Analysis of Life Cycle Costs and Social Acceptance of Solar Photovoltaic Systems Implementation in Washington State Public Schools

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Abstract

Analysis of Life Cycle Costs and Social Acceptance of Solar Photovoltaic Systems Implementation in Washington State Public Schools

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Solar photovoltaic (PV) systems are currently the most competent renewable energy methods to retro-fit in and offset electricity for existing and newly constructed school buildings. Amidst the increasing electricity prices every year, depletion of fossil fuels reserves, disturbance in hydrological pattern and damage to present environment, has given stimulation to search for most viable and effectual solution, to offset public schools need for electricity. The present study is focused for state of Washington and in the arena of its public schools. The existing report uses four schools with PV systems as actual case studies. These case studies are evaluated - to understand the Life cycle costs associated and studies the acceptance of PV systems in social context, amongst school community. Two of the four schools examined, show PV systems as economically beneficial while two schools as case studies do not exhibit the same results. Parameters like solar radiation received and peak demand offset by PV, play an essential role in the whole analysis. Based on survey performed, all of the seventeen schools are influenced and have found a newly learning curve – to reinforce renewable ideas at a very young age among students. Though Public schools are surely enthusiastic to implement PV systems, reduced funding per year and decreased

incentives are a major concern. Despite this fact, reducing solar module prices, inflation of electricity and all items every year drastically reduces the payback period to less than ten years. Concurrently, diversion of school funding, applying retrofits and or power purchase agreements are certainly some solutions to attain desired objective of study.

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Introduction

Photovoltaic system is currently, one of the most widely used technologies in solar renewable energy. With students and school staff becoming aware of sustainable environment and its advantages for health of students, reduction in greenhouse gases and energy efficient school buildings, school districts are striving to incorporate new measures and resources in design and construction process of K-12 schools. These measures include adopting environmental site assessment, providing better learning environment, incorporate sustainable energy saving features in existing and new construction for high performance of K-12 schools, to have less impact on our nature (CHPS 1996) (USGBC 1993).

Based on 1995 statistics of CBECS building type categories (EIA 1978), educational buildings rank third most amongst the thirteen categories under commercial buildings. Majority of its energy in the form of electricity is consumed by lighting, cooling, refrigeration and water heating. In regard, to all these statistics, photovoltaic systems have emerged as one of the most efficient, with less repairs, operation efforts and easy to retro-fit in new as well as existing buildings.

In regard to provide a valid background for researcher's question and analysis, the subject is explored at its maximum to understand the implementation need of solar PV for public schools, market analysis of photovoltaic system, history of solar cells, functioning procedure, its types and efficiency. Chapter 1 of this report termed as Literature review, provides understanding of the subject.

The main objective of this report is to understand the economic feasibility of solar photovoltaic project amidst Northwest's weather, in the state of Washington and investigate non-economic benefits meaning, the social understanding behind these projects. The beauty of sustainable living using renewable methods lies in consideration of both the financial and non-financial aspects of desired method. A step by step approach also called as research methodology is described in chapter 2 of this report.

Public schools receive reduced funding from state and federal government every year. The essential federal tax credit (Dsireusa 1995) and MACRS depreciation (IRS 1862) are not available for public schools. As a result, schools receive fewer incentives for solar renewable energy projects, in state of Washington. In spite of this prevailing fact and Northwest's cloudy weather, schools have been very enthusiastic and passionate about pursuing these projects in large scale in state of Washington. The cash flow developed as a part of this report, to present the performance measures and analysis is explained in depth, in chapter 3.

Solar photovoltaic system has many social benefits that include educating the students, enhancements in the curriculum, participation in national competitions, conducting exhibitions, developing creative thoughtful thinking and change in attitude of students (UWSP n.d.), (solar4rschools 2002), (NEED 1982), (NREL 1977). An online survey is initiated, that represents the questionnaire, while its responses are investigated in chapter 4 of this report.

The financial and non-financial analysis, on account of certain limitations like vastness of subject topic, available time frame, and restricted information availability leaves some gap that needs further exploration. Finally, chapter 5 of this report provides the applicable conclusion along with suggested recommendations for future study and recognition.

Problem Statement –

At present, photovoltaic systems are more adaptable for commercial buildings with major installations. Public school buildings are one of the thirteen types of commercial buildings. In this research, an effort is being made to evaluate the suitability of photovoltaic systems for Washington state public schools.

The research question to be spoken about is, "Are solar photovoltaic systems efficient to offset electricity and acceptable to school community, within the state of Washington?"

This thesis is divided among five chapters. Chapter 1 has review of existing relevant literature suitable for existence of subject topic, Chapter 2 explains research methodology. The case study analysis is performed in Chapter 3 while the Survey analysis is executed in Chapter 4. Eventually, Chapter 5 presents conclusions and recommendations for future scope of study.

Chapter 1.

Literature Review

There are several studies performed to determine the proficiency of solar photovoltaic system (Nawaz I 2006), (Ruben Lalemana 2011), (A.F. Sherwani 2010) (Mohammad Ramadhan 2011), (Harder February 2011), (Fthenakis August 2011), (Chel 2011). These studies involve measurement of either or both, fiscal benefits and non- fiscal benefits. Interestingly, based on my survey and interviews, some of the public schools as commercial buildings are more associated with monetary benefits and find solar project implementation non-profitable, pursued with extensive payback and individual limitations. In spite of this fact, installation of solar photovoltaic systems is gaining momentum, locally, nationally and globally, in public and private sectors. This is because a detailed payback illustrates different factors like, expected net metering savings during summer months, carbon emissions saved, use of innovative efficient solar modules, involves quest for new alternatives to install PV system with provision for healthy and educational environment.

In a novel study performed with different types of buildings as case studies, to investigate different renewable energy options, make these buildings energy efficient and apprehend its benefits, it is found that solar PV falls at second position after solar thermal option as the most suitable alternative to meet the demands of electricity (Rezaie January 2011). Measures to provide better learning environment, approve environmental site assessment techniques, adopt sustainable energy saving features in existing and new construction of high performance K-12 schools, to have less impact on our nature, is at large being implemented by school districts (CHPS 1996) (USGBC 1993). On similar terms, solar photovoltaic projects are extensively being installed in various public schools in state of Washington (Ruben Lalemana 2011), (Chel 2011). Present review shares information on – A) Significance of solar energy B) Life cycle costs of solar photovoltaic project installation and C) Social acceptance of solar photovoltaic installations within the school community.

A) Significance of solar energy:

Solar Energy is energy obtained from sun's light. Solar energy is used by two technologies a) Photovoltaic technology and b) Solar Thermal technology (NREL 1977), (Nawaz I 2006). The following figure illustrates the solar application.

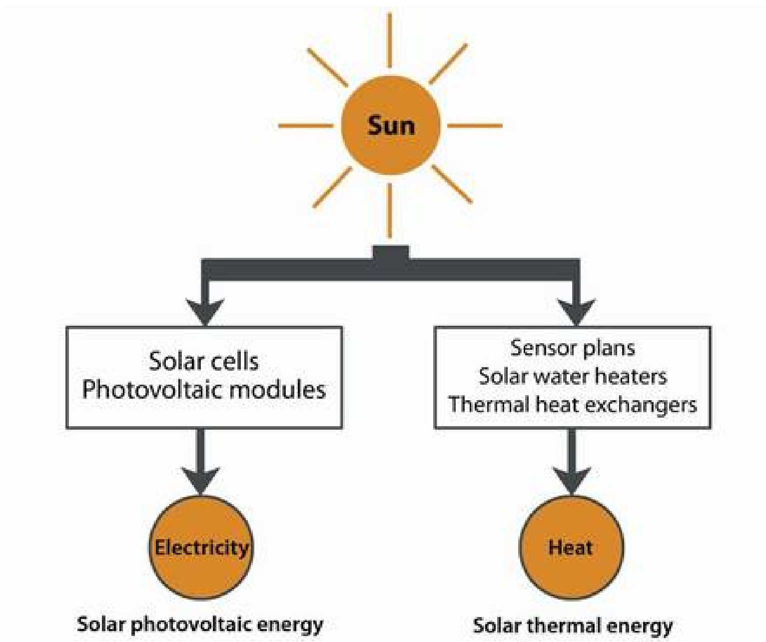


Figure 1 Solar energy application

The Photovoltaic (PV) technology –

The PV technology is used to make solar panels with solar cells that, convert solar rays into electricity. This electricity is used for running variety of electrical appliances.

The Solar Thermal energy –

This technology is used to harness solar energy for thermal (heat) energy, as solar water heaters and thermal heat exchanger.

1.1 Why Solar photovoltaic technology for Public schools?

Solar photovoltaic technology is currently implemented in various public schools in state of Washington, in spite of Pacific North West's cloudy weather. Public schools have several reasons to use solar energy, as photovoltaic projects (NREL 1977), (Ardenhamenergy 2007). The reasons are:

- Energy from Sun is free, abundant and serves as an unlimited source of energy.
- Solar energy is clean, safe and advantageous for health.
- Energy from Sun can offset energy generated from fossil fuels.
- Provides Energy security and independence from import of fuels.

Following statistics explicates the need for change. The data also supports the necessity for enactment of solar photovoltaic projects using solar energy in public schools and how it can work effectively in the state of Washington:

- ➢ According to the data collected in 2008 by Carbon dioxide information analysis center (CDIAC) for carbon dioxide emissions, United States ranks second on CO2 emission estimates from fossil fuel usage and cement production (CDIAC 1982), (IEA 1973). United States, in the year 2009 contributes to 18% of worlds CO2 emissions (IEA 1973). During the period from 1990-2007, globally greenhouse gas emissions increased by 17 percent, while CO2 emissions from United States increased by 21.8 %, for the same period (Fifth U.S.Climate Action Report 2010). In contrast energy obtained from Sun is pure and safe with no traces of pollution. Solar energy is received in enormous quantity, healthy for mankind and good for environment. There are no CO2 and greenhouse gas emissions in solar energy (Solarhome n.d.).
- ➢ In 2010, 45% percent of electricity generation comes from burning coal in United States (EIA 1978). Globally, CO2 emissions from fuel combustion were composed of 43% from coal, 37% from oil and 20% from gas (IEA 1973). Coal is a major contributor of carbon dioxide emission and air borne pollutants. On the other hand, solar power decreases this consumption of coal, reduces greenhouse gases and air borne pollution (Solarhome n.d.).

- As per the statistics from 1995-2005 (Entergy 1913), (EPA 2001), (EIA 1978), the cost of generating electricity using natural gas rose from $2.57/million Btu in 1999 to $8.20/million Btu while coal prices have increased from $1.22/million Btu in 1999 to $1.54/million Btu in 2005. The investment in infrastructure development for transmitting electricity has grown 116% since 1999 with utility companies planning to invest additional $18.5 billion through 2008. Along with this there are tremendous costs associated for approval from environmental agencies. It's estimated that utility industry would spend another $47.8 billion between the years 2007 till 2025 for reduction in emissions.

- As per 2005 statistics (EERE 1977), state of Washington uses 72% of hydropower (compared to 6% for nationwide) , 7% of coal and 9% of its nuclear resources as fuel mix for electric power generation. The electricity consumption is increasing at the rate of 2.3% every year with a prediction of 43% higher increase in consumption of electricity, and infrastructure development to produce electricity by 2030. Though rates of electricity are one of the cheapest in the nation, hydropower has its own limitations (USGS 1879), (EPA: Energy Kids n.d.). They are -
    - Construction of dam and reservoir has high investment costs.
    - Depends on yearly precipitation
    - Obstruct fish migration and population
    - Operation of these plants changes water temperature, water quality and direction of flow of water
    - Construction of reservoirs may use vast areas of useable agricultural land, archeological sites and natural areas.
    - Re-location of local population is required.
    - Methane, carbon dioxide and greenhouse gases may be formed in some reservoirs and emitted to atmosphere.

Through photovoltaic research conducted with National renewable energy and its associated laboratories, it can be understood that immense efforts are applied to increase efficiency of solar cell, module, its balance of system and its reliability. High reliability of solar cells, inverters and Balance of system (BOS), degradation of solar cells during its life span, still being a concern (Sarah Kurtz 2009), various strategies are being employed with use of different materials and technology to bring down the cost of solar photovoltaic system (NREL 1977), (Solarbuzz 2001). Even though electricity produced from solar energy costs more in comparison to conventional electricity generation, it is making a fast approach to meet electricity tariff charged to consumers in different sectors.

- Solar energy helps reduce country's dependence on imported energy from fossil fuels. Based on the type of Solar system used with specific installation, a clean energy system offers a degree of independence from existing line of energy suppliers. In an event of grid power outage, provisions for energy backup supply using batteries, provides energy security (Solarhome n.d.), (Ardenhamenergy 2007), (NRDC 1970).
- Based on 1995 statistics of CBECS building type categories (EIA 1978), educational buildings rank third most amongst the thirteen categories and have an electricity intensity of 8.4kWh per square foot under commercial buildings.

Similar to green revolution in construction industry that provides various sustainable solutions to improve the construction process for better environment and healthier future generation, it is essential to have photovoltaic change in electricity generation to conserve and reduce dependence on fossil fuels. However, primary education begins at home, and schools are second most important place in child's life. Therefore it becomes our moral responsibility to provide education, resources and necessary encouragement from early stages in a child's life for preserving Mother Nature's resources by using renewable sources of energy like solar energy, applying practices of recycling, reducing paper wastage and avoiding carbon emissions.

1.2 Surveillance of PV system in state of Washington

Hesitation and queries always hover around solar PV's reliability, as only suitable in presence of sun, like - Does enough solar energy prevail in state of Washington? What would be the efficiency of the system in cloudy days? Can solar energy be stored to be used at night? What happens to excess energy produced by Sun, during Summer holidays?

The Figure 2 below shows that WA schools annually produce 62.5% of solar energy in comparision to the school in California. Production of solar energy is observed for different public schools in different areas of state of Washington, as shown in the figure. The areas covered are Olympia, Anacortes, Camas in state of WA and Los Angles in California. All the schools have rougly 1Kw PV system installed, while the data is observed from January 2011 till December 2011 (Solar4rschools 2002).

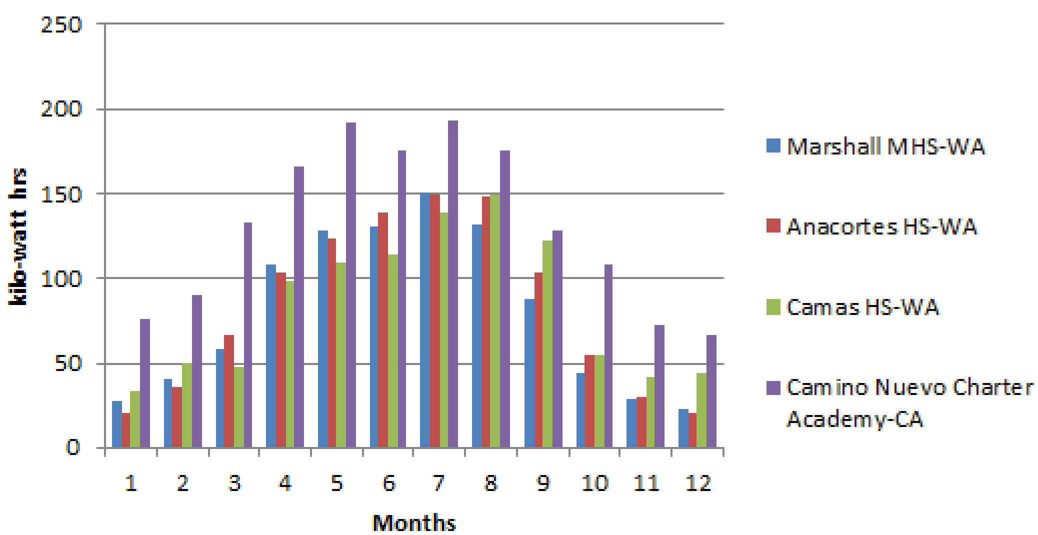


Figure 2 Monthly Production of solar Energy

Solar panels undoubtedly perform the best in sunny and unshaded conditions, however, based on above chart; it is clear that when the sky is overcast with clouds – as is the case with different parts of Washington, usually 45% - 65% of solar energy is still captured to provide photovoltaic electricity and keep it functioning (Boreham 2009) , indirectly showing the systems efficiency in cloudy conditions. Table 1 below shows the seasonal and annual average for three schools in state of Washington and one school in state of California.

Table 1 Seasonal and Annual solar energy production

	Avg WA	Avg CA	Percentage
Fall	37.95	82.13	0.462072324
Winter	42.35	99.53	0.425499849
Spring	116.96	177.73	0.658076858
Summer	131.19	165.43	0.79302424
Total Avg	82.1125	131.205	0.625838415

Yes, solar energy can be stored using batteries often termed as battery banks, with or without a generator so as to use at night or when sun is not shinning. The generator helps charging and maintenance of batteries (DFW n.d.). This occurs with standalone systems that are not connected to grid or off-grid. In case of grid connected solar PV, any excess solar energy produced is transferred to grid. The grid is provided by utility companies to supply backup electricity, whenever needed (NREL 1977), (ANL 1946). This term is called net metering. A diagrammatic representation is shown in Appendix F. Public schools surveyed in this report are all connected to grid, meaning during summer months when schools have vacation and sun provides maximum solar energy, all the excess energy produced is transferred to grid leading to net-metering savings.

1.3 Solar Photovoltaics

The principal focus of researcher's study is restricted to solar Photovoltaics (PV). The scope of research is further narrowed down to apply solar photovoltaic system to public schools in state of Washington.

In a comprehensive study performed, to determine the environmental impact of 3KW residential PV system (Renewablesg 2005), in areas of low radiation and its life cycle impact assessment methods (LCIAs), show solar PV's suitability to areas of low solar radiation. The various tests performed like, eco-indicator 99, global warming, cumulative energy demand, energy payback time with co-relation test on six different types of PV determine that, solar PVs produce more energy than energy consumed in manufacturing process and have less environmental impact than the other cities considered for analysis receiving high solar radiation. This also underlies the fact that solar PV works in Seattle (3Tier 1999) and its associated neighborhoods, in state of Washington effectively (Ruben Lalemana 2011).

Another research undergone in identification of costs and benefits of large scale solar power production identifies social damages in $ per ton, from variety of air pollution assessment from worldwide information. The article also states that identification of these social benefits in Life cycle analysis would drastically increase the net present value as a performance measure and make the project financially viable (Harder February 2011). Following Table 2 states the values from the article

Table 2 Social damage estimates in dollars

Table 8
Summary of social damage estimates from a variety of air pollution valuation studies worldwide. Estimates scaled up to present 2010 dollars.

Pollutant	Minimum ($/ton)	Mean ($/ton)	Maximum ($/ton)	Reference	No. of studies
NO_x	$4396	$345	$14,915	[37]	9
SO_2	$3140	$1208	$7379		10
PM_{10}	$6751	$1491	$25,434		12
GHG	$-10	$57	$277	[34]	28

Solar Photovoltaic system consists of solar cells also called photovoltaic cell, is a solid device that converts energy of sunlight, by photovoltaic effect directly into electricity (NREL 1977). Photo-voltaic panels are the most appropriate renewable solution, as they have various technical benefits:

- Solar PV is easy to retro-fit to existing buildings.

- No groundwork is required.
- There is practically no disruption to existing services.
- Planning permission is not normally required.
- Working of the system has silent operation – No noise pollution.
- No moving parts.
- No maintenance requirements.
- No carbon dioxide and greenhouse gas emissions.

Public schools budget reduce every year, in contrast the cost of school operation keeps going up. One of the ways to help our schools save money is by reducing energy costs, with wise usage of energy by implementation of renewable sources of energy. Using solar energy is one such viable option (The California Energy Commission 1974).

Making our school solar has an obvious benefit of reducing carbon emission and greenhouse contribution to the environment, but the major benefits observed are:

- ❖ **Save money on electricity bills.**
  The schools are closed during summer holidays, during which the system can generate most power, send to the grid and even sell energy.
- ❖ **Raise awareness among students from early childhood.**
  Allows conversation of environmental issues and challenges; explain the importance of sustainable method of living.
- ❖ **Introduce a variety of environmental topics into the national curriculum.**
  Helps in developing a more resourceful learning environment

1.4 Science behind solar Energy

Basic terms and technical facts involved in study of Solar Photovoltaic panels are as under (NREL 1977), (Solarexpert 1974), (Sunenrgy systems n.d.) (Facts-about-solar-energy n.d.), (USsolargy.com n.d.):

- Solar energy is measured in kilowatt-hour.

1 Kilowatt-hour = 1000 watts.

- 1 Kilowatt-hour (Kwh) equals the amount of electricity required to burn a 100 watt light bulb for 10 hours.
- A Solar panel system consists of Solar panels, an inverter, a battery, grid, balance of system consisting of mounting system with/without tracker, AC and DC disconnects conduits, brackets, cables and connectors, a charge controller and electric meter
- 1 Kilowatt solar panel system is made up of four to five panels with dimensions around 12-15 feet in length and 3 feet in height. Present costs are round 4000$ to 7000$ per Kw depending upon the quality of panels and equipment.
- School buildings come under a category of non-residential, commercial buildings while some schools come under different levels depending upon the amount of Kilowatt system needs to be installed at a particular school site (EIA 1995), (css.snre.umich 1991).
- 1 Kilowatt Solar system will generate approximately 1600 kw-hours per year in a sunny climate with average of five hours sunshine per day and approximately 750 kw-hours per year in a cloudy climate receiving two and half hours sunshine per day.
- 1 Kilowatt system will prevents approximately one hundred and seventy pounds of coal from being burned and three hundred pounds of carbon dioxide from being released into the atmosphere.
- Photovoltaic system consists of solar modules tested under standard test conditions with a life of twenty-five (25) years and above. The workmanship warranties typically last for about five (5) yrs.
- A battery backup in solar photovoltaic system provides electricity twenty four hours a day, seven days a week and even during cloudy days and nights.
- Solar panels come in different colors and can have attractive, creative looks.
- Solar energy has the provision to collect, store in batteries, reflect, insulate, absorb and transmit.

