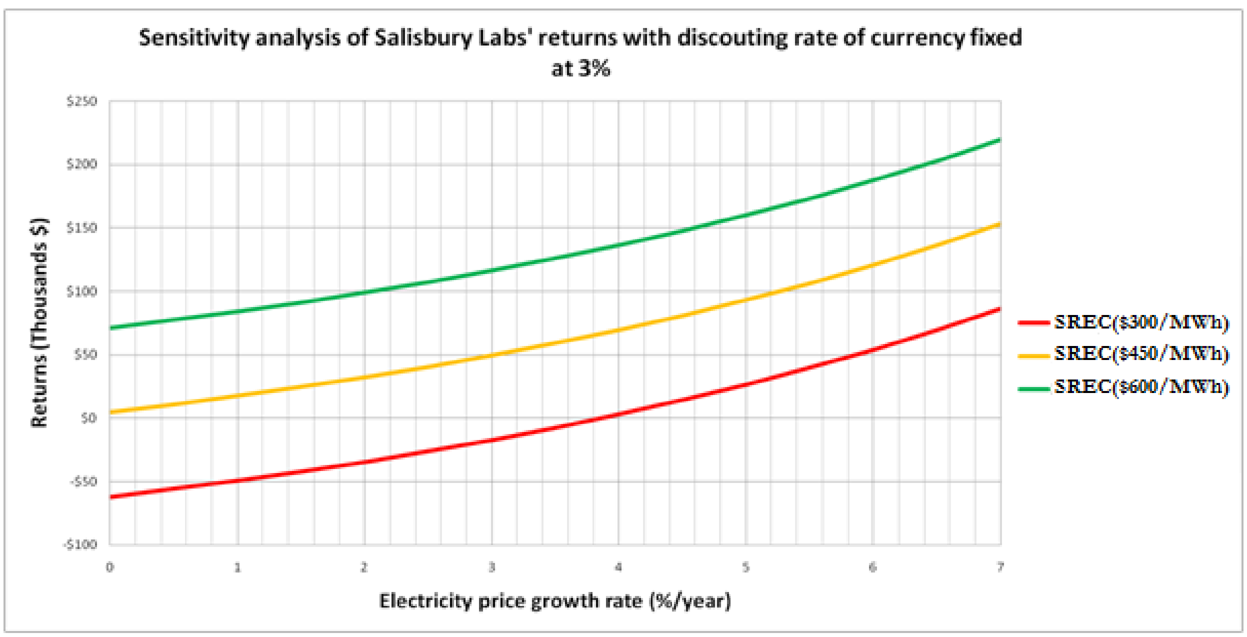


Figure 21: Sensitivity analysis of Discounting Rate vs. Returns

Figure 22 plots the discounting rates necessary to provide a break-even point (where total returns are zero) at the corresponding electricity price growth rates. This analysis allows the user to understand how different ratios of electricity price rates and discounting cash flow rates would affect the economic feasibility of the investment. Any points above the lines indicate favorable rates for making the investment profitable. So for example, with discounting rate of currency at 2% and electricity price growth rate at 4% the investment will be profitable at all SREC prices. However, for a discounting rate at 4.4% and electricity price growth rate at 2%, the investment is only guaranteed to be profitable if SREC are priced over $450/MWh.