1.5 Present Market Economics:

Advanced technologies have caused increase in manufacture of solar panels with an enormous decrease in price. Solar cells have increasingly become cost effective with more distributors entering the market. New technology provides more choices and products as more people realize the benefits of solar energy. In a study performed, to evaluate the life cycle assessment of 1^{st} and 2^{nd} generation solar cells, as described later in the chapter, new designs, materials used, increased efficiency, effort to discard solar cells in recycling, photovoltaic systems are one of the excellent resource for electricity generation and CO2 reduction (A.F. Sherwani 2010).

In past 20 years, electricity produced with solar energy has grown by an average 30% per annum. In 2009, the photovoltaic industry generated $38.5 billion as revenues globally. The market trend for decline in prices is determined by large scale production of solar panels, improvement in efficiency of cells and manufacturing technology (Solarbuzz 2001).

Organizations like National Renewable Energy Laboratory (NREL), perform extensive research and scientific improvements in photovoltaic systems, for U.S department of energy. NREL concentrates on improving conversion efficiencies of solar cell, with minimized cost of cell and consistencies in associated PV components (NREL 1977).

With Government realizing the benefits, incentives are being available from federal, state, local government and utility companies (Dsire 1995) to encourage its establishment in market. Solar energy users like schools, residential consumers, and commercial consumers get paid for excess electricity produced through a system called 'Net-Metering' serving as an additional monetary benefit.

1.6 Renewable Savings and Incentives:

Presently public schools account for usage savings and demand savings as Avoided costs of conventional electricity. The incentives received by schools incorporate Washington state incentives applicable till June 2020 (Dsire 1995). Public schools do not receive federal tax credit and MACRS depreciation benefits (IRS 1862). These benefit itself save more than 40% of the total costs of solar PV. The reason being, schools do not pay taxes and hence are not eligible for either of the above federal benefits, which otherwise are availed by other buildings in commercial category (EIA 1995). The other benefits schools can avail are for net metering savings (DSIRE 1998), (EERE 1977)and renewable energy certificates or carbon equivalent savings (EERE 1977). Following are details of available savings and incentives.

Usage savings –

These savings are defined as, total kilowatt-hours produced by sun/PV system during an academic year or in one year. These can be measured via data monitoring systems like NREL's PV watts calculator (NREL 1977), Bonneville Foundation's solar for schools site (solar4rschools 2002).

Following Figure 3 illustrates the solar energy generated for the current week of May 2012 for Hayes Freedom high school, Camas school district in Washington State (Solar4rschools 2002). This solar energy observed throughout the year establishes the usage savings, as the monitoring system (for student observation) and production meter (for regular billings) installed at the school campus, records solar data and that way offsets electricity from utility.

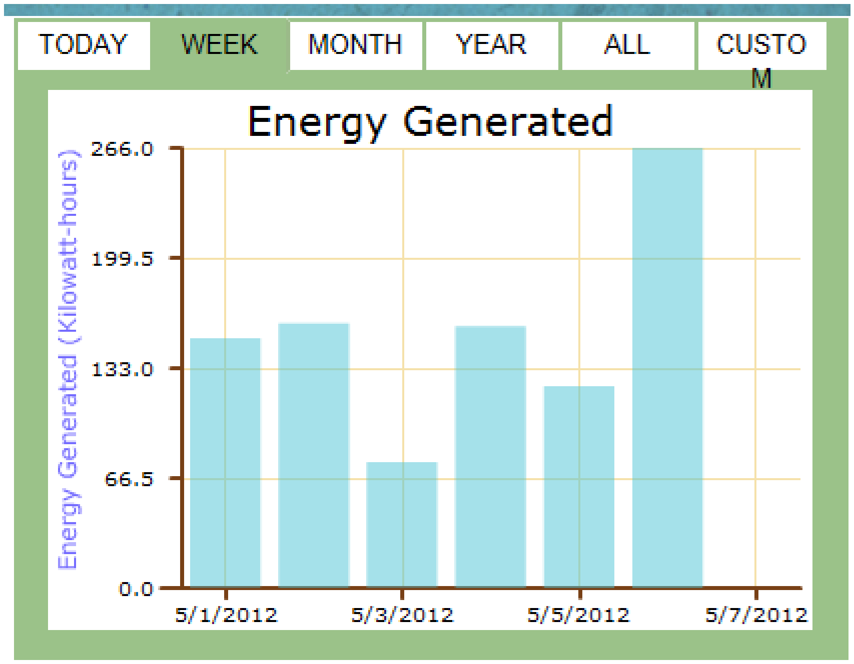


Figure 3 Data monitoring system for solar observation

Demand savings –

Demand savings are comparatively difficult to determine, as it is based on facility's highest demand per 15 minute interval, calculated for over the month. It is essential for solar PV, to offset this demand, during that 15 minute interval for the given month. Hence, the offset from PV can be anywhere from exact demand from utility to nil for a given month. This offset demand value is then multiplied by the demand rate provided by the utility, which is much higher than retail electricity rate (Raphael 2011). Thus avoided costs from electricity comprises of usage savings and demand savings.

Figure 4 explains the demand rate applied by Clark public utilities for specific peak demands identified. The peak demand observed in the electricity bill is multiplied by demand rate (Clark public utility 1938). These demand amounts when compensated by solar PV lead to demand savings.

Second Tier Schedule 134
Applicable to services with a monthly, metered demand greater than 30 kilowatts.

Basic charge: $58.00
Energy charge:
Sep.- Mar.: 4.91 cents per kWh
Apr. - Aug.: 4.38 cents per kWh
Demand charge: $6.77 per kW for secondary point-of-delivery; $5.94 per kW for primary point-of-delivery

Figure 4 Demand rates – Clark Public Utility

Washington state incentives –

These are performance based incentives, delivered by state of Washington, existing till 30th June 2020. The incentives are based on location of manufacturer of solar PV , inverter and amount of electricity produced by the solar PV. The incentives range from 12cents/kWh till 54 cents/kWh, with the manufacturers from state of Washington receiving most incentives. The highest cap provided is $5000 per year (DSIRE 1998) for any commercial consumer using solar PV as its renewable source.

Net metering incentives –

Net metering programs provide incentives for on-site renewable energy generation, to offset their electricity consumption. This is calculated over monthly basis or annually. The electric meters run backwards, when PV system generates electricity in excess of their demand. The excess electricity turned in to utility company, provides schools/customers retail rate per kWh, as incentive for excess electricity produced (EERE 1977), (Watson 1998), (Doris 2009).

Renewable energy certificates (REC's) or Carbon equivalent incentives or Green Tags –

These tags or certificates are property rights for environmental, social and other non-power qualities of renewable electricity generation. The attributes can be sold separately from electricity produced by the school/customer. The renewable energy generator like solar PV, generates one REC for every 1000 kilowatt-hours (or 1 megawatt-hour) of electricity placed on the grid. The REC's provide primary attributes of renewable fuel source, emissions control, geographic location and vintage of generator, RE certification and secondary attributes of avoided emissions and price stability in renewable energy market. The certificates are priced anywhere from 1.2cents/kWh till 2.0cents/kWh. Solar REC's or green tags are priced comparatively higher than regular REC's. (EERE 1977), (EPA 1970)

1.7 History of Solar Panels:

The journey of Solar panels begins as early as 7th century BC till 1200's AD, from 1767 till 1897 and from 1900s till present. As history recollects, the concept of solar energy is observed and confirms presence of Sunlight, being capable of generating usable electrical energy. The Solar power is used historically in situations where electrical power from the grid is unavailable (EERE 1977), (Solarpowerbeginner n.d.). A brief timeline is established here with:

- 1839 - Photovoltaic effect was first developed by a nineteen year old boy named Alexandre-Edmond Becquerel.
- 1873 - Willoughby Smith finds that Selenium shows Photoconductivity.
- 1876 – W.G.Adams created the basis for basic Solar cell. He discovered that Selenium generated electric current when exposed to light. This gave a clue, that solid material could change light into electricity without heat or moving parts, leading to invention of solar electricity.
- 1883 – Charles Frits developed a Solar cell using Selenium on a thin layer of gold to form a device giving less than 1% efficiency. These Solar cells were not efficient enough to power electrical equipment.
- 1905 – Albert Einstein explained the Photoelectric effect for which he received Nobel Prize in Physics in 1921.
- 1954 – Bell laboratories developed a Solar cell with Silicon instead of Selenium with about 6% efficiency. The highly efficient Solar cell was first developed by Daryl Chapin, Calvin Fuller and Gerald Pearson using diffused p-n junction. The use of technology was very expensive and was used to power toy subs and model air planes only.

- 1957 – Hoffman Electronics creates a 2% efficient commercial Solar cell at 1785$ per watt. Since then the company strives to achieve more efficient commercial Solar cell with 14% efficiency and introduced grid contact reducing cells resistance.
- 1985 – Silicon cells with 20% efficiency were developed by Center of Photovoltaic engineering at University of New South Wales.
- 1994 – The National renewable energy laboratory's solar energy research facility develops a GainP/GaAs a two terminal concentrator cell as first Solar cell with 30% conversion efficiency.
- 1996 – The national center for Photovoltaics established in Switzerland, achieves 11% efficiency, using energy conversion dye sensitized cells that use a photo electrochemical effect.
- 2008 – Scientists at U.S department of energy's National Renewable Energy laboratory (NREL) set a world record in Solar cell efficiency with photovoltaic device that converts 40.8% of sunlight into electricity. The inverted metamorphic triple-junction Solar cell was designed, fabricated and independently measured at NREL.

Presently, the industry has increased almost 200 times in the last twenty years. Solar power is now used for many activities like power lights, television, radio, for heating, pumping water, by railways, by coast guards and even satellites.

As a result, new advancements in photovoltaic technology, anticipates solar energy as the promising source of energy for forthcoming generation. The future buildings would be designed as net-zero energy building, with renewable energy electricity, efficient designs and best practices in construction. The prices of Solar cells have dropped over the past decade, with use of solar electric panels becoming more feasible. Solar panels and its types are now used in various situations like buildings far from power lines, schools, on flat roofs, parkways, bus shelters and more.

1.8 How does Solar Photovoltaic system work?

Figure 5 shows a picture of a house to explain functioning of photovoltaic system, However Photovoltaic system consisting of solar modules, inverters and balance of system installed in school building works in a similar way. (Sunenrgy systems n.d.)

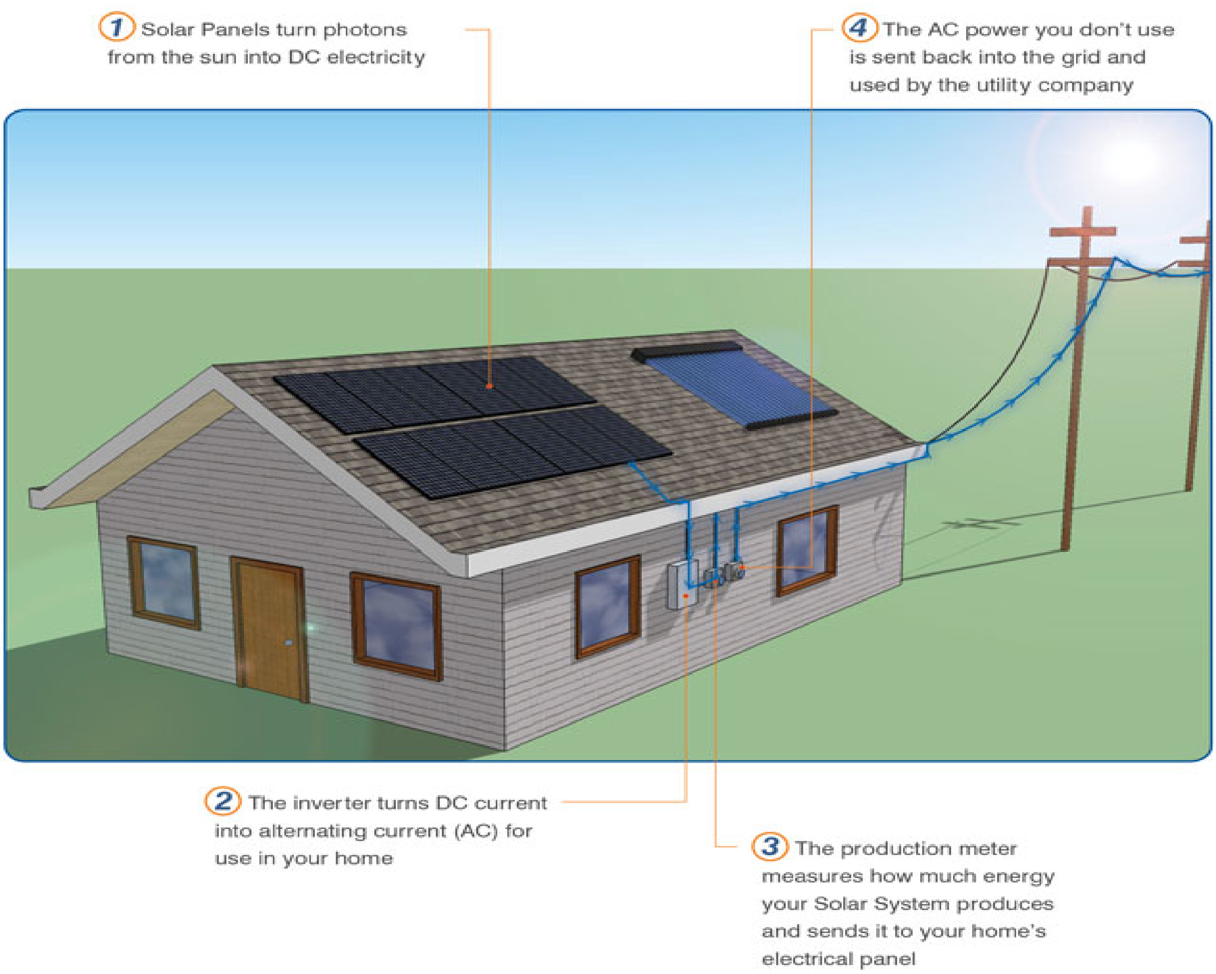


Figure 5 Functioning of Solar PV

Each solar panel receives energy from sun as photons. The panels harvest these photons and convert them to electricity. Solar panels are connected in series, parallel or series-parallel wiring to generate the DC voltage. Based on type of module, panels convert around 7% -17% of the energy they receive into electricity (Solarexpert 1974), (NREL 1977).

- The solar panels instantly convert sun's energy into DC voltage. The DC voltage output of the solar array need to be converted to a 60Hz AC power while the inverter have its voltage either increased or decreased to 120 volts.
- The inverter takes the solar arrays DC power and transforms it into school and utility grids 120 volts AC, 60 Hz electricity.
- The inverter is mounted close to the electric panel either on the inside or outside wall.
- The 120volts AC power leaving the inverter is then connected to a dedicated breaker in the main electric panel. This panel provides solar electricity to all of the electrical loads in school and entire utility grid.

•The solar array's output is directed from roof to the inverter placed next to electric panel.

•The inverter converts the solar array's power from a high voltage DC to a clean 120V AC.

•The 120V AC output of the inverter goes through an electric meter, to record all the solar energy in kWh, produced for the entire year.

•The 120V AC continues to flow from the solar meter to a breaker in school's electric panel.

•This integrates solar electricity to both the school and the utility grid.

•When a solar PV system provides exact amount of power that the school is currently using, then the electric meter will stand still.

•When a solar PV system provides more power than the school is using, any excess will flow backwards through the utility meter and school will build a credit with the utility company, called net metering.

•When a solar PV system provides less power than the school is using, then the utility grid will provide the rest. In this case, meter will be spinning forward only for the excess electricity that is required.

1.9 How Solar cell works?

Solar cells are individual cells of a solar module also called solar panel. These solar panels together are called solar array. Solar panels are measured and priced as dollar per watts for a solar array. This is explained in the following Figure 6, (EERE 1977):

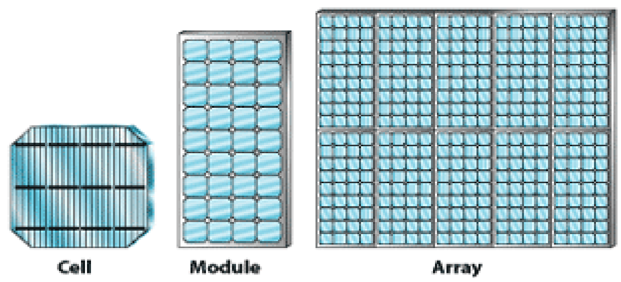


Figure 6 Solar Cell, Module and Array

Solar cell consists of various layers of material. Following Figure 7 shows different layers of a solar cell:

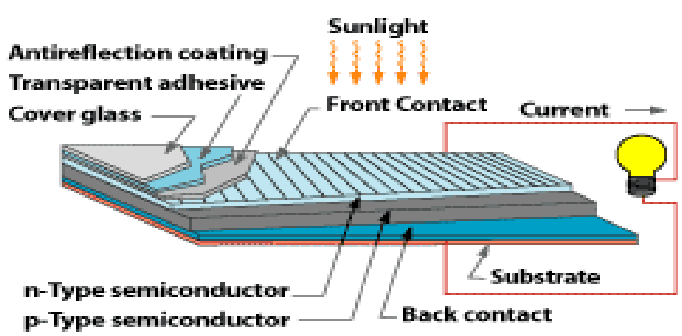


Figure 7 Different layers of Solar Cell

Silicon is a semiconductor material that conducts electricity. A solar cell is a sandwich of two different layers of silicon that are specially doped to let the electricity flow through it.

The lower layer is p-type (positive-type silicon) as electrons are negatively charged, doped with few electrons. While the upper layer is doped with many electrons called n-type (negative-type silicon). This is explained with the diagrammatic representation in Figure 8, (Woodford n.d.):

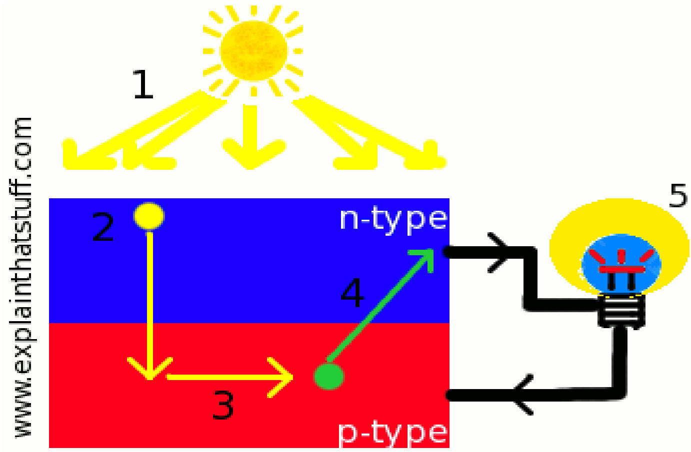


Figure 8 Crossection of Solar cell

A solar cell is a sandwich of n-type silicon (blue) and p-type silicon (red).

1. When sunlight shines on the cell, photons (light particles) attack the upper surface.

2. The photons (yellow blobs) carry their energy down through the cell.

3. The photons give up their energy to electrons (green blobs) in the lower, p-type layer.

4. The electrons use this energy to jump across the barrier into the upper, n-type layer and escape out into the circuit.

5. These electrons flowing through the circuit makes the lamp light up.

1.10 Classification of Solar cells:

Solar cells are classified as (NREL 1977), (EERE 1977):

• 1st generation Solar cells – consist of the traditional Wafer Silicon cells made of semi-conducting p-n junctions.

• 2nd generation Solar cells – consist of Thin film Silicon cells, based on reducing costs of first generation solar cells by employing thin film technologies.

• 3rd generation Solar cells – consists of quantum dots made from nanocrystals that are potentially able to overcome the efficiency limit of 31%-41% for single bandgap solar cells. These cells are explored for new materials other than silicon like solar inks using conventional printing press technology, solar dyes and conductive plastics.

Following Figure 9 and description, helps to explain the first and second generation solar cells while the third generation solar cells are relatively new and being researched (Wikipedia n.d.), (NREL 1977) (A.F. Sherwani 2010)

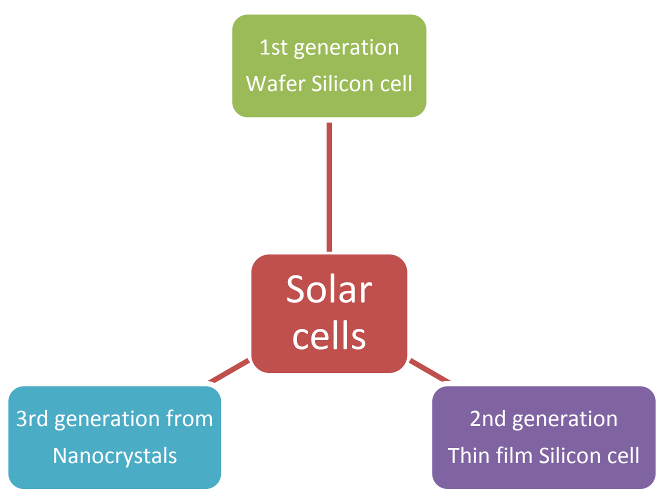


Figure 9 Types of Solar Cells

1.10.1 Wafer Silicon cells:

Materials used –

- Crystalline Silicon (c-si) most prevalent bulk material

- Based on crystallinity and crystal size result as ingot, ribbon or wafer

Types –

1) Monocrystalline Silicon cell(c-si) (A.F. Sherwani 2010)

Process –

- Made from Czochralski method.
- Single crystal wafer cell.
- Cut from cylindrical ingots.

Advantages –

Higher efficiency cells

Disadvantages -

- Method expensive
- Cylindrical ingots do not completely a cover square solar cell module
- Causes substantial waste of refined silicon
- Uncovered gaps at four corners of cells

2) Poly or Multicrystalline Silicon (poly-si or mc-si) cells

Process –

- Made from cast square ingots
- Large blocks of molten silicon carefully cooled and solidified

Advantages –

Less expensive

Disadvantages –

Less efficient

3) Ribbon Silicon (Type of multicrystalline silicon(mc-si))

Process –

Formed by drawing thin films from molten silicon to form a multicrystalline structure

Advantages -

Saves production costs by reducing silicon wastes

Disadvantages -

Low efficiency than poly-si cells

1.10.2 Thin film Silicon cells:

1) Cadmium telluride solar cell

Material used –

Cadmium telluride

Process –

Thin film of cadmium telluride acts as semiconductor layer to convert sunlight into electricity.

Advantages –

Less expensive than crystalline silicon

Disadvantages –

Cadmium in cells can be toxic if released, though impossible during normal operation

2) Copper Indium Selenide (CIGS)

Material used –

Compound semiconductor material made of copper, indium, gallium and selenium.

Process –

Fabrication involves vacuum process of co-evaporation and sputtering

Advantages –

- Direct bandgap material
- Highest efficiency of 20% achieved

Disadvantages –

High manufacturing costs

3) Gallium arsenide multijunction cells

Materials used –

Gallium, Arsenide, Germanium, Gallium, Indium, Phosphide.

Process –

- Multijunction cells are sub class of solar cell with multiple thin films
- Produced by metalorganic vapor phase epitaxy for higher efficiency

Advantages –

- High efficiency cells as much as 42.3%
- Used in Satellite and space exploration

Disadvantages –

Increase in costs of metals

4) Light absorbing Dyes

Material used –

Ruthenium metal organic dye

Process –

Manufactured by screen printing and use of ultrasonic nozzles

Advantages –

- Less expensive
- By do it yourself. Use of low cost materials
- No advanced elaborate equipment needed

Disadvantages –

- Dyes in cells suffer from degradation and UV light
- Cell casing difficult to seal due to solvents in assembly

5) Organic polymer solar cells

Materials used and Process –

Built from thin films of organic semiconductors processed including polymers like polyphenylene vinylene from solution with small molecule compounds like copper phthalocyanine, carbon fullerenes and its derivatives called PCBM. Based on the concept of electron donor and acceptor method

Advantages –

- Novel technology with promising price reduction
- Faster return on investment
- Optical absorption co-efficient of organic molecules high
- Inexpensive in large scale production

Disadvantages –

- Low efficiency
- Low stability
- Low strength

6) Silicon thin films

Material used –

Amorphous Silicon, protocrystalline Silicon and Nanocrystalline silicon

Process –

From chemical vapor deposition, silane gas and hydrogen gas.

Types –

Based on deposition parameters there are three types:

a) Amorphous silicon (a-si or a-si:H)
b) Protocrystalline silicon
c) Nanocrystalline silicon or micro crystalline silicon(nc-si or nc-si:H)

Type a)

Made up of amorphous or microcrystalline silicon with basic electronic structure as p-i-n junction

Process –

Uses glass as substrata and deposits a very thin layer of silicon by plasma enhanced chemical vapor deposition

Advantages –

- A film 1 micron thick can absorb 90% of usable solar energy
- Higher efficiency , Higher band gap
- Tandem cells can be formed with a-si and nc-si)

Disadvantages –

High costs per watt

Type b)

Protocrystalline silicon with low fraction of nanocrystalline is optimal for high open circuit voltage

Advantages –

Less expensive to produce

Disadvantages –

- Low efficiency than bulk silicon
- Low quantum efficiency
- Dangling effect and twisted bonds

1.11 Manufacture of Solar cells:

1.11.1 Wafer Silicon cell (Wikipedia n.d.):

- Solar cells are semiconductor devices with quality control in semi-conductor fabrication. Large-scale commercial solar cell factories make screen printed poly-crystalline silicon solar cells. Single crystalline wafers used in the semiconductor industry can be made into excellent high efficiency solar cells, however are considered too expensive for large-scale mass production.
- Poly-crystalline silicon wafers are made by wire-sawing block-cast silicon ingots into very thin (180 to 350 micrometer) wafers. These wafers are usually p-type tampered. A surface diffusion of n-type dopants is performed on the front side of the wafer, to form p-n junction a few hundred nanometers below its surface, to form a solar cell.
- To increase the amount of light coupled into the solar cell, antireflection coatings like silicon nitride with exceptional surface passivation qualities are applied. It prevents carrier recombination at the surface of the solar cell. Several hundred nanometers thick antireflection coating, using plasma-enhanced chemical vapor deposition (PECVD) is applied. Solar cells with textured front surfaces like antireflection coatings are formed on single-crystal silicon and in recent years methods to apply them on multicrystalline silicon have been established.
- The wafer has metal contact on back surface by screen-printing aluminum metal paste, while grid-like metal contact made up of fine 'fingers', 'busbars' screen-printed with silver paste on the front. The paste is then fired at several hundred

degrees celsius to form metal electrodes in ohmic contact with the silicon. Cell efficiency can be increased with additional electro-plating.

- With metal contacts made, the solar cells are interconnected by flat wires or metal ribbons, and assembled into modules or "solar panels". Solar panels have a sheet of tempered glass on the front, and a polymer encapsulation on the back (madehow n.d.).

1.11.2 **Thin Film Solar cell** (Howstuffworks n.d.)**:**

- Traditional solar cells use silicon in the n-type and p-type layers. New generation of thin-film solar cells uses thin layers of either cadmium telluride (CdTe) or copper indium gallium deselenide (CIGS). These nanoparticles, the four elements self-assemble in a uniform distribution, ensuring correct atomic ratio of the elements.

- The layers that make up the two non-silicon thin film solar cells are shown below. There are two basic configurations of the CIGS solar cell. The CIGS-on glass cell needs a layer of molybdenum to create an effective electrode, while in the CIGS-on-foil cell metal foil acts as the electrode. A layer of zinc oxide (ZnO) plays the role of the other electrode in the CIGS cell. The semiconductor material and cadmium sulfide (CdS) are sandwiched in between the solar cell layers. These two layers act as the n-type and p-type materials, necessary to create a current of electrons. Following Figure 10 shows the Thin-Film CIGS solar cell.

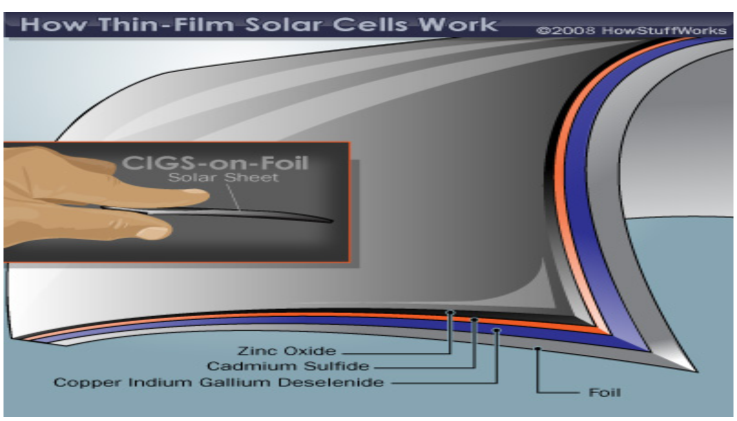


Figure 10 Thin-Film CIGS Solar cell

- The CdTe solar cell has a similar structure. One electrode is made from a layer of carbon paste infused with copper, the other from tin oxide (SnO_2) or cadmium stannate (Cd_2SnO_4). The semiconductor in this case is cadmium telluride (CdTe), which, along with cadmium sulfide (CdS), creates the n-type and p-type layers required for the PV cell to function. Following Figure 11 represents the Thin-Film CdTe solar cell.

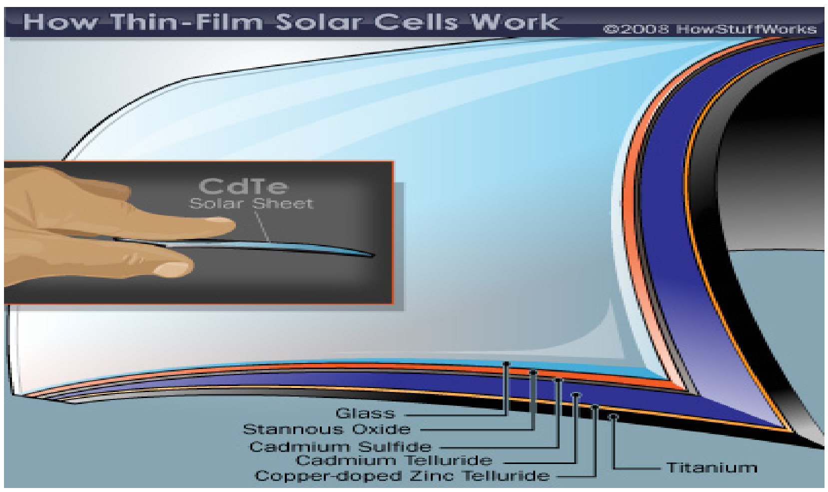


Figure 11 Thin-Film CdTe Solar cell

1.12 Price of photovoltaic systems, Costs and Efficiency of Solar cells:

1.12.1 Price of Photovoltaic systems:

The distributions of costs in percentages, for various components of a photovoltaic system are shown in the following Figure 12 (Solarchoice n.d.), (solar-estimate 2000)

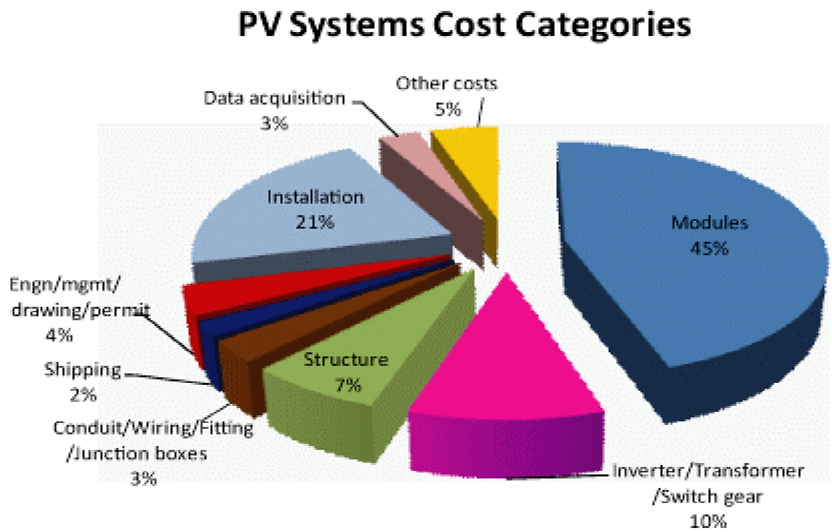


Figure 12 Cost distributions of PV components

Price of PV system depends on system rating, location and type of installation, required electricity, circuit equipment and manufacturer.

System rating – is based on output watts under standard test conditions (STC). More is the wattage power, high are the costs and rating for the PV system.

Location and type of installation – explains the geographical location and difficulties involved in installation of PV system. The costs increase with type of connectivity required for proper functioning of system.

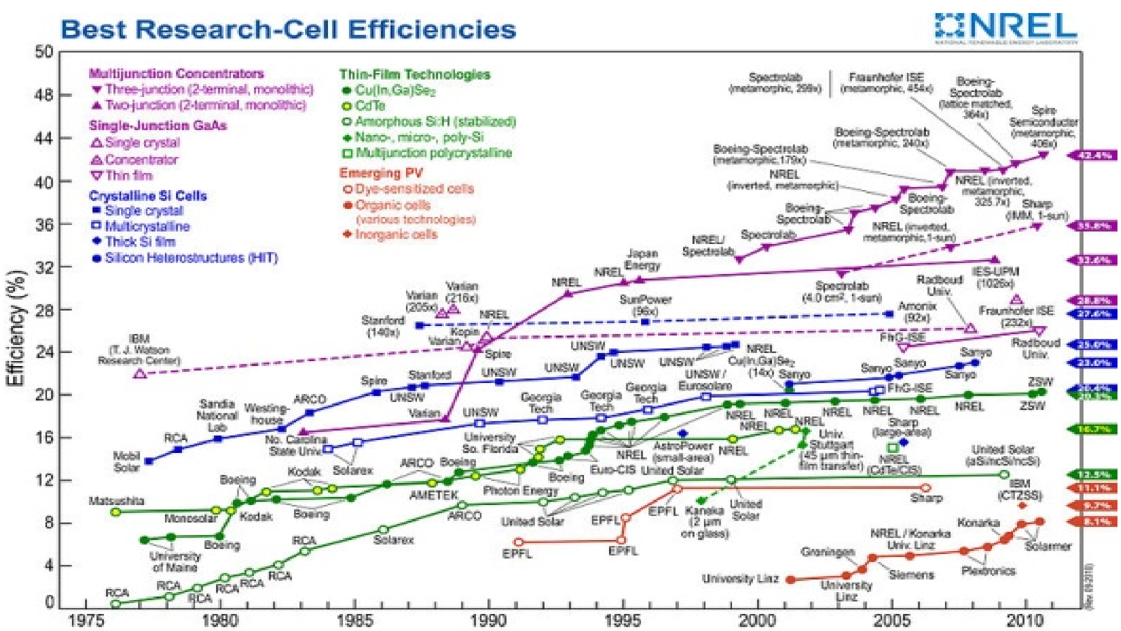
Required electricity and circuit equipment– This involves the costs for inverter. The inverter converts the direct current (DC) from sun to alternating current (AC), suitable for functioning of all electrical appliances and machinery.

Manufacturer – Brand names are costly in comparison to generic names, though they have same usable life and warranty.

<u>1.12.2 Cost of solar cell</u> (Wikipedia n.d.)**,** (NREL 1996)**:**

Cost of solar cell is given per unit of peak electrical power. Manufacturing costs are defined as cost of energy required for manufacturing solar cells. Solar tariffs vary worldwide and state by state

The following Figure 13 illustrates the solar cell efficiency obtained in best laboratory, (Wikipedia n.d.), (NREL 1977). These efficiencies are obtained for different materials and new technologies, experimented on one square centimeter cells. Actual efficiencies show slight variations. The basic parameters checked for are short circuit current and open circuit voltage.



<u>Figure 13 Best Research-Cell Efficiencies</u>

Extensive efforts are being made to lower the cost of solar cell, to produce electrical energy at a price competitive with fossil fuels and nuclear power energy. This includes second and third generation photovoltaic cells that are cheaper than first generation cells. As per NREL's DOE SunShot initiative, large scale cost effective solar energy systems would be established by 2020, (NREL

1996). While Grid parity – the point at which photovoltaic electricity is equal to or cheaper than grid power would be reached in United States by 2015. However, increasing price of silicon, various economic issues and lessening of subsidies are some potential risks affecting the cost of solar cells in near future.

1.12.3 Solar cell efficiency (Wikipedia n.d.)**:**

Reflectance efficiency, thermodynamic efficiency, charge carrier separation efficiency and conductive efficiency are essential components of solar cell efficiency. The overall efficiency is the product of each of these individual efficiencies. With difficulties in measuring these parameters directly, they are substituted for thermodynamic efficiency, quantum efficiency, VOC ratio and fill factor.

The several losses accounted in measuring the efficiency are - Reflectance losses as a portion of the quantum efficiency, Recombination losses as a portion of the quantum efficiency, VOC ratio, fill factor and Resistive losses categorized under fill factor, with minor portions of the quantum efficiency and VOC ratio.

- **Thermodynamic efficiency** (Henry 1980) **-**

Maximum theoretical conversion efficiency for sunlight is about 93% due to the Carnot limit, based on the temperature of the photons emitted by the Sun's surface. Solar cells operate as quantum energy conversion devices, and are subjected to the "thermodynamic efficiency limit". It is found essential for photons with energy to match with band gap of absorber material to generate a hole-electron pair. Photons of greater energy if absorbed, convert the excess energy above band gap to kinetic energy. This excess kinetic energy converts to heat through phonon interactions as kinetic energy of the carriers slows to equilibrium velocity. Solar cells with multiple band gap absorber materials improve efficiency by dividing the solar spectrum into smaller bins where the thermodynamic efficiency limit is higher for each bin.

- **Quantum efficiency -**

Photons absorbed by solar cells produce electron-hole pair. One of the carriers may reach the p-n junction and contribute to the current produced by the solar cell. Quantum efficiency represents percentage of photons that are converted to electric current, when the cell is operated under short circuit conditions. Sometimes the light striking the cell gets reflected. External quantum efficiency is fraction of incident photons that are converted to electric current. Internal quantum efficiency (IQE) is the fraction of absorbed photons that are converted to electric current.

Quantum efficiency is spectral measurement as function of photon wavelength or energy. Some wavelengths are absorbed more effectively than others, spectral measurements of quantum efficiency yield essential data about the quality of the semiconductor bulk and surfaces.

- **Fill factor-**

Fill factor (F.F) is another term used for measuring performance of a solar cell. This is the ratio of the available power at the maximum power point (Pm) divided by the open circuit voltage (Voc) and the short circuit current (Isc):

$$F.F = Pm / (Voc * Isc)$$

The fill factor is directly proportional to associated cell's series and shunt resistances. Increasing the shunt resistance and decreasing the series resistance provides higher fill factor that result in greater efficiency, leading cell's output power closer to its maximum theoretical value.

The cell power density is given by P = JV. P (Power density) reaches maximum at cells maximum power point, J is the current density and V is the voltage for a solar cell. This occurs at a voltage Vm with corresponding current density Jm as shown in the figure. The optimum load has a sheet resistance given by Vm/Jm.With Voc as the open circuit voltage and Jsc as the short circuit density. Fill factor is defined as, (Nelson 2003)

F.F = Jm*Vm/Jsc*Voc and describes the squareness of J-V curve – (1)

Figure 14 below represents Bias voltage versus Current density, used to determine the fill factor

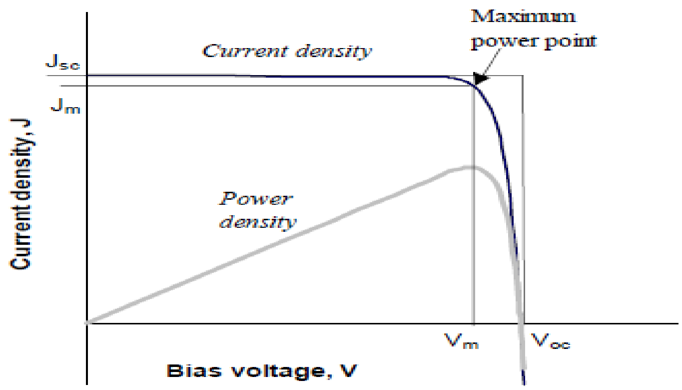


Fig. 1.8. The current voltage (black) and power–voltage (grey) characteristics of an ideal cell. Power density reaches a maximum at a bias V_m, close to V_{oc}. The maximum power density $J_m \times V_m$ is given by the area of the inner rectangle. The outer rectangle has area $J_{sc} \times V_{oc}$. If the fill factor were equal to 1, the current voltage curve would follow the outer rectangle.

Figure 14 Bias Voltage v/s Current density

The efficiency ‘n’ of the cell is the power density delivered at the operating point as a fraction of the incident light power density Ps.

n = Jm*Vm/Ps - (2)

Efficiency is related to Jsc and Voc using F.F

n = Jsc*Voc*F.F/Ps - (from (1))

The four quantities Jsc, Voc, F.F and n are crucial performance characteristics of a solar cell. The standard test conditions (STC) for solar cell is the air mass 1.5 spectrums, an incident power density of 1000 W/m2 and temperature of 25 degree celsius. Following Table 3 displays the performance characteristics for commonly used solar cells.

Table 3 Performance characteristics of solar cells

Table 1.1. Performance of some types of PV cell [Green *et al.*, 2001].

Cell Type	Area (cm^2)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF	Efficiency (%)
crystalline Si	4.0	0.706	42.2	82.8	24.7
crystalline GaAs	3.9	1.022	28.2	87.1	25.1
poly-Si	1.1	0.654	38.1	79.5	19.8
a-Si	1.0	0.887	19.4	74.1	12.7
$CuInGaSe_2$	1.0	0.669	35.7	77.0	18.4
CdTe	1.1	0.848	25.9	74.5	16.4

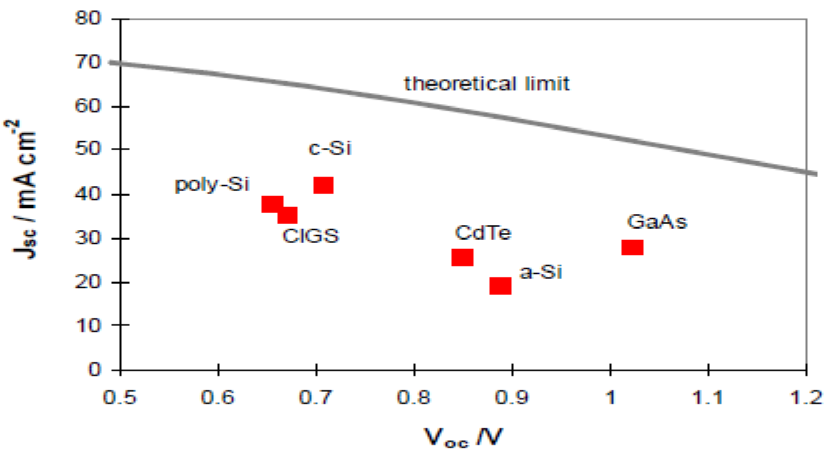


Figure 15 Voc v/s Jsc

From the above Figure 15 Voc v/s Jsc, it is understood that, solar cell materials with higher Jsc tend to have lower Voc. This value depends upon sequence of the material used and bandgap of particular semiconductor, in a solar cell. The next figure illustrates the co-relation between Jsc and Voc for cells with relationship for a cell of maximum efficiency. The grey line shows the expected theoretical limit.

B) Life Cycle Cost Analysis of Solar photovoltaic (PV) system for public schools:

Life cycle cost analysis (LCCA) is defined as assessment of total costs for owning the solar photovoltaic project (Fuller 2010). In a plenary paper to check photovoltaic reliability during its life span, cost analysis with key assumptions of costs and degradation factors are evaluated to determine the functionality of PV system, under different conditions (Sarah Kurtz 2009). An article from Life cycle analysis of Photovoltaics shows flow chart of life cycle stages of Photovoltaics from production through raw materials through its recycling stages. The article also determines from national database the risks associated with conventional method of electricity generation and through solar PV method, through its entire life span (Fthenakis August 2011).