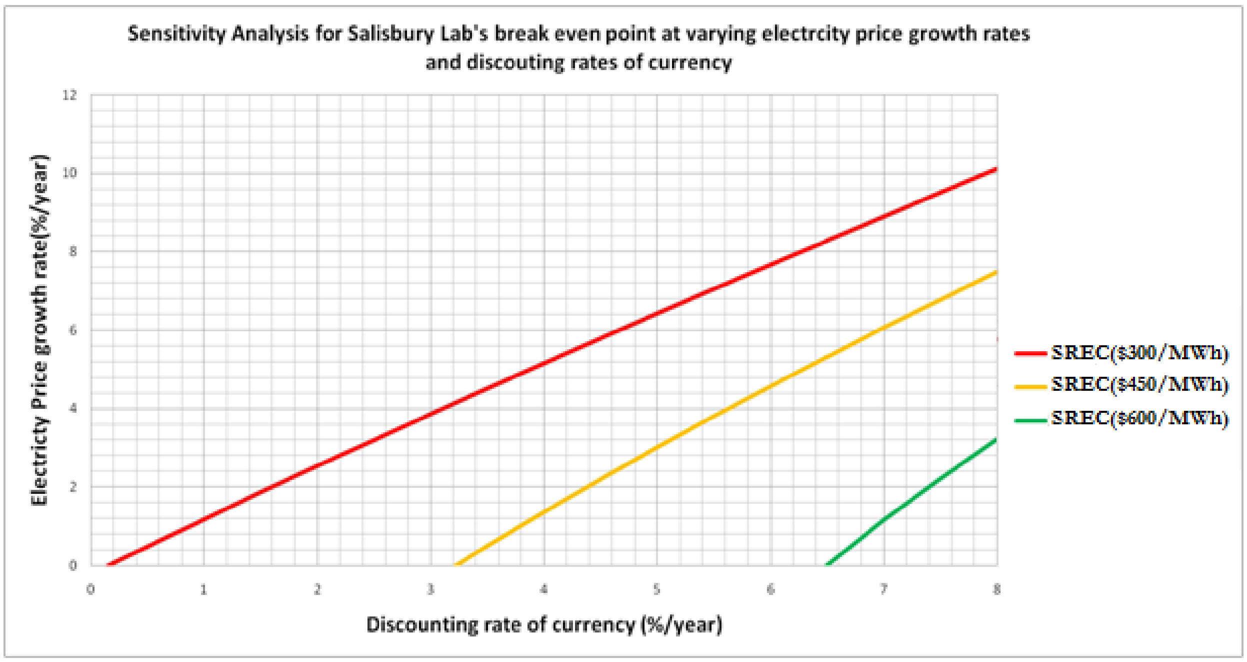


Figure 22: Breakeven Point for Salisbury Labs

7.4-Results for WPI's potential as PV host

Table 1 summarizes all the findings for the major potential hosts of solar panels on WPI's campus. The rankings are based on a timeframe describing which building should have photovoltaic installations done first.

					Savings after 25 years		
Rank	Building	Size (kW)	Installation Costs	Production (kWh/year)	SREC 300	SREC 600	Pay-back period
1	**Admissions Office**	18.5	$120,250	23,413	$13,108	$61,990	6 to 9 years
2	**Morgan Hall**	43.7	$284,050	52,848	$20,705	$131,039	7 to 10 years
3	**Salisbury Labs**	42.4	$275,600	51,276	$20,000	$127,052	7 to 10 years
4	**Daniels Hall**	32.1	$208,650	38,820	$14,419	$95,465	7 to 10 years
5	**Atwater Kent**	24.5	$159,250	28,251	$2,276	$61,256	8 to 10 years
6	**Alumni**	42	$273,000	50,792	$19,784	$125,825	7 to 10 years
7	**Institute Hall**	19.1	$124,150	23,098	$7,374	$55,598	7 to 10 years
8	**Stoddard Complexes**	46.2	$300,300	55,872	$22,060	$138,705	7 to 10 years
9	**Library**	48.3	$313,950	58,411	$23,198	$145,146	7 to 10 years
10	**Fuller Labs**	35.5	$230,750	42,932	$16,261	$105,892	7 to 10 years
11	**Stratton Hall**	25.3	$164,450	30,596	$10,734	$74,611	7 to 10 years
	Total	**377.6**	**$2,454,400**	**456,310**	**$169,918**	**$1,122,579**	

Table 1: Individual Building Analysis

The ranking is primarily based on roof conditions, roof warranties, and when the next planned roof renovation will occur. Admissions Office has a tilted roof and the portion of its roof that is facing south is at near perfect orthogonal to solar radiation making it a great host for PV installations. Apart from its roof condition, installing solar panels on Admissions office will have a good market appeal for prospective students and visitors as the tilted roof of Admission office is easily viewable from outside. It can serve as a flagship for future installations. Ranking of the other buildings are primarily based on available roof surface area with a few exceptions. Even though library has a huge flat roof area but it has a low rank in our analysis. The primary reason for this discrepancy is that library has roof warranty which would void if we install solar panels on it because its roof condition would get changed. On the other hand installation of PVs on Stratton Hall is not feasible due to building's historical recognition. Also, the roof of the Stratton Hall may get damaged due to massive load of PV modules as the building is very old. Harrington Auditorium is going to get its roof renovated in near future so feasible analysis of Harrington Auditorium was not considered.

A thorough research was conducted to find the relation of total returns from different buildings of WPI with the initial PV installation investment. Figure 23 on the following page highlights this analysis. Total returns were calculated using discounted cash flow model with discounting rates and electricity price growth rates both at 3%. The upper and lower limits of the feasibility lines are due to max SREC and lower SREC rate respectively. So, SREC value for WPI would be within the ranges depending on prevalent values at the time when WPI goes ahead with the installation. The way to observe the graph is to look at the ratio of Total returns vs. initial investment after 25 year time period.

$$Feasibilty = \frac{Total\ Return}{Initial\ Investment}$$

Equation 2: Feasibility

From the figure, it can be seen that admission office has the maximum ratio which is one of the major reasons for its high feasibility as mentioned also in the previous table and fuller labs has a low ratio so it has a low rank in feasibility analysis of Photovoltization of WPI.

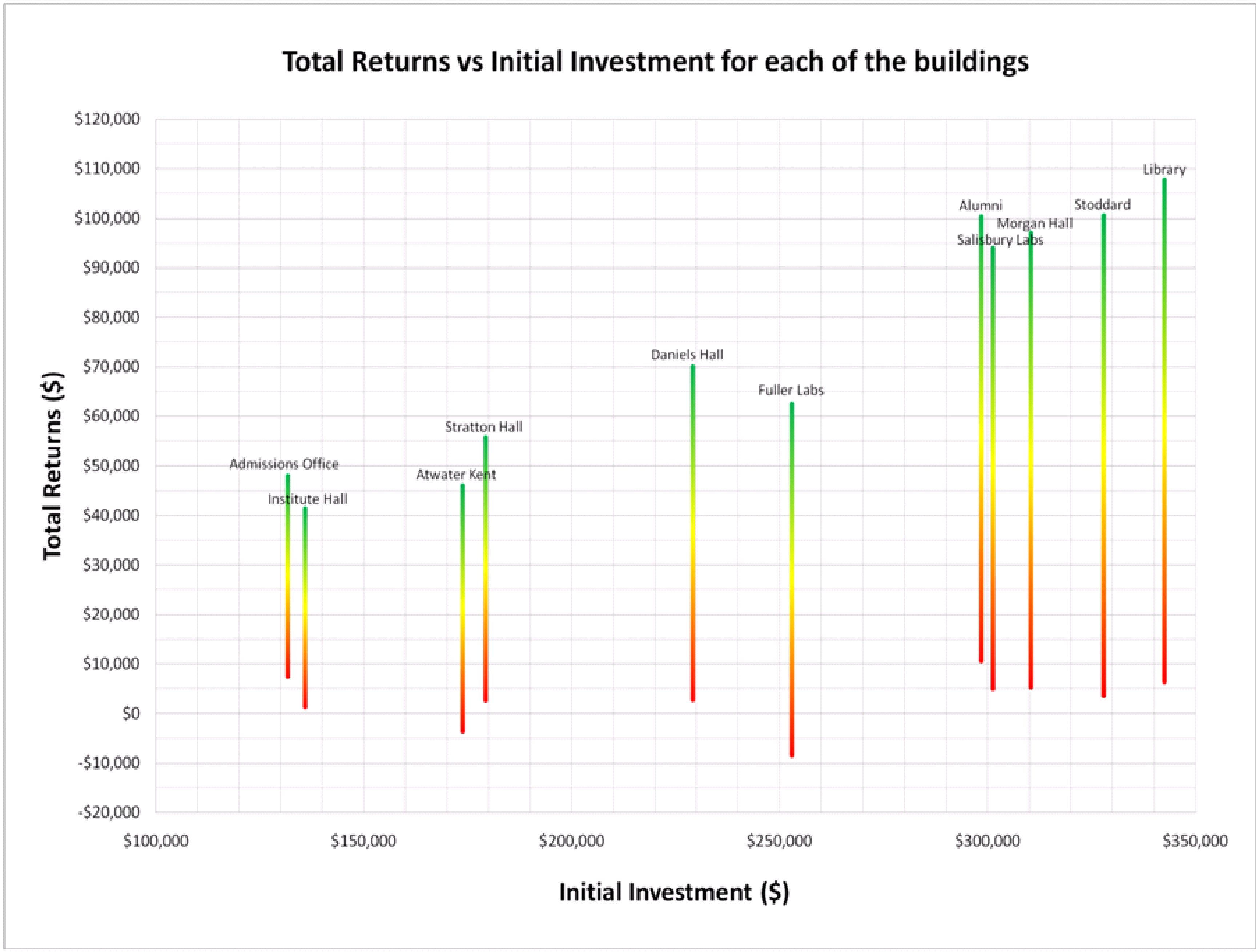


Figure 23: Total Returns vs. Initial Investment for proposed buildings.

-8- Social Impact

Perhaps one of the biggest reasons to consider the transition to cleaner and more renewable forms of energy is the impact it would have on society and the environment. Every kWh of energy that WPI would produce from PV system will not only be providing them with a financial benefit but would also be offsetting any addition to the carbon footprint that would normally be produced from the fossil fuels. Also, as was discussed in previous sections, the energy market, primarily the oil market, is greatly affected by America's foreign relations. So depending on these relations, the price of importing and exporting certain fuels can vary. Photovoltaics can offer a more stable means of energy.

8.1-Quality of Life

It is generally accepted that in today's world the basic quality of life is greatly affected by access to energy resources. Residents of United States are privileged with the availability of cheap energy which greatly improves the society's productivity, and can be linked to US's status of being a first-world country. However, most of the harnessed energy is generated from non-renewable fossil fuels. In Massachusetts for example, over 50% of all supplied electricity comes from the combustion of natural gas, coal, and oil. The harmful byproducts of fossil fuel combustion worsen the quality of life of the general population by exposing them to smog and CO_2 pollution. These emissions are strongly linked to deteriorating human health as well as causing global climate change, and are one of the reasons why our society should gradually transition to cleaner energy technology. Photovoltaic technology has made major advancements in the past few decades, and has shaped into a prominent player in the energy market. Today, solar panels come with 25 year warranties, and record energy yield efficiencies. WPI can make an impact in reducing the negative byproducts from conventional energy production by investing in photovoltaics as illustrated in Figure 24 below.