The LCCA takes into consideration all costs associated with the equipment during the estimated life span of the solar PV project. This is considered as a valuable performance measure evaluated from a well-designed cash flow. Various other performance measures determined are Benefit to cost ratio (B/C) ratio, Internal rate of return (IRR), Payback period, Net savings and Net costs for the project. LCCA helps evaluate project alternatives for solar equipment, inverters, labor and balance of system. These alternatives might have high initial costs but low operation and maintainenance costs or vice versa. However, in a cost benefit analysis performed for PV implementation in Kuwait, the analysis shows that including the value of saved energy resources in producing traditional electricity and cost of reduced carbon dioxide emissions, the levelized cost of electricity (LCOE) reduces drastically (Mohammad Ramadhan 2011). An analyst may gauge only life cycle costs or all of the performance measures to best judge the economic viability of the project. Lowest life cycle costs are the most preferred method for effective analysis of any solar photovoltaic project.

In order to perform Life cycle cost analysis for public schools in state of Washington, data has been collected in the form of case study. Presently, based on solar energy expert from Washington State University, there are seventy (70) K-12 public schools with Solar PV. While Solar 4 R schools website from Bonneville Environmental Foundation (BEF), has forty-two (42) schools that includes both public and private schools (solar4rschools 2002). Centered on the information provided, four public schools are used as case studies, with three of these schools are from Lake Washington school district while one is from Camas school district. These case studies are analyzed with the perception of performing Life cycle cost analysis. In 2008 report from department of revenue, to evaluate tax incentives for renewable energy systems program shows more businesses performed in solar energy area as 101 out of 118 and employment increased in solar sector than any other sector in renewable energy, in state of Washington (Ray Philen and Don Taylor 2009). The following Figure 16 displays the statistics of solar businesses with respect to other renewable energy sectors, proving renewable energy through solar, as most effective alternative to offset electricity.

Number of Businesses in the Renewable Energy System Sector
Calendar Years 2004 – 2008

	2004	2005	2006	2007	2008
Solar Manufacturing	9	9	8	8	8
Solar Components, System Sales, and Installation	44	50	61	76	93
Bio-Systems Development	2	2	3	3	3
Wind Power Systems Design	7	9	9	13	14

Figure 16 Solar business statistics

Detailed description and analysis for the case studies is explained in chapter 4, of the thesis. Primary data collected for the analysis consists of size of photovoltaic system desired or installed by the public school as per their needs, cost of PV system per watt, gross cost of PV system, month and year of installation, area of public school and yearly avoided savings from PV system. These schools have installed the systems with funds from either yearly capital levy funds for the respective school or by district capital bonds. However, the present LCCA is developed as a base case assuming no funding is available for school. Preliminary steps involved are step by step development of cash flow, to recognize manufacturing costs for solar panel consisting of silicon cells which includes glass, polymer backing, aluminum framing, total inverter costs, direct labor costs involved as lump sum, and balance of system consisting of solar panel mounting system with or without tracker, AC and DC disconnects, cables, connectors, conduits and brackets.

Operation and Maintainenance costs are recognized very minimal almost equivalent to zero for the analysis. The life span of PV system is considered for thirty (30) years while, the inverters are replaced once during this life span.

As per National Renewable Energy Laboratory (NREL) numerous tools and software's are available to analyze life cycle assessments and design solar photovoltaic system (NREL 1977). Following Table 4a and 4b displays a brief overview of various tools and software's used by NREL.

Table 4a Tools & Software's used by NREL

DISC Model	Supplies hourly average global horizontal data
In my backyard tool	Estimates PV based electricity
PV-Design Pro	Simulates PV operation on hourly basis
PV Watts	Calculates electrical energy from grid PV
ReEDS	Observes critical issues in conventional & Renewable electricity sector
RETScreen	Evaluates energy production, Life cycle costs, GHG emissions

Table 4b Tools & Software's used by NREL

System Advisor Model (SAM)	As decision making tool for performance observation and financial model development
SWERA Model	Compiles data and facilitates investments
SolarDS	Evaluates market penetration of solar PV
SOLTrace	A ray tracing model
SUN_CHART	Solar design software
PVWatts Viewer	Provides map interface to access solar resource information

The other cross cutting analytical tools used by NREL are CREST, Energy-10, Energy Technology cost and performance data, GIS-Geographic information system, Green power network, HOMER Models, Hybrid2, HYDS, REFLEX, RET Finance, SERA-Scenario Evaluation Regionalization and Analysis and SEDS-Stochastic Energy Deployment system (NREL 1977).

The goal of Life cycle analysis - by using an economic model, is to understand, the initial costs of solar panels, there component costs, operation and maintenance costs, identification of cash flow through savings observed along the study period and determine the salvage value for its installation at public schools. Though the initial costs are considered high for solar PV implementation, manually performed scenario analysis and @risk software developed by Palisade are used to determine minimization of total costs over life time. The convenience of the user friendly software analyzes and simulates uncertainty .The uncertainty is involved with inflation rate for all items and electricity rate as risks that directly affect the performance measures of NPV, IRR, LCC and B/C ratio. Though the economic model is simple, it reflects the overall efficiency of PV system. Eventually, In a definition from Environmental protection agency (EPA) sensitivity analysis is defined as, "Sensitivity analysis, as it is applied to risk assessment, is any systematic, common sense technique used to understand how risk estimates and, in particular, risk-based decisions are dependent on variability and uncertainty in the factors contributing to risk" (EPA 2001). As stated above, sensitivity analysis is further performed on the LCCA developed, for analyzing the most likely value of inflation and discount rate. This helps to evaluate the dependency of performance measures on the variables of inflation and discount rate

C) <u>Social acceptance of solar photovoltaic project in public schools:</u>

Solar photovoltaic projects within public schools are undoubtedly gaining momentum. This is supported by the fact that school communities that comprises of students, teachers, principal, parents and neighbors are increasingly being aware of their environment, conscious of greenhouse gases, carbon emissions and global warming. Public schools have incorporated wonderful scientific programs, quizzes, experiments, training workshops for teachers, and state and national level competitions (Need 1982), (UWSP n.d.). Utility companies like Seattle city light (Seattle 2000), Puget sound energy (PSE 1877), and non-profit organizations like Bonneville Environmental foundation (BEF), (Solar4rschools 2002) have shown active participation with numerous voluntary demonstration solar PV projects either installed individually or by entering into partnership.

The above understanding is best recognized through extensive survey, with email conversations and telephonic interviews. This collective data acquisition is analyzed and explained in chapter 5, to understand the practical observation made with installation of PV systems, by the public schools, in state of Washington. In a way schools have observed vast educational benefits for school community, within years of installation of PV system.

Some schools initiated with low cost, no cost conservation methods like improving operation and maintainenance, lighting retrofit and HVAC retrofit. After observing convincing changes and significant costs savings, the schools implemented PV project as a renewable energy project. It is also understood that students, parents, and school staff of these schools are very fascinated to have solar panels system in their school. In yet another case, Grass Valley Elementary School, exhibits interesting art work by Sarah Hall. She displays an art window, made of photovoltaic panels that powers light in the stairway. School district feels encouraged, by incorporating photovoltaic projects as one of the primary electricity saving methods and believes in educating the community, the students, and their parents in energy usage decisions. This proves that students of all ages have started looking and thinking beyond conventional ways of electricity production. Students now develop interests in green environment and explore new ventures. Moreover, this movement has cultivated positive opinion amongst its school community which, goes beyond saying a word automatically.

As per, whole building design guide subcommittee, educational facilities including elementary and secondary schools have grown from customary way of education, spatial relationships to computer based and video incorporated instruction. It has become essential to build structures, from health, comfort and improved performance of facilities, by using strategies of sustainable construction and renewable energy sources in the school design with good maintenance of existing and new facilities (WBDG 2010). Hence solar energy is viewed as sustainable promising resource, with no environmental assessment (Rowlands 2008), that avoids carbon and greenhouse gas emissions by replacing fossil fuels with photovoltaic systems (GCEP Energy acessment analysis 2006).

Summary:

Overall the chapter provides scope for discussion regarding the roots of solar energy and its belief within the mankind as very important source of energy that

used the solar photovoltaic technology to develop the first solar cell. Since its first development, every effort is being made via research to improve the efficiency and decrease the costs of solar cell by using different materials and enhanced technology. The chapter discusses the functionality, types and manufacturing process involved with solar photovoltaic cell. As proved by the market analysis, with current depletion of fossil fuels, increase of carbon and greenhouse gases, drawbacks of hydroelectric power generation, and decrease in the costs of solar cell with considerable increase in its efficiency, there is essentially a viable reason to implement solar photovoltaic technology. Given the present situation and with reduced funding available to schools every year, poses various questions, as to how effective is the application of PV technology within the public school system? Does the Northwest weather create hindrances in its application? Are primarily the students and secondly the school community aware about the introduction of solar project within the school? How does it benefit them? Are these PV projects going to be the building blocks to conserve fossil fuel usage and reinforce clean energy for healthier future generation?

Yes, truly these are very important questions for any analyst to determine the viability of a particular project. Various studies are being performed to determine the usefulness of solar photovoltaic system, in spite of its high cost of electricity generation. The latitude of research is limited within the public schools in state of Washington. The forthcoming chapters discuss both the financial and social benefits of implementing solar PV technology, either by installing as a demonstration project or as a major installation for saving electricity, for a given school. Life cycle analysis performed deals with the financial aspect while a survey developed, later in the chapter deals with social aspect of its

execution within the school community. The following chapter identifies the research methodology used to answer above questions step after step in the subsequent chapters.

Chapter 2.

Research Methodology

2.1 Basic study approach:

The photovoltaic system application is gaining momentum as common place across public schools in state of Washington, in spite of Northwest's average sunshine rating. As stated in chapter one, the purpose of this study is to understand how photovoltaic system are beneficial both financially and socially to public schools. The scope is further narrowed to public schools within the state of Washington. The approaches used to achieve this purpose include a) Selection of public schools and demonstration of case studies b) Undergo interviews, email conversations c) Develop economic model d) Analyze monthly electricity bills one year before and after Photovoltaic installation e) Develop online survey. Following Figure 17 displays the basic study approach used in the thesis

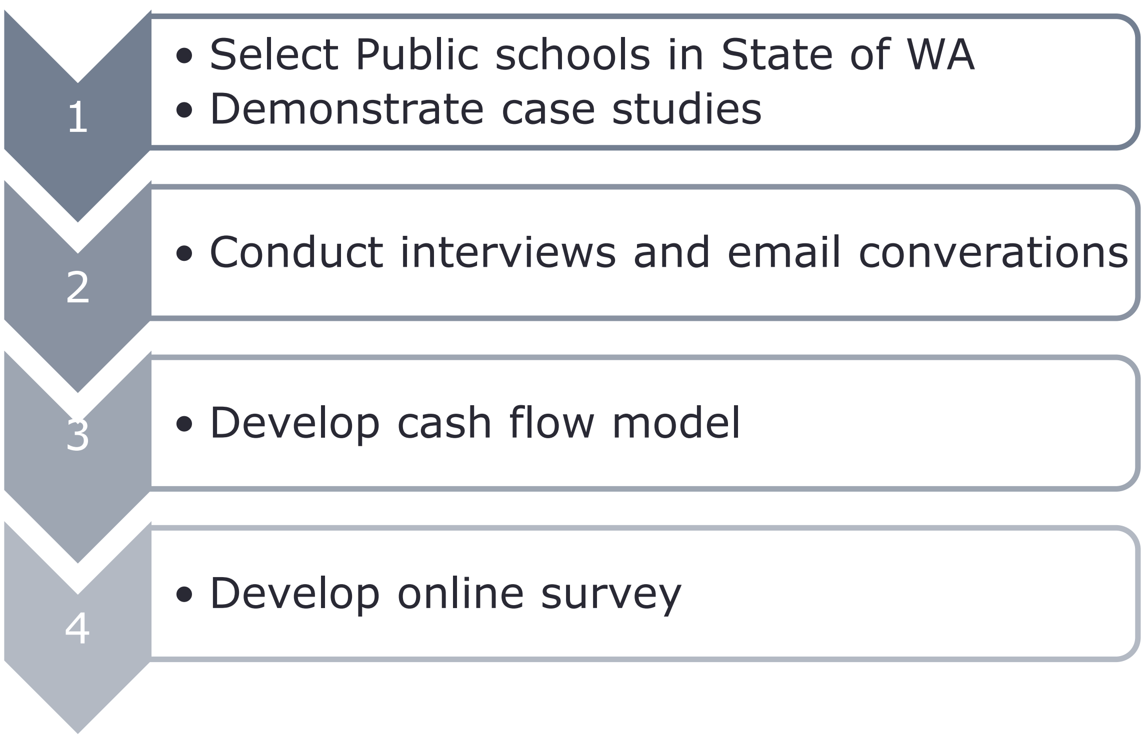


Figure 17 Basic study approach used

2.2 Objectives of Research:

- Determine the effectiveness of PV technology within public school system

- Understand the implications of Pacific Northwest weather
- Recognize various costs, savings and evaluate life cycle costs associated with the PV system
- Observe the social changes and benefits in school community
- Decide whether solar PV is really a viable renewable option for public schools, in spite of reduced funding every year.
- Discuss the possible alternatives to make solar PV a part of school's funding and objective for implementation

2.3 Limitations of the research study:

Along with the best efforts to accommodate all details, there are certain limitations to the researcher's study:

- The research study is limited to geographical location of Washington State of Pacific Northwest region.
- Time constraints with respective authorities in providing information on account of hectic work routine and researcher's time frame.
- Numerous holidays with public school districts.
- Minor changes were incorporated in survey questions, as some of the detailed questions on internet questionnaires received low response rate with more time involvement from participant.
- Constraints in receiving break down of costs from manufacturers of solar PV system

2.4 Reach the goal –

Following approach is used to collect and analyze data for recognition.

A. The study used following data:

- Data was collected from four public schools in state of Washington to serve as case studies. This assisted to comprehend the practical implications of weather and its effect in generation capacity of system. These schools have installed the system with intent to observe reduction in monthly electricity bills.

- Analyze monthly electricity bill provided, for one year before and one year after the photovoltaic system is installed.
- Conduct email conversations and telephonic interviews to realize social acceptance of solar PV within its school community.
- Finally, a survey is initiated to recognize substantial cross section of data, to study as many number of public schools as possible.

B. <u>The study performed and evaluated following information:</u>

a) <u>Determination of Life cycle costs, study scenarios and perform risk and sensitivity analysis –</u>

- As a first step in analysis, an interactive cash flow is developed displaying the available costs associated with purchase of solar photovoltaic system.
- Life cycle costs are determined taking into account all credits, incentives, depreciation received and salvage value for installed solar equipment.
- A United States government nominal 30yr treasury constant maturity, average rate for past ten (10) years (2002-2011) is used as discount rate, while United States average inflation rate (2002-2011) for electricity and all items is considered in the analysis.
- Performance measures are recognized for Life cycle costs (LCC), Benefit to cost ratio (B/C ratio), Net present value (NPV), Payback period and Internal rate of return (IRR) to determine profitability and economic feasibility of PV project.
- In order to understand the best results for performance measures, six scenarios are developed and evaluated, as a part of scenario analysis.
- A software tool called @risk is used to perform simulations and measure risks associated with PV project (Palisade, 1987), (Ritme n.d.). This tool performs risk analysis, given the necessary, independent and risky input variables to conclude with desired performance measures as output values.
- Further a sensitivity analysis is performed for the most likely discount and inflation rate. The software performs simulations and determines the associated risks to figure out the most likely value.

b) <u>Survey Methodology:</u>

A survey is designed to answer researcher's objectives using internet questionnaires and interview survey methodology (Victoria L. Bernhardt, 2009). The primary purpose of survey is to collect information which after evaluating, analyzing results gives statistical characterization of target population sampled. Secondly, survey helped to have practical opinion, recognize benefits observed, enthusiasm and drawbacks of solar PV installation amongst school community. Questions included in the survey are aimed for data collection, their experience and opinion. The survey also involves gaining insights into the strengths, weaknesses of the PV system and its applicability within the public sector.

After understanding different types of survey (Bryman, 2001), (Paul D. Leedy, 2005) creating online web based internet questionnaire was the appropriate choice to complete the survey in timely manner. The target populations are participants of survey. These participants include project managers, resource conservation managers, and school science staff from various public school districts.

The survey begins with name of school, and determination of solar PV project as either demonstration or PV project installed to offset electricity. Followed by are two main sections in the survey –

1) Section a: requests information from respondents for details of demonstration projects. Based on the purpose of installation for school, questions are directed to observe the educational benefits, change in student's attitude and ideas. Questions specific to costs and savings are not detailed in this section,
2) Section b: requests information from respondents for details of solar PV projects as tools for conservation of fossil fuel energy, to save electricity from utility. Questions are asked to determine year of installation, size of system, details of costs and savings along with the specific benefits observed

The survey data is discussed and analyzed in more depth, in Chapter 4 of the report. The survey questionnaire is presented in Appendix B.

c) <u>Interviews and Email conversations:</u>

Prior to development of survey questionnaire, the information was received through constant email conversations and telephonic interviews. These interviews helped to understand the background for installation, calculation processes involved, and procedures with school system. Recognizing the time constraints with availability of project managers, school staff, numerous holidays with the public school system and available time frame for completing the report, it was very essential to use the available period most effectively and still receive abundant information required for all of the analysis. The conversations and interviews also reduced participant's time to fill out the survey, as all the information cannot be condensed within the survey questionnaire.

Based on my study (Paul D. Leedy, 2005) (Bryman, 2001), considering the importance of interviews, telephonic interviews were undertaken with two (2) project managers and one (1) project mechanical engineer and three (3) officials from utility company, to receive in depth details for section b, as discussed above in the survey methodology. These project managers were extremely enthusiastic and co-operative, to share all publicly available relevant information associated with the PV installation at their school. They were passionate to provide information for questions associated with specific details of installation, practical understanding and observation of associated PV project. The interview questions assembled following information like–

State the brand name of PV system, specific cost details, calculation procedure for usage savings and demand savings used for estimation. The questions also requested information for grants received by school, electricity rates applied by a certain utility company, energy modeling details and incentives information.

These email conversations equally helped to receive pdf files and power point slides for relevant questions like, electricity bills one year prior and one year after the solar project connection, net metering details and associated necessary documents, for connection of photovoltaic system at a respective public school. The interview data is discussed in more detail in Chapter 4, while the interview questions are presented in Appendix C of this report.

Chapter 3.

Case Study Analysis

This chapter accounts for quantitative information of the Thesis. Section 3.1 offers specifics for each school, to have an understanding and details of installed solar photovoltaic system. Section 3.2 explains analysis for Life cycle costs associated with solar photovoltaic system package and its related savings.

3.1 Case study description:

Case study methodology is used for providing actual data and practical representation of Life cycle cost analysis. This research used four case studies for evaluation of "Life cycle cost analysis". These case studies represent four public schools, with major solar photovoltaic installations from state of Washington. Details for each installation are provided, to have an understanding of mounted solar photovoltaic system.

A. Eastlake high school – Lake Washington school district

Eastlake installed its 12 KW photovoltaic system (PV) in July 2009.

Following are the brand of PV system (Schott 1958) , (Solardesigntool n.d.) and utility company (PSE n.d.) facts, for Eastlake high school, as shown in Table 5:

Table 5 Eastlake high school PV data

Size of PV	12 KW
Brand of PV	300W Schott ASE-300-DGF/50/300 modules
Utility company-Puget sound energy (PSE)	Eastlake JH (PSE-Rate 43) as electricity rate
Rate of Installation	$10 per Watt
Inverters	2
Category of Building	Commercial - School building
Area of the building	210,663sqft

B. Evergreen junior high school – Lake Washington school district

Evergreen installed its 12 KW photovoltaic system (PV) in September 2008.

Following are the brand of PV system (Panasonic 1929) (Wholesalesolar 1992) and utility company (PSE n.d.) facts, for Evergreen junior high school as shown in Table 6:

Table 6 Evergreen junior high school PV data

Size of PV	12 KW
Brand of PV	200W Sanyo HIP200BA3 modules
Utility company-Puget sound energy (PSE)	Eastlake JH (PSE-Rate 25) rate of electricity
Rate of Installation	$10 per Watt
Inverters	2
Category of Building	Commercial – School building
Area of building	103,400sqft

C. Redmond high school – Lake Washington school district

Redmond high school installed it 1.1KW system in September 2006 and expanded its PV system to 6.6KW in May 2009.

Following are the brand of PV system, (Sharpusa 1963), (Wholesalesolar 1992)and utility company (PSE n.d.) facts, for Redmond high school as shown in Table 7:

Table 7 Redmond high school PV data

Size of PV	6.6KW (1.1KW, in 2006 expanded to 6.6KW, in 2009)
Brand of PV	175W Sharp NT-175U1modules
Utility company-Puget sound energy (PSE)	Redmond HS (PSE-Rate 31) rate of electricity
Rate of Installation	$10 per Watt
Inverters	2
Category of Building	Commercial - School building
Area of building	211,092sqft

D. Hayes Freedom high school – Camas school district

Hayes Freedom installed its 40.63KW photovoltaic system (PV) in September 2010.

Following are the brand of PV system (Sanyo 1929), (Wholesalesolar 1992)and utility company (Clark public utility 1938) facts, for Hayes Freedom high school as shown in Table 8:

Table 8 Hayes Freedom high school PV data

Size of PV	40.63 KW
Brand of PV	Sanyo HIT Power 215N PV modules
Utility company-Clark Public utility	Rate of electricity-Second tier schedule 134 (General schedule 34)
Rate of Installation	$7.3 per Watt
Inverters	4
Category of Building	Commercial - School building
Area of building	20,500sqft

3.2 Life cycle costs analysis using case studies:

The researcher uses the solar photovoltaic installation data from four public schools as actual data for development of cash flow. Life cycle cost analysis (LCCA) is performed on all associated costs and benefits observed by the system. The goal of this study is to determine whether solar photovoltaic systems (PV) application can be beneficial from financial perspective, to public schools in state of Washington.