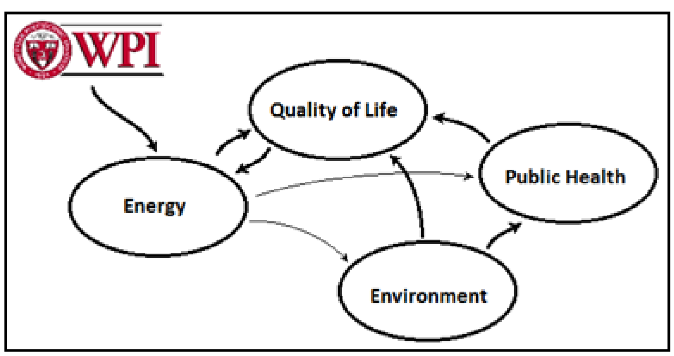
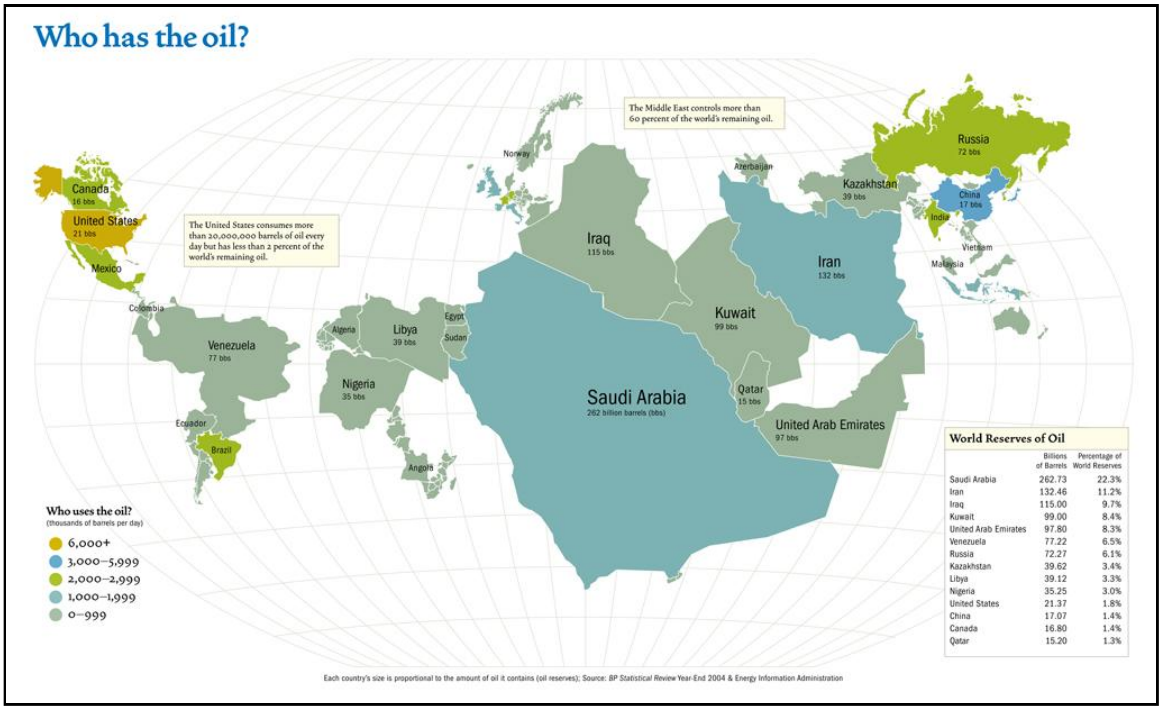


Figure 24: Social interactions between energy and quality of life

8.2-Foreign Relations

Figure 25 below shows an altered map of the world. This map is based off data provided by British Petroleum (BP). The map represents the percentage of the Earth's remaining oil reserves in each country. It can be seen that over half of the world's oil is in the Middle East, where chances of military conflicts seems likely in future. The outcome of such conflicts, if they should occur, could greatly influence the price of oil, making it a less reliable energy source.



	Billions of Barrels	Percentage of World Reserves
Saudi Arabia	262.73	22.3%
Iran	132.46	11.2%
Iraq	115.00	9.7%
Kuwait	99.00	8.4%
United Arab Emirates	97.80	8.3%
Venezuela	77.22	6.5%
Russia	72.27	6.1%
Kazakhstan	39.62	3.4%
Libya	39.12	3.3%
Nigeria	35.25	3.0%
United States	21.37	1.8%
China	17.07	1.4%
Canada	16.80	1.4%
Qatar	15.20	1.3%

Figure 25: Earth's remaining oil reserves [16]

8.3-Survey

A survey was conducted amongst the WPI student body regarding photovoltaics and green energy concept. Over 100 students were surveyed. A complete version of the survey used can be seen in Appendix C and the results can be seen in Appendix D of the Appendices. It was found that 82% of students think that WPI needs to do a better job in promoting alternative energies and 49% of students would like a part of their tuition to go towards the investment in alternative energies, while 24% had no opinion. Not only do students want a stronger push for green energy, they would also be willing to contribute towards the effort.

8.4-Population Health

According to the National Research Council, a study of 406 coal-fired power plants estimated their non-climate damages (health damages) at approximately $62 billion dollars a year. 94% of these damages were accounted by 49,000 deaths and 450,000 serious illnesses

[25]. If the proposed system is installed on WPI's campus, there will be the potential to produce 456,310 Kwh/year. This information can be obtained from table 1 in Economics section. If this energy were to be produced by coal-fired power plants, it would result in 340 tons of CO2. This much CO2 results in medical implications, which can be factored into the cost of one's health. This is known as an "Externality Adder" [11]. The externality adder reflects the added cost to a standard resource, in this case population health. The externality adder for each ton of CO2 in terms of health cost is approximately $40/ton [12]. This results in a savings of $13600 per year in medical costs.

-9- Conclusion

The research for the "Photovoltization of WPI" shows promising result. The main proposal of this project was to conduct the feasibility analysis of installing solar panels at WPI campus. The first step was to look at WPI's electricity bill for previous years, and then look at the price of different solar panels. After measuring the roof area and calculated the number of panels that can fit on each roof area, we could determine the rough cost of the project. The contractors were invited to the campus and did estimation on price and installation. They were able to give great economic insight regarding to different rebates and incentives available on the market. Intensive research on different government incentives programs and analysis on the eligibilities were conducted. Different business models, installation choices, and investment options were studied. The result of the overall project shows that the payback period of the investment can be dramatically reduced by participating in the Solar Renewable Energy Certificate market. This market allows WPI to receive incentives from utility companies by selling the greenness WPI produced to them. According to the market policy and after the three phases of installation, WPI can expect to receive anywhere between $169,918 to $1,122,579 from utility companies each year. And the total investment of $2,454,400, will be paid back between 7 and 10 years, while the general warranty of the PV system is 25 years. Meanwhile, the overall electricity productivity will be 500MWh/year, which will help to reduce the amount of CO2 by 400 tons/year which will lead to a total savings of $13,600/year for healthcare. It is strongly advised that WPI consider investing in the installation of photovoltaics.

Appendices

Appendix A

<u>Evergreen 210 Watt Solar Panel, ES-A-210-fa3</u> [30]

Cost of one solar Panel with the dimensions 64 * 37.5 *1.2 inches. Without rebate = $ 756 for 28 or more

Description and Benefits:-

- Power output: 210W in full sunlight
- Dimensions: 64 * 37.5 *1.2 inches.
- UL4703 certified cables
- *New* MC® Type 4 lockable connectors**
- Complies with the latest codes for accessible arrays
- Most extensive range of mounting options
- Allows installs virtually anywhere and anyhow
- Smallest carbon footprint of any manufacturer
- For the greenest of the green
- 100% cardboard-free packaging
- Minimizes job site waste and disposal costs
- 5 year workmanship and 25 year power warranty

ES-A series panels have the best power tolerance in the industry
(-0 / +5 W) and consistently deliver more electricity than competitors in field tests.

1. **Guaranteed Power**

   The minimum guaranteed power is the nameplate so you never get less than you paid for.

2. **Independently verified power:-H**

   Four independent test labs regularly check panel power so you get the power we promise.

3. **Anti Reflective Glass:-**

   Delivering 2-3% more electricity compared to panels with standard glass

4. **Temperature rating over 90%:-**

   Maintaining up to 4% higher output than most other crystalline silicon panels under hot conditions.

5. **High Ranking in Field trip:-**

   Long-term Photon and TÜV field tests prove Evergreen panels produce more electricity (kWh/kW).

Our ES-A series panels have the smallest carbon footprint and fastest energy payback of any silicon-based solar panel ever made.

6. **Smallest carbon Footprint:-**

   Our String Ribbon™ wafers are made with a fraction of the emissions resulting from making conventional silicon panels.

7. **12 Month Energy Payback:-**

   Our panels begin generating truly clean electricity faster than any other silicon-based panel on the market.

8. **100% Cardboard- Free Reusable Packaging:-**

   Reduces disposal costs and on-site manpower while eliminating tons of landfill.

9. **Lead- Free Solar Cells:-**

   Our panels make clean electricity, and the way we make them is clean too.

Next table highlights the different solar panels available in the market and their specifications. From the table, we see the 315 Solar Panel has a much higher power generation, and approximately cost 4 years to have the investment back. However, from the contractor's information, the Evergreen ES-A-210-fa3 is more popular and has the largest market share.