LCCA evaluates the economic worth of solar photovoltaic system over its entire life. The analysis consists of evaluation of all component costs and financial benefits over the life of the PV system – to balance and measure the initial monetary investment with its long term expenditures, credits, incentives, depreciation and savings for owning and operating the equipment.

3.2.1 Assumptions and considerations made in the analysis:

1. The LCCA considers (K-12) public schools as one of the thirteen categories in commercial buildings, of CBECS 1995 release of data (EIA 1978).
2. School buildings usually have an average life of forty-two (42) years (Ncef 1998) (Lewis, Snow and Farris 2000, June). Solar photovoltaic systems last for more than twenty-five (25) years. Hence the thirty (30) years' time frame is considered as study period for the LCCA (NREL 1977).
3. Public schools within a school district have the academic year, lasting for ten months, beginning from September till June, of any academic year. The students enjoy two (2) months of summer vacation, to make a total of twelve (12) months. For example – a school year would be from September 2009 till June 2010, with July and August 2010 as months of summer vacation. For convenient standardization and articulate explanation, an academic year is assumed from January till December, in the analysis.
4. LCCA scope of study is limited to state of Washington. The purpose for this limitation is to recognize the effectiveness of solar photovoltaic system's production of solar energy - to offset electricity, amidst the rainy and cloudy weather.

5. The public schools used as case studies are assumed to have received no funds for investment in the solar photovoltaic project. In practicality they have received funding in the form of capital levy fund, district capital bonds and state funds.
6. Washington State provides attractive incentives for manufacturers of solar equipment, inverters, and solar energy production within state of Washington (Dsireusa 1995).
7. The incentives provided by state of Washington are till June of 2020.
8. The consumer price index (CPI) and discount rate values are taken as average values for past ten (10) years. The time frame for average values of CPI, in percent is from 2002 till 2011 (BLS 1884).
9. The consumer price index (CPI) accounts for inflation in electricity and all items for these ten (10) years.
10. The CPI listed is available explicitly for Seattle-Bremerton-Tacoma region and United States. The analysis considers the CPI for United States.
11. Survey analysis shows, photovoltaic systems, inverters installed by the public schools as manufactured outside of state of Washington. As a result, analysis considers the CPI for United States. This helps to understand the effect of transportation, weather and location of manufactures of photovoltaic systems.
12. The case study analysis uses the average CPI for all urban consumers, which are not seasonally adjusted for all items for time frame of (2002-2011) as 2.42%, as inflation of all items.
13. The case study analysis uses the average CPI for all urban consumers, which are not seasonally adjusted for electricity for time frame of (2002-2011) as 3.68%, as inflation of electricity (BLS 1884).
14. Average discount rate is derived from Federal Reserve bureau, H-15 rate schedule (Federal reserve 1913). A United States government, nominal 30yr treasury constant maturity rate is determined (Wong, et al. 2003). Average discount rate for past ten (10) years from (2002-2011) is calculated as 4.528%, for the present analysis.

15. The rate for electricity is considered is based on November 2011 statistics for commercial buildings for state of Washington as 7.69 cents per kilowatt hour (kWh) (EIA 1978).
16. Salvage value of the PV system is assumed to be twenty percent (20%) of the initial costs of PV system in the thirtieth (30) year, of LCCA (Appleyard 2009, April), (Sandia 1949).
17. Avoided costs of electricity are summation of electricity savings and demand savings (Leung 2010), (Craig 2011), (Walker 2012).
18. Solar production for usage savings is derived from www.solar4schools.org website on yearly basis for analysis.
19. Demand savings are calculated as difference of avoided costs and electricity savings for the year into consideration (Leung 2010), (Craig 2011).
20. By using excel functions and appropriate inflation rates, the future value (FV) of money invested today is determined, for inverter, maintainenance and operation costs, electricity savings, incentives and demand savings. The FV is determined for each year, of the study period (Aziz 2010), (Sandia 1949), (Tim Mearig 1999), (Fisher 2007).
21. Using above future value (FV) and discount rate, present value (PV) that is the present worth of money is recognized.
22. Six (6) performance measures - Net present value (NPV), Internal rate of return (IRR), Benefit cost ratio (B/C), Life cycle costs (LCC), Simple payback and Discounted payback are deliberated.

3.2.2 Case study evaluation:

Four (4) case studies are evaluated and examined to check the effectiveness for application of solar photovoltaic system to public schools in state of Washington. These case studies are gauged from the perspective of reduction in electricity costs for public school. Financial cash flow in excel spread sheet, depicts the essential information for school related photovoltaic project and its Life cycle costs. These schools are numbered as

A, B, C and D in the table, shown below. For convenience of effective communication, the schools are referred as A, B, C and D, in the report.

Performance measures like NPV, IRR, B/C, LCC, simple payback and discounted payback are examined for cost effectiveness of implementing the PV system, in spite of high initial costs. Finally, a cumulative, discounted cumulative and cash flow chart is developed for graphical representation of breakeven year and its respective cash flow trends for every year.

Following table displays the combined information, of performance measures, for above mentioned schools. This table is the base case for analysis. Each scenario is compared with its related base case for a particular school. The base case uses 3.68% as electricity inflation rate, 2.42% as all items inflation rate and 4.528% as discount rate. The detailed cash flow for LCCA during its thirty (30) year study period, is represented in the form of excel spread sheet for each of above schools, as Appendix A of the report.

Table 9 Base case performance measures

No	Public school	Sqft area in sqft	NPV	IRR	B/C ratio	LCC costs	Simple payback	Discounted payback
A	**Eastlake H.S**	210,663	$24,078.93	3%	0.83	$129,200.82	25yrs	Never reaches
B	**Evergreen H.S**	103,400	$163,457.31	12%	2.18	$125,777.90	9yrs	11Yrs
C	**Redmond J.H.S**	211,092	$73,003.42	11%	1.98	$67,959.39	9yrs	12Yrs
D	**Hayes Freedom H.S**	20,500	$141,528.47	1%	0.57	$300,162.36	29yrs	Never reaches

From Table 9, as shown above, it is understood that out of four schools, schools B and C have shown positive net present value and internal rate of return more than 2 times its assumed discount rate while, schools A and D have shown negative net present value and internal rate of return.

3.2.3 Scenario analysis:

Based on spread sheets data, as shown in the Table 9 above, it can be found that, viability of school projects are directly related to avoided costs of electricity. Avoided electricity costs include annual electricity savings and demand savings. Demand savings play a major role in these savings, as they have higher electricity rate than regular electricity. With the variable nature of these savings (Raphael, Carbonlighthouse n.d.), (Focusonenergy 2001) and demand measured in increments of every 15 minutes (PSE 1877), (Focusonenergy 2001) , it is essential for the production meter of solar PV to record solar production every 15 minutes. This is essential to offset peak demand of electricity from utility. Considering this as one of the essential facts for analysis, following Table 10 shows the variables identified and the scenarios developed, as factors for Scenario analysis.

Table 10 Factors considered for Scenario analysis

No	Variables identified	Scenarios developed (in Tables)
1	Demand savings	• Zero demand savings (as column 4) • Reducing existing demand savings by 50% (as column 5)
2	Discount rate	• Reducing existing discount rate to 3.34% ,as present treasury rate (Qureshi 2012) – (as column 1)
3	Inflation for electricity, all items	• Increasing the existing inflation by 25% (as column 2)
4	Cost of solar PV per Watt	• Reducing the existing rate to 6$/Watt (as column 6)

Finally, an additional scenario (as column 3) is developed. This scenario combines present

2012 discount rate and increased inflation rate. This identifies scenario 3 & 6, as the best scenarios and scenario 4 as the worst scenario, in the analysis. The cost of PV system, inverter and its components are represented by cost of solar PV per watt, as scenario 6, as critical variables affecting performance measures. Tables as shown below, identify variable nature of variables. All six scenarios are developed for each public school. The data presented is compared to the base case, as also shown in table. The scenarios are presented as columns (1-6) while, performance measures are presented as rows.

A) Eastlake high school:

Table 11 Scenario analysis for Eastlake high school

	Base case	1	2	3	4	5	6
NPV ($)	24,078.93	4667.37	10,505.77	12,936.98	94,955.22	59,517.21	Constant values are feeded
IRR (%)	3	3	4	4	2	1	
B/C	0.83	0.97	0.93	1.09	0.33	0.58	
LCC ($)	129,200.82	128,275.59	128,843.99	127,373.70	129,200.82	129,200.82	
Simple Payback (Yrs)	25	25	24	23	Never reaches	29	
Discounted Payback (Yrs)	Never reaches	29	29	26	Never reaches	Never reaches	

B) Evergreen junior high school:

Table 12 Scenario analysis for Evergreen junior high school

	Base case	1	2	3	4	5	6
NPV ($)	163,457.31	220,351.69	204,929.01	273,192.13	88,775.67	60,759.68	187,047.34
IRR (%)	12	12	13	13	2	1	15
B/C	2.18	2.55	2.46	2.89	0.36	0.56	2.70
LCC ($)	125,777.90	124,165.77	125,082.83	122,857.76	125,777.90	125,777.90	102,187.87
Simple Payback (Yrs)	9	9	9	8	Never reaches	30	7
Discounted Payback (Yrs)	11	10	11	10	Never reaches	Never reaches	9

C) Redmond high school:

Table 13 Scenario analysis for Redmond high school

	Base case	1	2	3	4	5	6
NPV ($)	73,003.42	98,856.83	81,357.02	123,110.55	47,846.22	6399.47	96,130.82
IRR (%)	11	11	12	12	3	5	18
B/C	1.98	2.28	2.09	2.56	0.36	1.09	2.97
LCC ($)	67,959.39	68,142.03	67,995.45	68,093.59	67,959.39	67,959.39	44,831.99
Simple Payback (Yrs)	9	9	9	9	Never reaches	19	5
Discounted Payback (Yrs)	12	11	11	10	Never reaches	27	6

D) Hayes Freedom high school:

Table 14 Scenario analysis for Hayes Freedom high school

	Base case	1	2	3	4	5	6
NPV ($)	141,528.47	122,567.37	127,482.05	104,672.48	172,963.89	157,246.18	89,880.81
IRR (%)	1	1	1	1	0	0	2
B/C	0.57	0.63	0.62	0.69	0.47	0.52	0.67
LCC ($)	300,162.36	306,436.18	303,244.17	310,187.50	300,162.36	300,162.36	248,514.70
Simple Payback (Yrs)	29	29	29	29	Never reaches	29	29
Discounted Payback (Yrs)	Never reaches	Never reaches	Never reaches	Never reaches	Never reaches	Never reaches	Never reaches

As indicated in Tables 11, 12, 13 and 14, the different scenarios observe the changes in variables and measure feasibility of solar PV project, for a respective school. All values indicated in red identify negative numbers. The higher the solar insolation received on the modules, higher is the annual savings in electricity. However, in present situation we can conclude that for –

Scenario 1-

When the discount rate is reduced from 4.528% to 3.34%, as emphasized, all of the schools show considerable increase in the benefit cost ratio, with 75% of the solar projects having a discounted payback during the useable life of 30 years. There is a positive increase in net present value and B/C ratio, while the IRR remains same as the base case. Schools B &C have shown highest benefit cost ratio with discounted payback almost 10 years. The simple payback stays unaffected. The life cycle costs are reduced in 50% cases while increased in remaining 50% of cases. Hence, In my opinion though discount rates (Mohammad Ramadhan 2011) are very sensitive and directly relate to the performance measures identified the lower the discount rate more probable are the chances for public schools to install solar PV (Harder February 2011).

Scenario 2 –

The following Figures 18 and 19 identify the growth in inflation rate of all items and electricity for period 2002 till 2011.

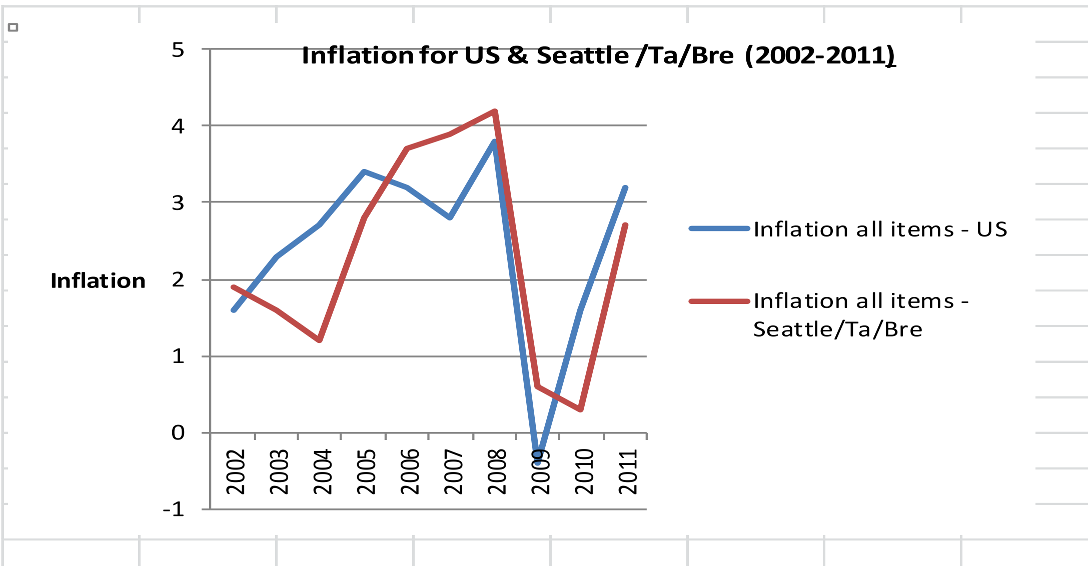


Figure 18 Inflation of all items for US & Seattle/Ta/Bre 2002-2011

The growth in inflation rate is measured around United States and for Seattle- Bremerton-Tacoma region. However, the present analysis applies inflation values for United States.

As observed in the figure 18, the inflation for United States and Seattle-Bremerton-Tacoma regions show an upward trend in recent, past two years. The same regions however show a varied trend for inflation of electricity. Hence in current economic situation (BLS 1884), a 25% increase is inflation rates for all items and electricity is applied to base case. This results in inflation of electricity from 3.68% to 4.6% while inflation for all items from 2.42% to 3.025%.

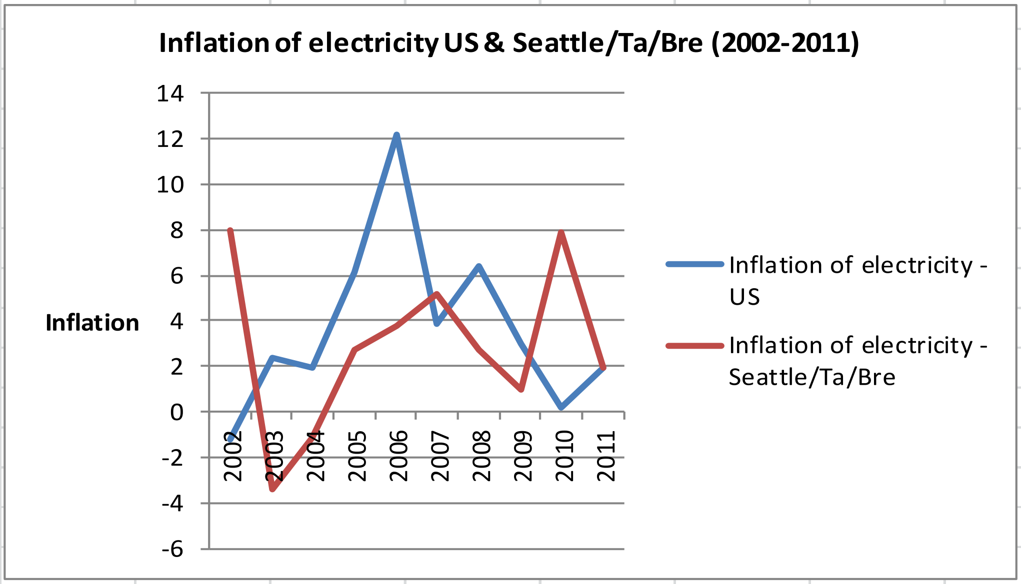


Figure 19 Inflation of electricity for US & Seattle/Ta/Bre 2002-2011

As a result, in comparison to base case of each school, all the schools showed increase in net present value and B/C ratio. The IRR increased by 1% in 75% of the cases. The payback mostly remained the same, while 50% of the school showed minimal increase in LCC while 50% of them showed decrease in these costs.

Overall, definitely increase in inflation of all items and electricity is directly associated to positive financial increments in majority of performance measures.

Scenario 3 -

This scenario is the most ideal situation. It combines scenario 1 and 2. All four schools showed positive improved NPV, B/C ratio and IRR. 50% of the cases indicated reduced paybacks by almost 2 years and 25% of the cases by 1 year with respect to base case.

In brief, scenario 3 is one of the idyllic situations for effective performance of solar PV in schools. The more the inflation of electricity, all items and reduced is the discount rate, more is the net worth and reduced payback for the respective schools.

Scenario 4&5 -

Demand savings have been one of the crucial concerns and major savings in the analysis. The more is the demand offset by solar PV produced electricity, the more is its net worth. In real world, there are risks associated, with solar PV's performance as it depends upon weather, solar irradiance particularly in state of Washington.

This case analyzes what if the region's solar radiation received - offsets zero demand and what if it offsets 50% of its demand observed in base case. This also means that solar PV's performance is now based more on annual electricity savings only, for zero demand situation. As per the valuation observed, scenario 4 shows a harsh decrease in accordance with base case for NPV, IRR and B/C ratio. The LCC costs remain the same for each school while none of the schools have either of their paybacks reached within their study period. Scenario 5 relatively is a better situation than scenario 4. The NPV, IRR and B/C ratios have reduced proportionately in reference to base case. The simple payback has increased from anywhere between 4 years till 21 years in 75% of the cases with 25% of the cases showing almost 15 years escalation in discounted payback, while the LCC remains same.

Based on the assessment made, it is clear that –

• Solar PV needs to offset peak demand of electricity from utility, required by school.
• The more demand savings observed more are the avoided costs of electricity.
• Application of effective tools to reduce sudden increase in peak demand is essential.

Scenario 6 -

The last scenario displays the estimation for reduced costs of solar cells. Considering the probable present market situation (Solarbuzz 2001), the scenario assumes what if the solar costs were 6$ per watt, instead of costs presented in each base case. School A could not be analyzed as hard core costs were provided for components of solar PV, with less flexibility in running the cash flow. However, the other three schools displayed excellent increase in NPV, B/C ratio and IRR. The LCC have reduced considerably. The simple payback reduced in a range 2 to 4 years while, discounted payback from 2 to 6 years in 65% of remaining schools. This concludes that reduction in costs of solar cells reduces the payback notably. This indirectly leads to reduction in rate of solar electricity.

Finally, the scenarios represent the real life situations for what if analysis. Of the six scenarios presented, scenario 3 and scenario 6 are more suitable, crucial for public schools to reap financial benefits as early in as 5 years, as presented by school C. Equally demand savings are very vital for survival of photovoltaic system in schools. The more peak demand balances are made by th system, more operative is the functioning of PV system financially.

3.2.4 Case study assessment with risk analysis:

In order to apply futuristic approach and extend further from scenarios offered, existent case studies are applied with software tool called @risk. Even with reduction of costs in solar PV cells, schools are hesitant to pursue photovoltaic application. Again schools in spite of being under commercial buildings category, do not avail federal credit, tax benefits as they do not pay taxes. In these situations, schools have less government incentives and solely have to depend on avoided costs of electricity as seen in the cash flow generated in Appendix A. This leads to the need for investigation of uncertainties using the software tool, to peak in future and examine the associated risks.

In the present research, each of the public school used as case study has a cash flow established. This cash flow with actual statistics is the base case for study. The assumptions are identified as seen in section 3.2.1. Based on the data for base case, the performance measures are recognized. The summary of these performance measures (Aziz 2010), for each of the schools is established in Table 9. The uncertainties associated with cash flow are identified. Moving further, the basic cash flow developed is now applied with software parameters for the different uncertainties observed. The uncertainties as risks (Nigel C Rayner 2002), identified are substituted with numerical values in probability distribution centered on judgment and past information from Consumer price index and Federal reserve bureau H-15, 30 year treasury maturity rate as input variables.

Next, a probability distribution is defined for unreliable and risk related values, as this is the way the software presents quantified risks for an input variable, to have a desired output in excel sheet (Palisade 1987), (Ritme n.d.).

Out of the many types of probability distributions available, a probability distribution or graphical presentation is specified with values, which best describes the uncertainty associated with the cash flow situation. Through identification of input variable along with its probability distributions and determination of desired output, for performance measures, the software called @risk performs Monte Carlo simulation for thousands of iterations to best simulate finest desired outcomes.

Finally, based on the simulation results, presented in the form of probability distribution, the results are understood and conclusions made. Following Tables 16, 17, 18 and 19 represent cash flow element that are uncertain risks identified as input elements and performance measures as output elements. The inflation rate for electricity and all items are displayed in Table 15 as commonly identified uncertain elements for each school, while the cost per watt of solar PV is displayed as individual uncertain risk. The performance measures are identified as output elements for each school. Detailed spreadsheets with analysis of uncertain risk elements performed, using the software tool, are presented in Appendix A of the thesis for each of the above mentioned public schools.