Appendix B

Module	Peak Power w	Price	$/watt	Dimension L*W*D (in.)	Safety & Rating Certifications	Warranty
Evergreen ES-A-195-fa3b	195	$444.6	2.18	65" x 37 1/2" x 1 3/8"	UL,CE,and TUV certified	25
Evergreen ES-A-210-fa3b	210	$478.80	2.18	65" x 37 1/2" x 1 3/8"	UL,CE,and TUV certified	25
Evergreen ES-A-210-fa2b	210	$478.80	2.18	65" x 37 1/2" x 1 3/8"	UL,CE,and TUV certified	25
SolarWorld Solar Panel SW 230	230	$750	3.26	65.94" x 39.41" x 1.34"	First UL-listed modules	25
315 SOLAR PANEL	315	$1200 - $1300	3.81—4.13	61.39" x 41.18" x 1.81"	UL, CE	25 years power warranty 10 years product warranty

From the above table, we see the 315 Solar Panel has a much higher power generation, and approximately cost 4 years to have the investment back. However, from the contractor's information, the Evergreen ES-A-210-fa3 is more popular and has the largest market share.

Appendix C

Photovoltization of WPI Survey

This survey is meant to help us evaluate how receptive is the WPI community towards investments in solar energy.

How well do you agree/disagree with these statements?

1.) **The byproducts from burning fossil fuels (coal, oil, and natural gas) are a real threat to the environment and our future.**

Strongly Disagree __ Disagree __ No Opinion __ Agree __ Strongly Agree __

2.) **The government is currently doing a suitable job at promoting renewable energy.**

Strongly Disagree __ Disagree __ No Opinion __ Agree __ Strongly Agree __

3.) **The government should be more involved in the promotion of renewable energy.**

Strongly Disagree __ Disagree __ No Opinion __ Agree __ Strongly Agree __

4.) **WPI is currently doing a suitable job at promoting renewable/green energy.**

Strongly Disagree __ Disagree __ No Opinion __ Agree __ Strongly Agree __

5.) **WPI should be making more of an effort to promote renewable/green energy.**

Strongly Disagree __ Disagree __ No Opinion __ Agree __ Strongly Agree __

6.) **It is better to wait until renewable energy becomes more efficient and marketable before WPI makes any big investments.**

Strongly Disagree __ Disagree __ No Opinion __ Agree __ Strongly Agree __

7.) **A percentage of tuition should go towards alternative energy investments.**

Strongly Disagree __ Disagree __ No Opinion __ Agree __ Strongly Agree __

8.) **If WPI had a "Greener" campus, it would be more appealing to prospective students.**

Strongly Disagree __ Disagree __ No Opinion __ Agree __ Strongly Agree __

Continued on reverse

Mark your gender?

Male __ Female __

What is your relationship to WPI?

Student __ Faculty __ Parent of Student __

If you are a student, what year are you?

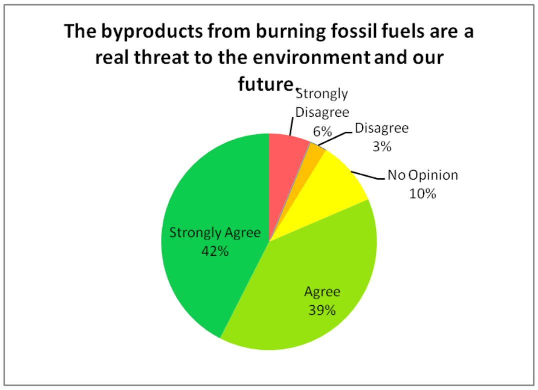
Freshman __ Sophomore __Junior __ Senior __ Grad Student __

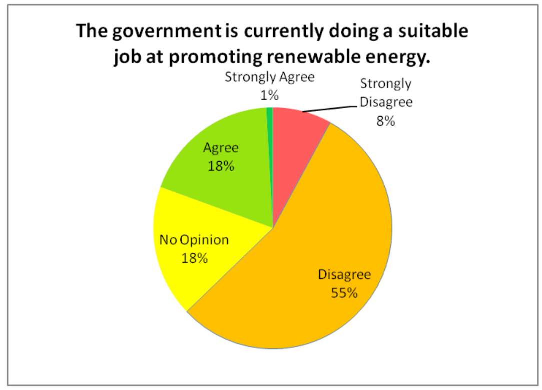
What is your major?