Table 15 Common uncertain risk elements

Common uncertain risk elements identified for each school:

No	Uncertain risks	Input elements
1	Inflation rate of electricity (%)	=RiskTriang(3,3.68,4.9,RiskStatic(3.68))/100
2	Inflation rate of all items (%)	=RiskTriang(2,2.42,3.5,RiskStatic(2.42))/100

Individual uncertain risks and Performance measures identified for each school:

East lake high school –

Table 16 Eastlake HS uncertain risks and Performance measures

No	Uncertain risks	Input elements
1	Cost of solar PV per Watt($)	=RiskBetaGeneral(2,2,5,10,RiskStatic(10))
No	**Performance measures**	**Output elements**
1	Net present value (NPV) ($)	=RiskOutput()+M25+M31+M32+M33+M45 +M53+M55+M57+M65
2	Internal rate of return (%)	=RiskOutput()+IRR(N69:AR69)
3	Benefit/Cost ratio	=RiskOutput()+(-(M53+M55+M57+M65)/(M25+M31 +M32+M33+M45))
4	Life cycle costs ($)	=RiskOutput()+M25+M31+M32 +M33+M45+M65

Evergreen high school-

Table 17 Evergreen JHS uncertain risks and Performance measures

No	Uncertain risks	Input elements
1	Cost of solar PV per Watt($)	=RiskBetaGeneral(2,2,5,10,RiskStatic(10))
No	**Performance measures**	**Output elements**
1	Net present value (NPV) ($)	=RiskOutput()+N69
2	Internal rate of return (%)	=RiskOutput()+IRR(O71:AS71)
3	Benefit/Cost ratio	=RiskOutput()+(-(N57+N59+N61+N67)/(N26+N32+N33 +N34+N36+N49))
4	Life cycle costs ($)	=RiskOutput()+N26+N32+N33+N34+N36 +N49+N67

Redmond high school –

Table 18 Redmond HS uncertain risks and Performance measures

No	Uncertain risks	Input elements
1	Cost of solar PV per Watt($)	=RiskBetaGeneral(2,2,5,10,RiskStatic(10))
No	**Performance measures**	**Output elements**
1	Net present value (NPV) ($)	=RiskOutput()+N71
2	Internal rate of return (%)	=RiskOutput()+IRR(O73:AS73)
3	Benefit/Cost ratio	=RiskOutput()+(-(N58+N60+N63+N69)/(N26+N32+N33 +N35+N37+N50))
4	Life cycle costs ($)	=RiskOutput()+N26+N32+N33+N35+N37 +N50+N69

Hayes Freedom high school –

Table 19 Hayes Freedom HS uncertain risks and Performance measures

No	Uncertain risks	Input elements
1	Cost of solar PV per Watt($)	=RiskBetaGeneral(2,2,5,7.5,RiskStatic(7.3))
No	**Performance measures**	**Output elements**
1	Net present value (NPV) ($)	=RiskOutput()+N79
2	Internal rate of return (%)	=RiskOutput("IRR")+IRR(O81:AS81)
3	Benefit/Cost ratio	=RiskOutput()+(-(N63+N66+N69+N77)/(N26+N33+N34 +N36+N39+N53))
4	Life cycle costs ($)	=RiskOutput()+N26+N33+N34+N36+N39 +N53+N77

As seen in the Tables 16, 17, 18 and 19, the software uses input and output probability distributions to display the simulation results. Based on the simulation results in spread sheets following inferences can be made.

The probability distribution chosen are Betageneral and Triangular distribution for the analysis. Built on judgment of past inflation data, triangular distribution is chosen with its bounded ends, while beta general distribution identifies variable nature of cost of solar PV per watt. The reason being convenience in explanation of arguments of distributions. Moreover the parameters are built on the understanding from numerical statistics collected from survey and interviews (Palisade 1987), (Ritme n.d.).

Summary of analyzing risk elements using @risk software as results for each school:

a)East lake high school has 90% chance that, Net present value would be around negative $17000, 3% Internal rate of return, 0.88 Benefit cost ratio and Life cycle costs of around negative $130,500.

b) Evergreen junior high school has 90% chance that Net present value is around positive $211,500, 15% Internal rate of return, 2.82 Benefit cost ratio, and Life cycle costs of around negative $103,000.

c) Redmond high school has 90% chance that Net present value would be around $105,000, 18% internal rate of return, 3.07 Benefit cost ratio, and Life cycle costs of around negative $45,000.

d) Hayes Freedom high school has 90% chance that; Net present value is around negative $ 66,000, 2% internal rate of return, 0.74 Benefit cost ratio and Life cycle costs of around negative $ 229,500.

On a comparative basis, it can be understood that the probability distribution for of Eastlake high school (School A), Hayes Freedom high school (School D) has greater risk, with more spread on negative side and less expected results than Evergreen junior high school (School B) and Redmond high school (School C).

Amongst , these four schools School D possesses most risk for Internal rate of return, as probability of occurrence is more spread out with respect to mean and has largest range followed by School A. The benefits to costs ratio as seen from the probability distribution, shows that schools B and C have ratios greater than 1 while School A has 90% chance of 0.88 with School D at 0.74. Centered on the size of photovoltaic system and wide spread nature of graphical presentation, School D has major Life cycle costs associated with the system.

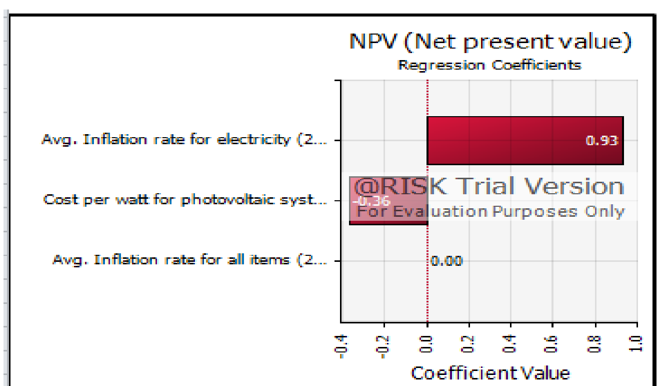
3.2.5 Sensitivity Analysis (Aziz 2010)**,** (Jan Emblemsvag 2001)**:**

In present thesis, Sensitivity analysis is performed between input and output variables identified. The three input variables are like inflation rate for electricity, all items and cost of solar panel per watt, identified as uncertainties or risk factors, While there are four output variables like NPV, IRR, B/C ratio and LCC, in the developed cash flow model. These variables are displayed in Table 15 and 16 above. The effects of varying nature of independent variables are observed one at a time for its consequence on the dependent performance measures. For example the effect of inflation rate of electricity on NPV, on IRR, on B/C ratio and Life cycle costs of PV system.

The co-efficient values for each dependent variable like NPV, B/C ratio are expressed as regression co-efficient. The value for each co-efficient either as positive increase or negative decrease gives the percent effect of variable as uncertain risk on dependent variable, establishing a co-relation amongst them. The R-square of the regression identifies fraction or percentage of variation caused by independent variable/uncertainty on dependent performance measure. The analysis also provides ranks for the independent variable's order of effect on dependent variable, as understood during simulation performed by software tool. Following Table 20 and Figures 20, 21, 22 and 23 explains sensitivity analysis observed for NPV, IRR, B/C ratio and LCC of Evergreen public school.

Table 20 Summary of Sensitivity Analysis performed

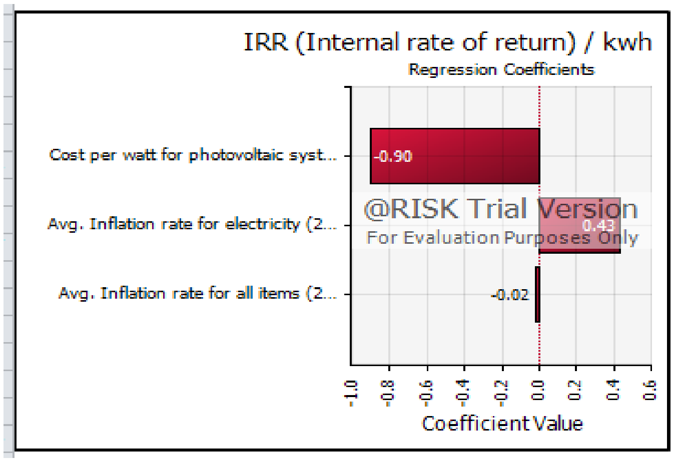
Rank For D78	Cell	Name	Description	Sheet1!D78 NPV (Net present value) Regression Coeff. RSqr=0.998	Sheet1!D79 IRR (Internal rate of return) / kwh Regression Coeff. RSqr=0.996	D80 Benefit to Cost ratio-Aggregate (B/C r Regression Coeff. RSqr=0.994	Sheet1!D81 Life Cycle Costs / kwh Regression Coeff. RSqr=0.999
#1	H12	Avg. Inflation rate for electricity (%)	RiskTriang(3,3.68,4.9,RiskStatic(3.68	0.934	0.432	0.661	n/a
#2	H9	Cost per watt for photovoltaic systen	RiskBetaGeneral(2,2,5,10,RiskStatic(	-0.361	-0.902	-0.75	-1
#3	H13	Avg. Inflation rate for all items (%)	RiskTriang(2,2.42,3.5,RiskStatic(2.42	0.002	-0.016	-0.056	0.005



Regression and Rank Information for NPV (Net pr

Rank	Name	Regr	Corr
1	Avg. Inflation rat	0.934	0.928
2	Cost per watt for	-0.361	-0.348
3	Avg. Inflation rat	0.002	0.011

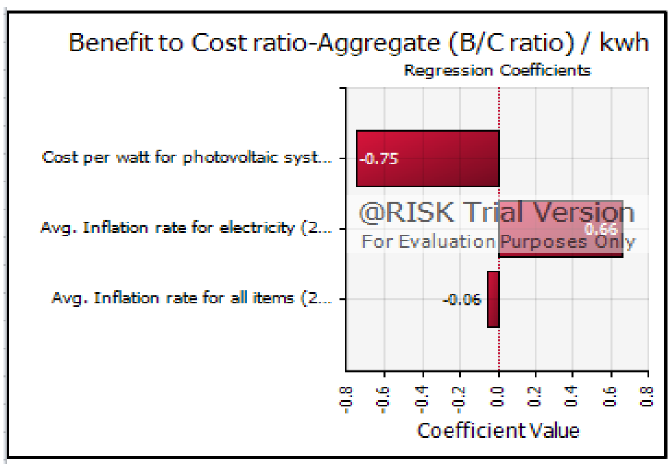
Figure 20 Sensitivity observed for NPV



Regression and Rank Information for IRR (Internal

Rank	Name	Regr	Corr
1	Cost per watt for	-0.902	-0.903
2	Avg. Inflation rat	0.432	0.408
3	Avg. Inflation rat	-0.016	-0.011

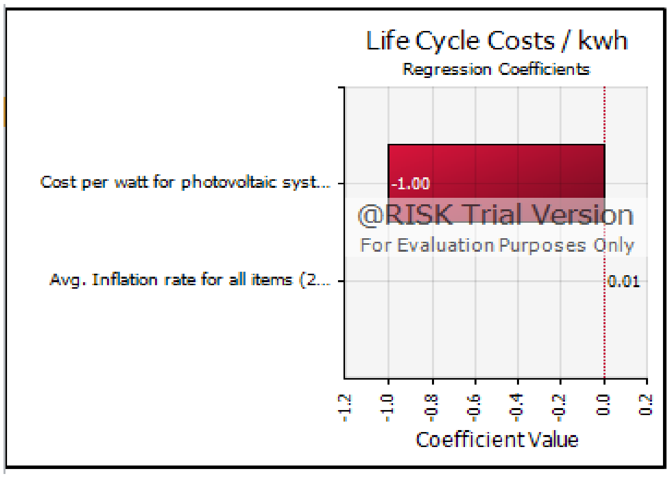
Figure 21 Sensitivity observed for IRR



Regression and Rank Information for Benefit to C

Rank	Name	Regr	Corr
1	Cost per watt for	-0.750	-0.745
2	Avg. Inflation rat	0.661	0.639
3	Avg. Inflation rat	-0.056	-0.046

Figure 22 Sensitivity observed for B/C ratio



Regression and Rank Information for Life Cycle Co			
Rank	Name	Regr	Corr
1	Cost per watt for	-1.000	-1.000
2	Avg. Inflation rat	0.005	0.005

Figure 23 Sensitivity observed for LCC

3.2.6 Analysis of actual electricity usage and costs:

In order to understand the actual impact of solar PV system on the monthly electricity bills, an effort is made to collect electricity bills form above schools one year before solar PV is installed and one year after solar PV is installed. Although Schools A, B, and C have introduced the PV system not to their full capacity to counterbalance all the electricity required for school needs, they have strived to see the effects of system and to offset some portion of electricity from their local utility. Schools A and B have provided data of at least two years' worth electricity bills before PV implementation and School C with five years' worth data, since year 2005 with its initial solar PV installation in year 2006. School D being a newly constructed facility, had implemented the system in their initial scope of design, construction along with other green features intended for school. As a result School D had no previous data for electricity usage and its associated costs. Hence the electricity data is now compared with Washington Code baseline building before PV implementation. The work was executed by in-house staff of school. The energy modeling is performed by eQUEST v3.64 modeling software. This matches the proposed building's geometry, uses minimal code-compliant insulation levels, lighting power densities and HVAC efficiencies based on the 2009 Washington State Energy Code (Rosenberg 2011). Total electricity consumption is summation of solar electricity and utility electricity, while net use of electricity is difference between total electricity use and solar electricity production. Detailed spread sheet and graphical presentation for each school is shown as Appendix B part of the thesis. Following Figure 24 shows the graphical demonstration of electricity use and demand use every month, while Figure 25 shows electricity and demand costs per month for Eastlake high school. This school installed its solar PV in July 2009 for academic year 2009-2010. Figure 26 displays visual presentation of total consumption of electricity as against baseline usage recommended by 2009 Washington state energy code for Hayes Freedom high school. This school introduced its PV system in September 2010, for academic year 2010-2011. Table 21 identifies the annual consumption of electricity for Eastlake high school, two years before and one year after solar PV is installed.

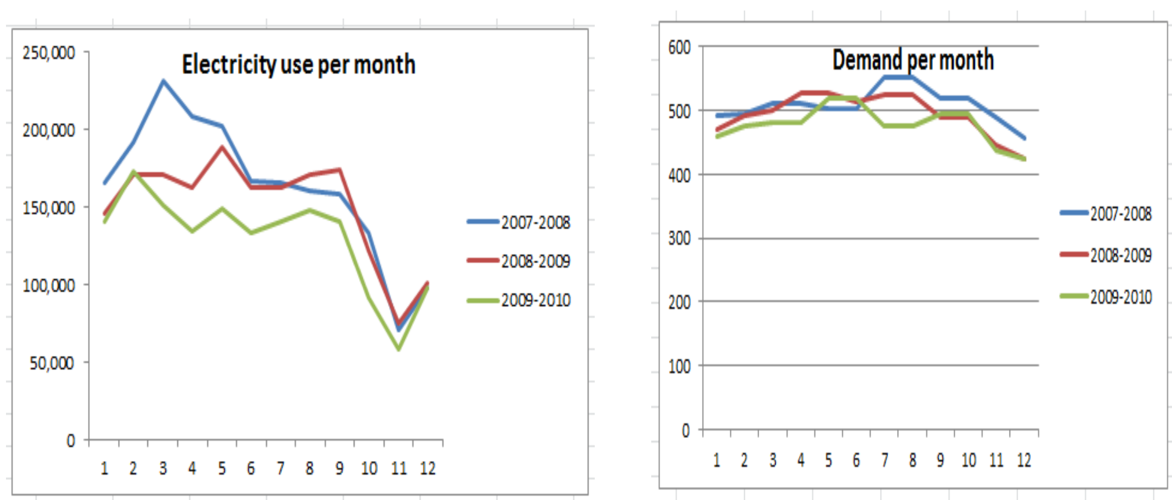
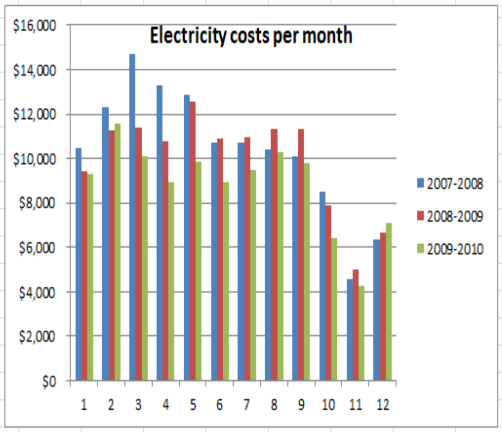


Figure 24 Electricity and Demand use per month –Easlake HS



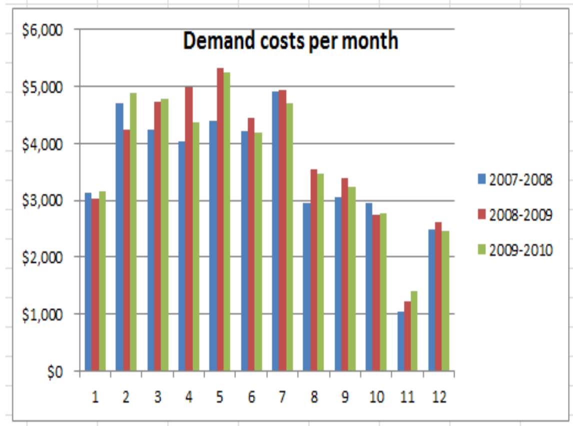


Figure 25 Electricity and Demand costs per month –Eastlake HS

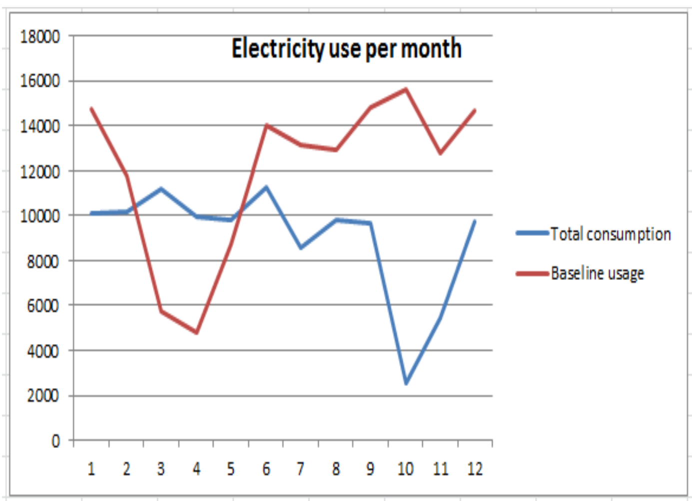


Figure 26 Total consumption v/s Baseline usage – Hayes Freedom HS

Table 21 Annual Consumption of Electricity before & after PV installation – Eastlake HS

Annual consumption of electricity	2007-2008	2008-2009	2009-2010 (Solar PV installed)
Electricity usage (kWh)	1,953,544	1,807,843	1,560,913
Demand usage (KW)	6105	5931	5735
Electricity costs ($)	$124,974	$119,409	$106,123
Demand costs ($)	$42,169	$45,219	$44,671

Based on electricity usage, its demand use and costs statistics, it can be understood as per Table 21 above that, overall there has been a considerable decrease in total electricity consumption. The actual evidence shows that when data is compared with previous year with no solar PV, either one of the months in Fall, Winter or during Spring, there has been a minimal increase of usage of electricity and its demand. Also, the factors affecting increase in electricity usage and demand are beyond the scope of present thesis. School D with its major 40KW installation, in the months of July and August has produced surplus solar electricity causing zero electricity needs from utility. This eventually directed to net metering savings. However, insufficient data regarding these savings as dollar value, caused difficulty in using them in the cash flow developed. Centered on its electricity and demand usage, directly proportionate are the electricity and demand costs, as charged with their applicable rates by the local utility.

4.2.6 Summary:

Overall it can be concluded that, Solar PV truly is an essential sustainable tool to counterpoise utility's electricity. The inflation for electricity has highest influence on positive performance measures, followed by solar panel costs. Measures to reduce peak loads either manually, by automatic provisions along with more solar irradiance would certainly enhance more positive outcome. The conclusions are summarized from solar and electricity data available from four public schools as under:

Based on the manually performed scenario analysis, It can be analyzed that centered on considered parameters, decrease in discount rate from existing 4.528% to 3.34% and increase in inflation rates of all items and electricity by 25% provides positive, improved performance measures and reduced payback period, when compared to base case. Further reduction in per watt costs of solar cell influences performance measures with reduced payback as early as 5years, in comparison to base case.

The analysis of uncertain risk elements using software tool called @ risk software shows that, more are the demand costs offset, by solar PV more are the demand savings followed by usage savings. Schools B and C with higher demand savings have shown excellent positive performance measures, as compared to schools A and D. Further the simulation performed shows probability of occurrence with positive desirable results for schools B and C, while spread relative to mean for schools A and D is greater, posing less desired results. Additionally, Sensitivity analysis ranks inflation of electricity to have highest impact on performance measures, followed by cost of solar PV.

After understanding and exploring actual usage of electricity, its demand and their equivalent costs, it can be analyzed that, overall all of the four schools have shown substantial decrease in the electricity consumption as compared to their previous years without photovoltaic system. Sometimes during one of the months in fall, spring or winter, the schools have shown some increase in its electricity demand and usage, yet the annual consumption has always demonstrated considerable decrease of electricity, when compared to electricity consumption before PV installation.

CHAPTER 4.

SURVEY ANALYSIS

4.1 Survey results:

This chapter collects information in the form of online survey, telephonic interviews and explores its results for making conclusions. The chapter is divided in following parts as survey preliminary information, purpose of survey data, identification of survey data, survey with flowchart, execution of survey, study of survey results and discussion of Interviews and email conversations.

4.1.1 Survey preliminary information:

An online survey is created, using University of Washington WebQ catalyst web tools. Surveys were sent as an email link to respondents from various public schools, for web based survey. Respondents for the voluntary questionnaire are public schools from within the state of Washington. The survey is posted as an anonymous survey. The Survey responses were posted on the catalyst website for analysis and interpretation of results. Data from these responses in the survey were analyzed and organized by the catalyst WebQ tool and Microsoft office Excel product.

4.1.2 Purpose of survey data:

The survey title states, "Cost and Benefit analysis of Solar Photovoltaic system in Public schools (Washington State)" differs from Thesis title, "Analysis of Life cycle costs and social acceptance of solar photovoltaic project with public schools in state of Washington". The essential purpose of data collection, as explained in preceding chapters is to weigh, the costs associated with solar photovoltaic system, determine monetary savings and social with educational benefits, offered by the PV system. Monetary savings can be measured in statistical terms while social with educational benefits cannot be measured in statistical terms. The LCCA performed displays the statistical measurement while Survey displays the non-statistical measurement, of the PV system.

4.1.3 Identification of survey data:

Twenty-six (26) public schools were contacted and identified as schools with solar photovoltaic system installation. These twenty-six (26) public schools choose to fill the survey. Of the identified schools, nineteen (19) schools essentially filled the survey. From the nineteen (19) schools, two (2) schools filled the survey twice and one school is a private school. Finally, analysis of survey data is made from seventeen (17) schools, from state of Washington. Out of these seventeen (17) surveys, seven (7) surveys represented PV projects for conservation of energy while, ten (10) surveys represented demonstration projects.

The questionnaire is divided in two (2) parts and consists of total forty-eight (48) questions. The survey begins with the determination of PV project as either for conservation of energy, with thirty-one (31) questions or as a demonstration project with nineteen (19) questions. The original questionnaire had forty (40) questions. Some of the public schools were unable to specify the details required in the questionnaire. Understanding there difficulty primarily dual sided as, either lack of time or inconvenience in finding the relevant data, the questionnaire format was changed slightly. An effort is made for survey participants, at the minimum to at least specify a range of values.

4.1.4 Survey with flowchart:

The survey questionnaire can be viewed in its entirety as Appendix C of this report. The questionnaire uses the concept of “skip logic” to direct the respondent, based on earlier answer. The second question determines the major skip logic decision. A simple flowchart is shown in Figure 27. Based on this choice, the respondents are then directed to question (a) category or question (b) category, as shown in the flowchart. The questions in category (a) relates to PV system installation as demonstration project while questions in category (b) relates to PV system installation as conservation of energy.

Although all twenty-six (26) schools were expected to participate in the survey, the seventeen (17) respondents who contributed provided abundant information, to draw desired conclusions of PV system, for the LCCA and as demonstration project.

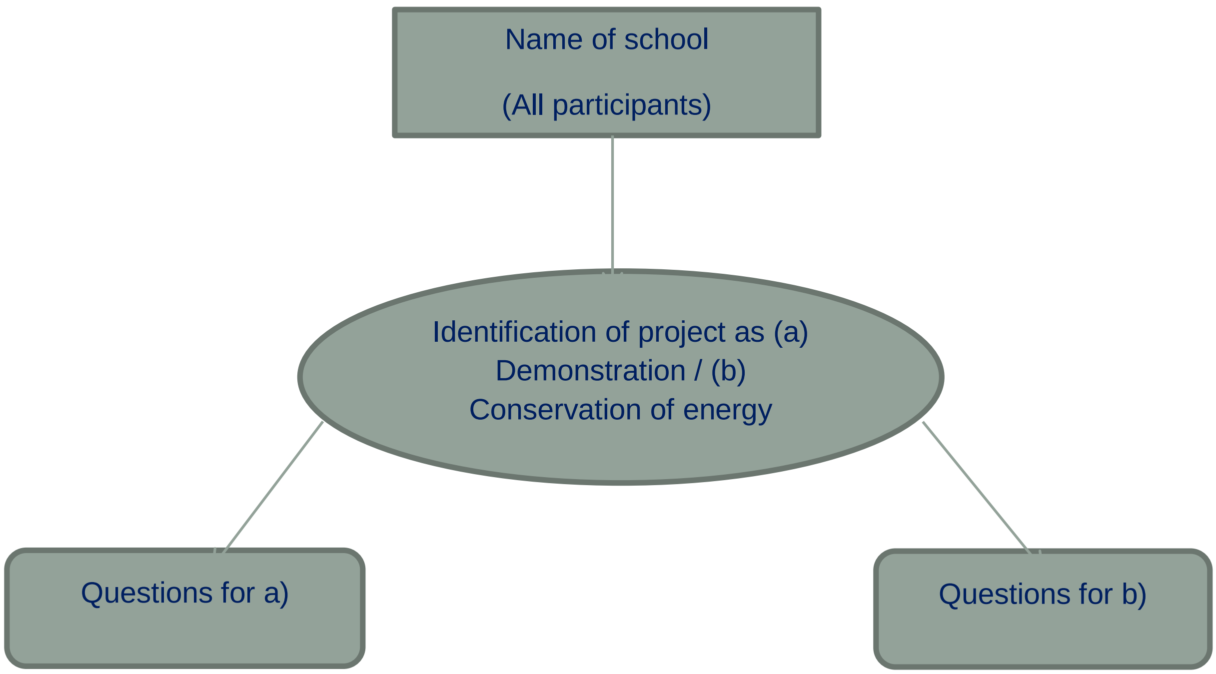


Figure 27 Survey flowchart with Skip logic concept

4.1.5 Execution of survey:

The online survey was available to respondents from afternoon of June 24th 2011. The survey questions were slightly modified and available from November 20th 2011 and closed to respondents from afternoon of February 28th 2012. The execution date for online survey is June 2011. This time frame essentially is the closing period of current academic school year, start of summer vacation period and beginning of new academic school year, posed some delay in receiving initial responses. However, this also allowed sufficient time frame for respondents to fill out the survey, during their convenient time. Results were stored by University of Washington catalyst tool with arbitrarily assigned identification number for each respondent.

4.1.6 Study of survey results

As stated in section 4.1.3, the responses from seventeen (17) schools and skip logic decision explained in section 4.1.4, the responses were classified in two major sections. The major sections were identification of PV project as demonstration project or for conservation of energy, necessarily conservation of electricity through photovoltaic installation. This section discusses and studies responses for forty-eight (48) questions involved in the survey. The survey questionnaire with its responses from each of its individual schools can be viewed as Appendix E of this report.

Being anonymous, the only required respondent identification is name of the school, where PV project has been installed. The next question requested information for identification of project as either demonstration project or for conservation of energy. Of the seventeen (17) received responses, ten (10) schools have installed PV system as demonstration projects while remaining seven (7) schools have installed PV system for conservation of energy, as shown in the pie-chart, in Figure 28. This clearly identifies, that public schools representing 59% are more interested to install PV systems for demonstration purposes. This also recognizes shortage of funds, extensive payback periods, high cost of solar panels, and lack of space as primary concerns in their year of installation, for a specific public school.

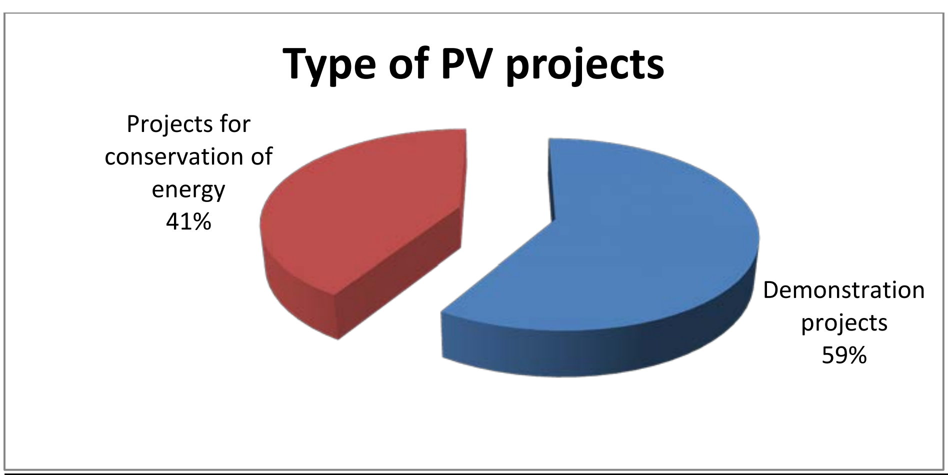


Figure 28 Type of PV projects

Installation year and Size of system:

Overall, during the last decade, there has been considerable increase in the installation of solar PV system, amongst public schools, in state of Washington. With more utility companies taking the initiative to sponsor solar projects as demonstration projects and with availability of state, school funds, public schools are very eager to incorporate the solar projects, on their campus. This can be visualized from the following pie-chart in Figure 29.

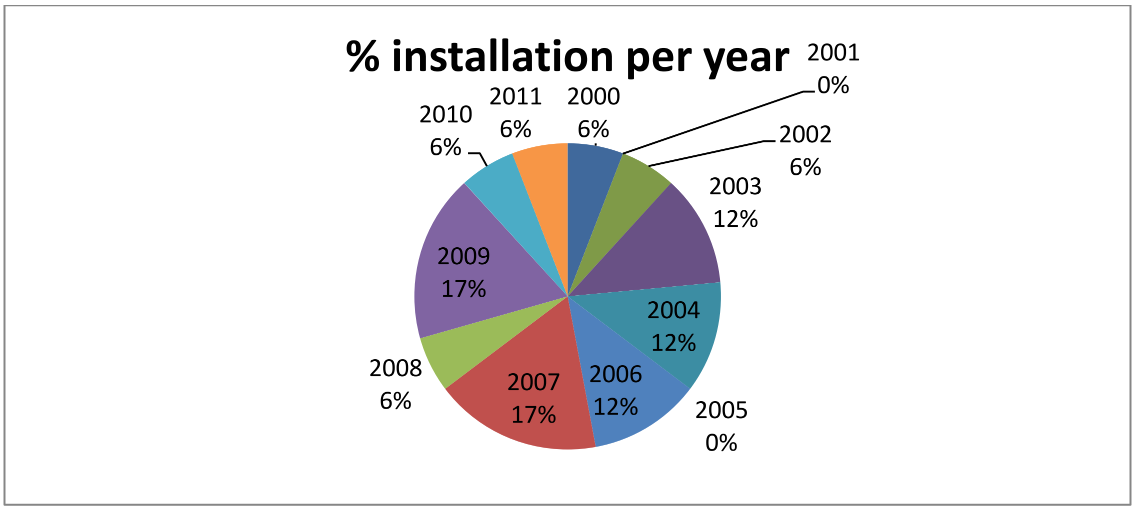


Figure 29 (%) installations per year

Size of solar projects analyzed from survey responses include, demonstration solar projects from one (1) KW system to 3.5 KW systems. These projects were available as grant from utility companies like Puget Sound energy, Bonneville Environmental Foundation, Seattle public utilities and Seattle City Light, as a part of their renewable energy program. The solar projects installed explicitly for conservation of energy, range from 4.0KW system to 40KW PV system.

Type of solar panels installed:

Of the various solar panels available in the solar market, the most prominently used panels on solar projects at public schools in state of Washington comprise, the Poly crystalline silicon cells, Mono crystalline silicon cells whereas the 'other' category includes semi-crystalline, thin single crystalline silicon cells and amorphous silicon cells. Five (5) out of the eight (8) responses in the 'other', category were unsure of the type of solar panels installed. The reasons understood were, non-existence of readily available data, change of management system with new officials being appointed, change of school building location leading to unorganized transfer of data and lack of computer data system being timely updated. The following bar chart shows the appropriate illustration for seventeen (17) solar projects in Figure 30.

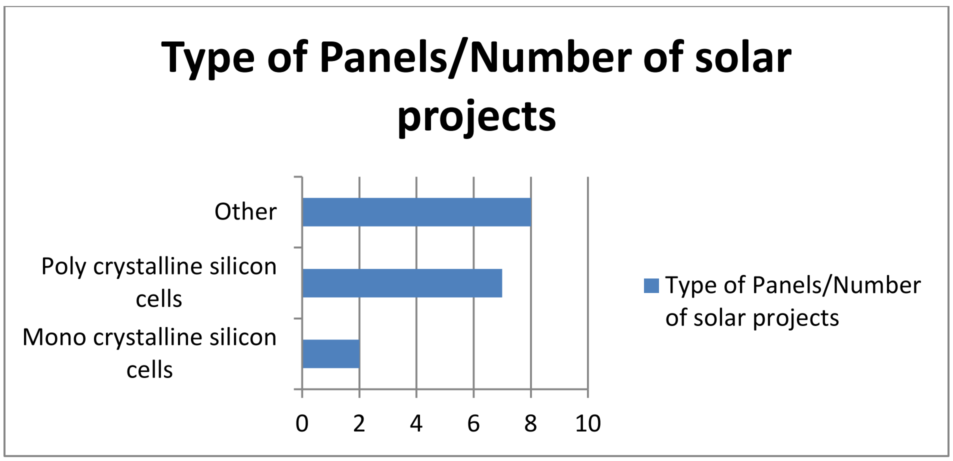


Figure 30 Type of Panels/Number of solar projects

Costs related with solar photovoltaic projects:

The responses for costs related questions represent different types of data. As mentioned earlier in section 4.1.3, few public schools were unable to put forward required numbers, the questions were then, modified in this section, for at the minimum to have an estimate of range of costs. Cost related questions were part of conservation of energy b) section and were related to seven (7) school projects.

The responses state the photovoltaic equipment costs as, entire cost of PV system, which comprises of solar panel, inverter, installation and balance of system costs. These costs were the agreed aggregate price for school solar project. Balance of system includes the grid, wiring, electric meter and other miscellaneous costs. Four (4) schools reported photovoltaic equipment costs. Of these four schools, one (1) of the schools was able to provide information for breakdown of required costs in the survey, whereas the other three (3) schools provided information during telephonic interviews, in the survey and email conversations.

One (1) school provided solar panel costs per watt, as the agreed aggregate price for solar project. Based on this cost, the photovoltaic system costs were evaluated. The same school was unable to provide the breakdown of costs, in which case a thumb rule is used to evaluate different costs for LCCA (solar-estimate 2000). The remaining two (2) schools provide installation costs as agreed aggregate cost of solar project. They were also unable to provide break down of costs.

Operation and Maintainenance of solar panels are recognized as zero dollar amounts by six (6) schools. One (1) school reported an amount very close to insignificant in comparison to original costs of equipment. The following pie-chart in Figure 31 shows the breakdown of different costs of solar PV system project. Balance of system (BOS) refers to other components, other than the solar modules and inverter(s). These are racking, disconnects, conduits, wiring, electric meter, monitoring systems and grid. These components vary from project to project.

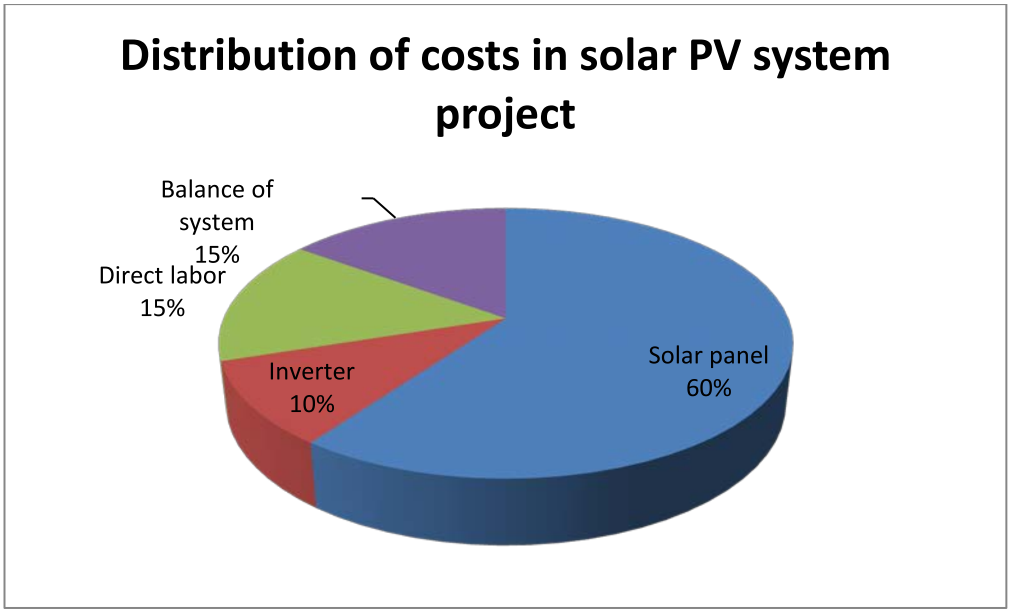


Figure 31 Distribution of costs in solar PV system project

As shown in the pie chart in Figure 31, the solar panel costs representing 60% form the major cost components, followed by direct labor, balance of system and inverter costs.

Number of inverters:

The next relevant question enquires about number of inverters. The number of inverters necessary for major installations, used for conservation of energy, as per seven (7) survey responses - varies with capacity of grid tied inverter. They are used to convert direct current (DC) received from sun to alternating current (AC), to perform essential functionalities of school. The capacity depends on direct current input data, alternating current output data, efficiency, size, weight and power consumption during operation and standby mode, of inverter. The inverters used by all seven (7) schools, can feed excess electricity into existing electrical grid. The following Table 22 shows the number of inverters used with respect to size of PV system.

Table 22 Number of inverters used per school

Name of school	Size of PV system	No of inverters used
Washington state school for blind	13.5 KW	5
Washington state school for blind	24 KW	7
Eastlake high school	12 KW	2
Evergreen junior high school	12 KW	2
Redmond high school	6 KW	2
Hayes Freedom high school	40 KW	4
Bertschi high school	4 kW	1

Annual savings/ Avoided costs of electricity:

The subsequent question requested information on annual savings recorded by each of the seven (7) schools, during the last four (4) years. These schools installed the PV system for conservation of energy. Based on the year of installation of system at a respective school, four (4) schools provided relevant amount of savings in dollars. Of the four (4) schools one (1) school gave a range for annual savings. The average value is considered for the range given, in the chart and for performed LCCA. One (1) school represented the amount indistinctly, while two (2) schools did not respond to this question. These annual savings/avoided costs comprised of usage savings and demand savings of electricity from utility. Usage savings justify the amount of kilowatt hours produced by the PV system times the rate of electricity from utility. Demand savings comprise difference between avoided costs and usage savings of electricity from utility. Demands savings are billed for highest demand determined each month times its appropriate demand rate of electricity (PSE n.d.). It has been established as per electricity data provided by four (4) schools in Appendix F, that demand per month gets reduced on account of PV system installation. Also demand rate differs and is higher from electricity rate of utility. Determination of demand savings is equally difficult to conclude as it accounts for summation of monthly demand and critical demand. Demand is the highest demand established during the month, during a specified time interval, while Critical demand is calculated as a highest average fifteen (15) min demand recorded between 5.00PM till 8.00PM for a given day (PSE n.d.), (fs.fed.us 2000) , (Copeenvironmental 1948). For convenient explanation, demand savings are recorded as difference between avoided costs of electricity and usage savings from electricity, in LCCA cash flow development. The following Table 23 displays the avoided costs/annual savings of electricity provided by each of four (4) schools.

Table 23 Annual savings per School

No	Name of school	Annual savings in Electricity			
		2008	2009	2010	2011
1	Eastlake high school	0	721.59	3472.25	
2	Evergreen Junior high school	0	1247	10713	
3	Redmond high school		1314	5032	
4	Hayes Freedom high school	0	0	0	4500

From the above chart, it can be inferred that every year there has been a definite increase in demand savings. This takes into account the summer vacation period of schools with maximum demand savings, by efficient use of electricity from school community with introduction, understanding of PV system and possible energy efficient features undertaken by school.

Incentives, Carbon credits, Renewable energy certificates, Grants and Funds received:

Questions for incentives, carbon credits, renewable energy certificates, were specifically diverted via skip logic concept of catalyst tools, for schools that saved electricity.

Incentives –

The state of Washington provides incentives centered on the place of manufacturing of PV system and inverters. With respect to (Dsireusa 1995), the instate manufacturers receive production incentives from 18 cents/kWh till 54 cents/kWh. Out of state equipment, also receives incentive, for producing electricity using solar power, at 15 cents/kWh. The limitation for state incentives is $5000 per year, starting August 2006 with expiration in June 2020, (Dsireusa 1995)

Six (6) schools received state incentives for producing electricity using solar power at 15 cents/kWh. One (1) school responded unclearly and is therefore omitted, in the analysis. These schools have out of state equipment and inverters. The email conversations and interviews along with survey, conclude, that when these systems were installed, there were no solar manufactures in the state, and had limited availability of inverters. Figuring out various costs was also very crucial for these schools, with limitation in availability of funds. The incentives are paid by associated utility company. The utility company in return receives tax credit equal to those payments.

All seventeen (17) schools had their photovoltaic system connected to grid. As a result these schools benefit from net metering savings. The net metering savings are credited forward each month and balance of credit is reimbursed at culmination of yearly billing period, usually in April, based on utility company (Clark public utility 1938).

Federal tax benefit accounts for 30% of total cost of photovoltaic system (Dsireusa 1995). Public schools surveyed; do not pay taxes, resulting which they do not receive corporate tax credit and corporate depreciation. These are the biggest savings for any commercial building with photovoltaic installation.

<u>Carbon credits</u> –

None of the schools responded affirmative for receiving carbon credits.

<u>Renewable energy certificates (RECs)</u> –

Schools presented vague information on renewable energy credits, in the survey. Based on brief information received from email conversations, survey generated, and United States environmental protection agency (EPA 1970), it is very vibrant that, these seven (7) schools should receive RECs, based on kWh of electricity generated, using solar power. In state of Washington, the ownership of RECs remains with the customer generating electricity.

<u>Grants and Funds</u> –

The next question requested information from all seventeen (17) schools. Of seven (7) schools with installation of PV system, for conservation of energy, four (4) schools received grants and funds while three (3) schools received only funds for their solar projects. The funds used were received from either district capital bonds or yearly school capital levy funds. Some of these projects were also funded by schools own facilities maintenance budget or operating budget. All ten (10) schools received demonstration projects as grants from either associated utility company or Bonneville environmental foundation (BEF). None of the schools had taken loan from commercial or federal bank for purchase of equipment or its components.

<u>Reduction in electricity costs/bills:</u>

The subsequent question inquired opinion for, reduction in electricity costs from solar project, in spite of rainy and cloudy weather existing in state of Washington. It's very encouraging to account that, all seven (7) schools replied positive and believed in existence of solar power in state of Washington. With a little twist, when all the schools, were surveyed to have information on savings in electricity bills, thirteen (13) schools replied positive, two (2) schools replied no savings, one (1) school replied not significant change and two schools did not respond to the question. The savings in electricity bills responses can be viewed from following pie chart. The pie chart in Figure 32 surely implies, as solar projects are significant resource for producing solar energy and reducing electricity bills, even in rainy and cloudy weather of Washington State.