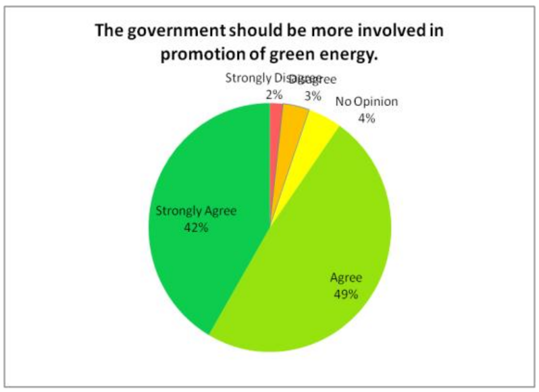
What is your state or country of origin?

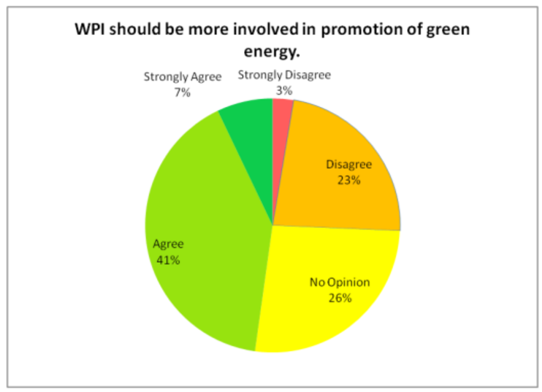
Appendix D

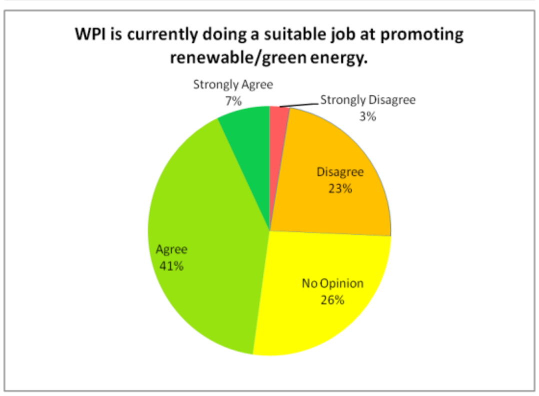
Survey Results

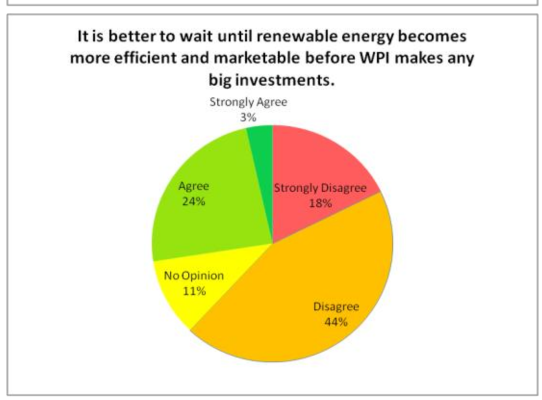


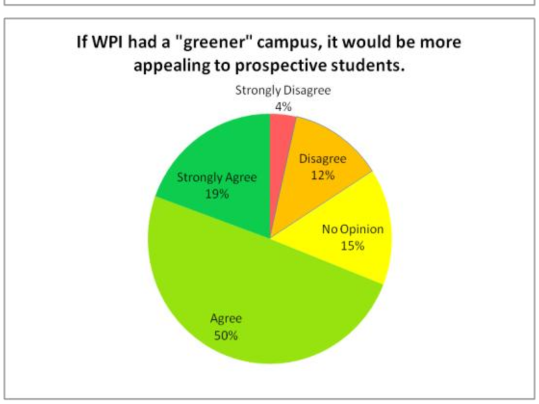


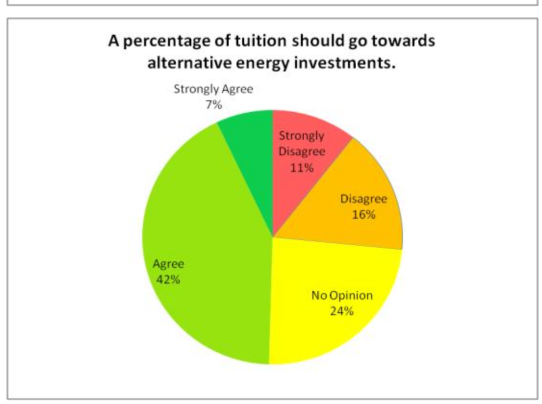












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