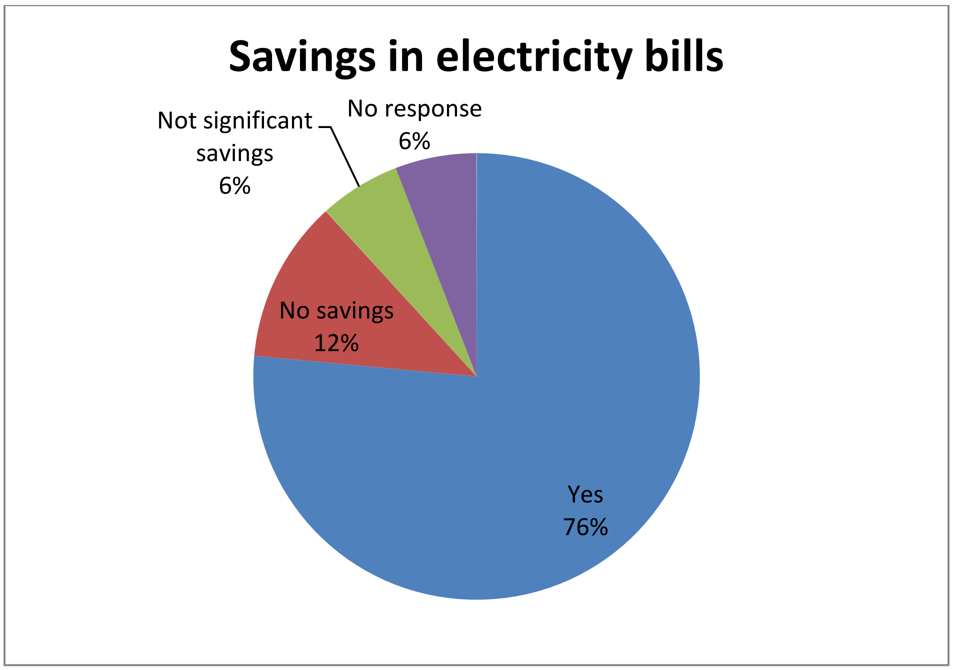


Figure 32 Savings in electricity bills

Positive change in performance of students and improvement in WASL (Washington assessment of student learning) scores:

Interestingly, all schools were unable to validate results, felt the possibility of other influences and had insufficient data to answer the above question.

Open ended questions:

- For schools with solar projects for conservation of energy –

The open inquiries requested information, to have insight and data, about the rationale used for validation of these projects for conservation of energy.

The first and only relevant question in this section asks for –

- State the factors considered for analysis of payback calculation?

Out of seven (7) schools, five (5) schools expressed their analysis, while two (2) schools did not respond to this question.

In brief, the payback was analyzed based on estimates made by associated architect for school.

The analysis incorporated the average kilowatt hours of electricity, avoided kWh, demand savings, revenues generated, solar incentives and inflation rate. The paybacks analyzed for these schools are anywhere from eight (8) till thirty-seven (37) years.

- <u>For schools with solar projects as demonstration projects</u> –

Following questions requested information from schools with installation of solar project as a demonstration project. The main idea behind these inquires is to have an understanding of social, educational and environmental benefits apart from monetary benefits, as is recognized in the LCCA –

The only relevant question in this section requested information as follows:

- With necessary funding available in future, will the public school undergo a major solar PV installation? a) Yes, please specify the reason b) No, Please specify the reason

Of the ten (10) schools representing demonstration projects, five (5) schools gave an affirmative response, one (1) school gave a negative response, while one (1) school was unsure and was interested to understand 'necessary funding', while three (3) schools did not answer this question.

In summary, the schools responding affirmative felt solar projects as excellent learning resource and solar power as the key alternative to conventional electricity. The schools responding negative felt solar projects are very expensive and investing in these projects gives low return on investment. The following pie chart in Figure 33 shows the distribution, with 50% of schools passionate for investment in solar projects.

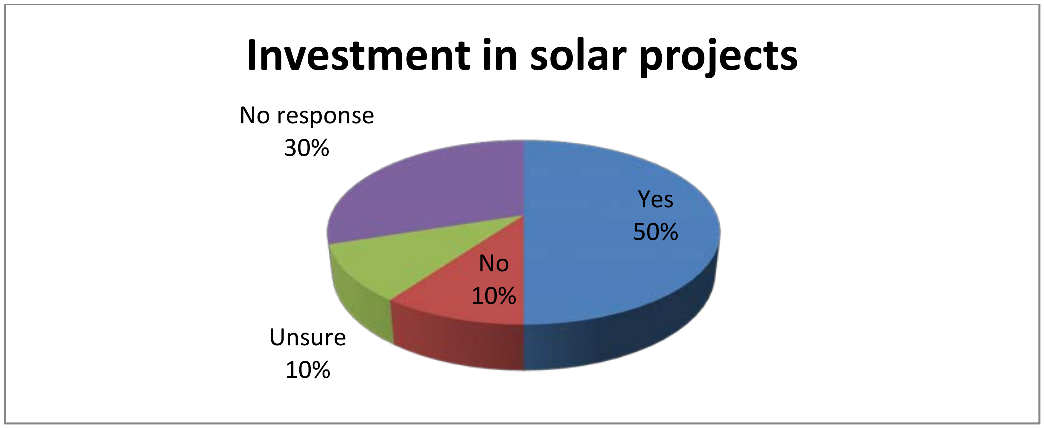


Figure 33 Investment in solar projects

- For schools with both type of solar projects:

The main idea is to collectively understand how the solar projects are socially accepted amongst the school community, who has installed the project as either demonstration project and for saving electricity.

- The next question enquired for - State the major changes incorporated in the school curriculum with the introduction of solar PV project?

This question requested information from all seventeen (17) schools. Of all schools six (6) schools have introduced at the minimum one (1) to maximum three (3) changes in their curriculum. Five (5) schools found insufficient data to answer the required question, four (4) schools did not comment, while two (2) schools found no major changes in their curriculum. It's very interesting and exciting to account the major modifications in their curriculum. In summary, the schools have incorporated –

1. Kiosk to get readings, check weather and solar energy production in kWh
2. Solar details in science and math classes

3. Watershed studies in 4th grade, Assignments on electricity in 7th grade, solar energy unit in 8th grade, Alternative energy project in 9th grade.
4. Enhanced recycling and composting programs.

Following pie chart in Figure 34 identifies above data.

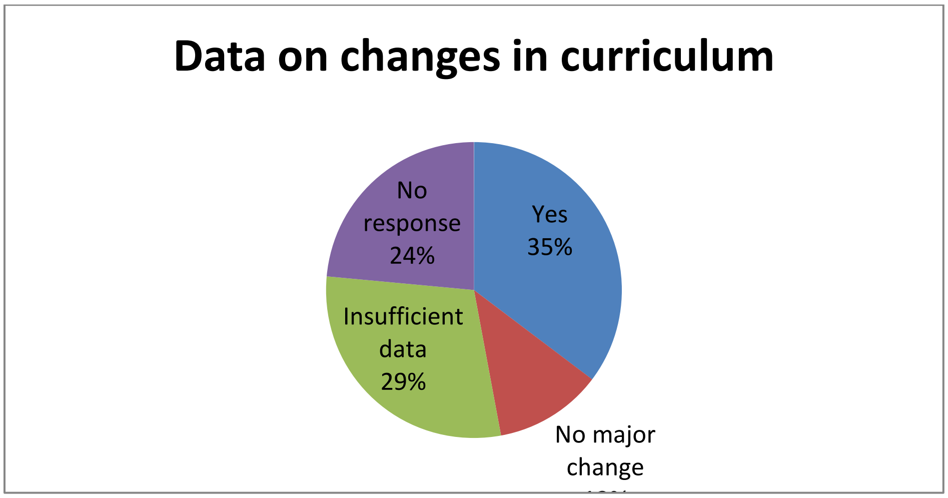


Figure 34 Data on changes in curriculum

The subsequent questions inquired innovative ideas developed by students and by school staff to conserve energy using solar PV project –

- State two new ideas/options developed by students to conserve energy using solar PV project?
- State three innovative ideas developed by school staff to conserve energy using solar PV project?

New ideas developed by students showed varied responses. Of seventeen (17) schools, five (5) schools developed new ideas, four (4) schools had insufficient data, six (6) schools did not respond while, two (2) schools responded with no ideas. Schools with new ideas exhibited some interesting thoughts.

1. Add solar water heating
2. Wanted to do solar cooking

3. Had ideas on conservation of electricity and gas
4. Felt the need to have more panels to generate more power
5. Became energy conscious, even told parents to conserve electricity
6. Have an understanding that, solar energy is converted and never destroyed
7. Solar device test, alternative energy devices at home.

Innovative thoughts developed by school staff equally showed minimal responses. The data shows that the thoughts are still at its infancy stage. Of seventeen (17) schools, three (3) schools responded, eight (8) schools had insufficient data while, six (6) schools gave no response.

In spite of lack of creative thoughts, some of the school staff came up with simple yet useful enhancements.

1. Change energy settings,
2. More awareness of energy used by heating systems, close windows and doors during winter months
3. Use natural light and ventilation, as much possible.

Multiple choice questions:

Some questions requested multiple choice answers. These questions enquired for information, explored different useful applications and limitless possibilities of use of solar energy, performed by students and teachers.

Primary reasons behind installation of solar projects:

Following question enquired for essential reasons behind installation of solar project as either demonstration or as major project for conservation of energy.

The following chart in Table 24 presents a complied ranking for the responses provided.

Table 24 Primary reasons behind solar PV installation

Purpose	Rankings
To educate students and introduce changes in student curriculum	1
To educate the school community as whole	1
To use renewable source of energy to reduce energy bills	2
To reduce carbon footprint and greenhouse gas emission	3

Based on the main reasons for installation of PV system, ten (10) schools believed solar projects are useful to educate students and introduce changes in curriculum. Also ten (10) schools believed solar projects educate the school community as whole, while nine (9) schools believed in use of solar energy as renewable source of energy and three (3) schools believed in reduction of carbon footprint and greenhouse gases. Ranks are displayed in the chart, based on complied preferences made by each school.

Programs and activities introduced for students and teachers in K-12, to enhance solar education:

The next question requests for responses on different programs organized by each school, either at preliminary, major project level, professional development courses, teacher training modules or as competitions. These activities should be designed for K-12 (Kindergarten till twelfth (12^{th})) grade. The activities are further segregated at elementary, middle school and high school level. Following chart recognizes the activities, school level and its compiled preferences. Ranks are then determined to prioritize the initiation effort made by respective level of school. The choices are compiled for both demonstration and energy conservation projects. The data accumulated and complied is shown in Table 25. As per data received in survey, of the seventeen schools, three are elementary, seven are middle/junior high, five as high and one state school with two different PV installations, have installed their PV between 2004 till 2010. This period can be considered as most recent in the past decade of installations, for schools. Based on this information the activities are defined as –

1) 1st activity - Represents basic/introductory science experiments/projects
2) 2nd activity – Increased knowledge/effort involved from students and or teachers without major computer tools, for development of science projects.
3) 3rd activity - Development of/ Effort to make Energy model using computer tools to simulate the energy use of a school building for entire year of operation or High level science projects with use of computers. (Higher effort involved).
4) 4th activity - Measures taken by school to deliver training/workshops for teachers.
5) 5th activity -. Identifies participation of schools in local/state/national competitions.
6) 6th activity - Introducing introductory professional courses for career development (was intended for higher grades).

Table 25 Activities for students and Teachers in K-12 for solar education

Activities	Elementary School	Middle School	High School	Ranks
1) Preliminary solar science projects/experiments	4	5	4	1
2) Major science projects/experiments	0	3	3	2
3) Preliminary Energy models/ Building science projects	0	4	1	3
4) Teacher training modules/workshops	0	2	1	4
5) Participation in Solar science contests/competitions	0	1	2	4
6) Professional development courses (beginners course)	0	0	0	5

Major difference in children's attitude towards solar PV projects, from K-12, at school:

The subsequent question explored for information, on behalf of children/students attitude towards conservation of energy specifically for electricity, as solar projects from K-12. The following matrix in Table 26 identifies their rate of responses. The question tries to ask and the responses are being analyzed for seriousness amongst students first, to make changes in themselves, then for their school and lastly their surrounding environment. To explain further, it checks whether students are only interested in saving electricity, by turning of fans and bulbs and more or they are just interested in clean energy, carbon emissions, or are they interested in the manufacturing process, science behind solar projects, or are they being versatile and would like to be part of green environment.

Table 26 Observation of change in attitude amongst students

Students attitude towards solar PV projects	Number of Responses
To conserve energy	1
Enthusiastic to learn more about clean energy with no greenhouse gas emissions	2
Observed more involved in analytical and critical thinking of functioning of solar PV projects	0
All of the above	7
Other	4
No response	3

The survey identifies with seven (7) out of seventeen (17) 'all of above', responses, that students have shown improvement in their understanding, reasoning and critically thinking in terms of solar energy as essential renewable source for energy. The responses confirm that solar projects are helping students build their foundations for reduction in carbon emission, conserving electricity, in a way conserving energy and fossil fuels, at a very young age.

4.1.7 Analysis of Interviews and Email conversations:

Telephonic interviews and email conversations formed an integral part of data collection method. They helped develop a basis for research and analyze not only the information received, but also develop questionnaire for survey. The questions were asked from perspective to conserve energy meaning reduction in electricity costs and from demonstration of solar project. The interview questions are identified as Appendix D of the report.

Five prominent personalities, compiled of two (2) project managers from public school districts, two (2) program managers from utility companies and a project mechanical engineer, helped tremendously, provide information as and when needed. These officials represented four schools for which the LCCA is developed. They have provided information, excel spread sheets with utility data for understanding electricity consumption, as attached in the Appendix F and shown honest interest, with belief in solar photovoltaic projects.

The interviews conducted are being summarized and analyzed to understand whether solar PV projects are suitable for reducing electricity costs. The above officials were also discussed for motivation behind installation of renewable energy solar project, in state of Washington. Along with discussions these schools during email conversations, provided valuable publicly available cost, energy use data, net metering agreement and baseline code energy usage pdf file.

Brand of solar PV, inverters and incentives provided by state of Washington:

Project managers from two school districts, gave precise names of the brands of solar PV and inverters, with detailed incentives source of information received by the school. The solar PV systems and inverters used by these schools were manufactured outside of Washington. The complete classification of incentives was useful, to determine under which cases the incentives are received (Dsireusa 1995).

Usage savings, Avoided costs/Annual electricity savings, Electricity rate applied for public schools:

In discussion and email conversations with the project managers, the usage savings were required to be determined from a website called www.solar4schools.org. This website provided live data of solar energy, also observed on data monitoring system installed at public school.

Avoided costs/Annual electricity savings were calculated as summation of usage savings and demand savings. The yearly data is determined by summing all month's data time's electricity rate, while demand savings are calculated as highest demand determined each month times its appropriate demand rate of electricity. Demand rate differs and is higher from electricity rate of utility. Determination of demand savings is equally difficult to conclude as it accounts for summation of monthly demand, critical demand and depends on many variables. These variables could be weather dependent, sudden turning on the lights, more sun-hours and more (PSE n.d.). Demand savings were also determined as difference between avoided costs and usage savings of electricity. The electricity rate applied for each school depends upon rate provisions applied by the utility company's service area. These rates are subjected to yearly increases and shows seasonal rate variations.

Formula for Avoided costs as used in their estimation and as provided by one of project managers of Lake Washington school district is given by –

Avoided cost = Usage savings + Demand savings

= (kWh*$0.08) + (kW of solar system *$7.20 *9)

= (Assumed sun hours per day * system size * electricity rate) + (Size of system * demand charge * 9 months of school)

Understanding units for electricity, gas and total energy:

One of the program managers from Puget Sound energy explained the various units observed in an electricity bill. This explanation occurred via email conversation.

- Electricity is monthly usage measured in kWh.
- Demand is for the peak use in 15-minute increments measured in kW.
- Natural gas measured in Therms
- KVAR cost is a cost created by how fast peaks are reached.
- Total energy measured in MBtu (also called Dekatherm)= kWh + Therms
- = ((Multiply kWh by 3412 Btu per kWh)/1,000,000) + (Divide Therms by 10)
- Example data from spread sheet provided, as shown in Appendix D:
- =(165,471 KWh * 3412 / 1,000,000) = 564 MBtu of electricity
- = (1,664 Therms / 10) = 166 MBtu of gas
- = 564 + 166 = 730 Dekatherms or MBtu.

Federal credit for solar installations, MACRS deprecation:

It is understood from conversations that taxes are not applied for school districts, therefore these schools are not eligible for tax incentives associated with solar PV incorporation at neither of public schools nor tax savings in the form MACRS depreciation and bonus depreciation.

Motivation for schools to install the solar panels system:

In case of three schools, the schools districts first initiated low conservation of energy methods like small scale retro-fit. Based on the changes observed in electricity bills, less maintenance required and behavioral changes observed amongst school community, the district developed a foresight, that solar as a type of renewable energy would bring more value to education, reduce greenhouse gases, carbon dioxide and would help mitigate climate change. This move received abundant appreciation from school community to keep motivated for renewable energy projects. One of the remaining schools in the analysis had a brand new school being constructed. They were more interested in making the school green but still staying within their construction budget, to educate students about their energy usage decisions, become advocates for the environment in their own school and have long term energy savings.

Cost effectiveness of solar PV in its life span:

School's calculation of payback includes project cost, payback rates from utility, incentives, avoided costs savings and assumed sun hours per day. The payback for three schools is approximately 22 years, while the other school had no data regarding the payback. Based on this estimated calculation, school districts are passionate and find solar PV cost-effective in its life span.

Essential excel spread sheets and pdf files:

During these interviews and conversations, the school district's program manager shared valuable publicly available information as follows –

- Excel spread sheets for yearly electricity usage and cost data for four (4) public schools, one year before and one year after the solar PV installation, shown in Appendix F
- Hayes Freedom code baseline energy usage pdf as Appendix G
- Net metering agreement between Hayes Freedom high school and Clark public utilities shown in Appendix H.
- Finally, there is power point presentation link for solar art work, by Sarah Hall at Grass wood elementary school. This is shown in Appendix I. She has created beautiful art work by integration of PV cells in design. The school has used the art work, as photovoltaic windows that power light in stairway.

Overall Summary:

The development, implementation, interpretation and integration of information from diverse methods like online survey, interviews and email conversations have evidently aided to decipher the financial, economic, social and educational benefits of solar photovoltaic projects. The information received is narrowed with respect to state of Washington.

Obviously, there are some inconsistencies observed with minor flaws in questionnaire development, data sets received, time frame available and absence of expected larger group. Despite this fact, online survey has proved to be most effective, time saving and convenient method of data collection for generated survey. With continuous guidance from my advisor, repeated evaluation, discussion with project managers, program managers and project engineer, some of these drawbacks in the process were modified and implemented as earliest possible.

With regard to data collected during the available time frame, it is clear that school districts are showing keen interest in implementing best practices in design, construction, maintainenance and operation for development of high performance K-12 schools (CHPS 1996) (USGBC 1993), (EERE n.d.). They are enthusiastic to incorporate green features like renewable energy sources either solar energy or retro-fit existing buildings with energy efficient and saving features. The seventeen schools surveyed are illustrative of their interest in solar photovoltaic technology. Of the schools surveyed 50% of these schools are passionate to install solar PV as major installation in future.

In current market trend, solar photovoltaic systems have emerged as one of the most promising renewable source of energy (Solarbuzz 2001). Public schools who have installed PV systems began their process of implementation of conserving energy by initiating small retro-fits. With greater insights, understanding new concepts, seeing positive changes, desire to motivate and add educational value to existing curriculum led to the installation of PV systems. Surely these systems are now reaping good electricity savings, identified by 76% of the surveyed schools demonstrative of savings in monthly electricity bills, which by itself proves efficiency of the system. These savings largely depend upon maximum solar radiation available on a given day and demand savings to offset electricity costs.

There is a prevailing concern for high manufacturing costs of solar photovoltaic systems leading to high cost of solar electricity production and reduced funds for school operation every year. However, with current reduction in prices observed as 27% drop for year 2010 as compared to 2009 based on survey, interview discussions and with innovative researches for solar cell efficiency, United States would soon achieve grid parity. Various options that could work out efficiently for PV implementation are at the minimum installation of demonstration solar projects, prioritize and divert school funds for energy efficiency projects and by leasing solar panels with a power purchase agreement (LaMonica 2008).

Solar photovoltaic projects conserve fossil fuels usage and save electricity costs. Along with these savings the schools have initiated different solar programs, experiments, quizzes and competitions, training modules for teachers to socially accept these changes within the school community. These programs are further recognized for elementary, middle / junior high and high school level (NREL 1977). All of these and 35% of surveyed schools integrating educational changes in curriculum have directed students to think critically, precisely, innovatively and systematically, at a young age, in the direction of saving our fossil fuels and looking for solar energy as promising renewable source of energy, identified in Table 25 and 26 of this report. These projects have helped students to interact with other students of similar interests from their school, other schools, school staff, to show inquisitiveness and build social skills as more conscious future citizens. These projects can even serve, per direction for their engineering interests to pursue higher studies as their choice of career development, at as early as elementary school level.

Chapter 5.

Conclusions and Recommendations

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5.1 Conclusions: Summary of Interpretations

As validated by case studies and survey collected from public schools, there is more to understand regarding the analysis performed on the data provided by schools. Our community revolves around our schools and is the basic foundation of our higher education system. The various literatures, case studies explored along the development of this report identify the usefulness of solar photovoltaic systems, in public schools, in Washington State as essential step towards one of the green solutions for revolution in schools. The statistics and information provide following insights and inferences.

- **Renewable, Retrofit and Reduction application:**

In comparison to other commercial buildings category, educational buildings that include schools are advancing themselves to reduce fossil fuel usage, emissions of greenhouse gases, by both using best practices and methods recommended for new construction in high performance schools guide or using retrofitting techniques performed on existing buildings by applying energy efficient features or renewable energy source to school building. These PV systems are excellently applied to newly constructed schools, as it is in their plan of execution from initial stages. This is also advantageous as, appropriate funds can be diverted accordingly for the purpose of achieving ideal health of students, effectiveness for net zero energy consumption and sustainability of environment. Applying retrofitting techniques is another cost effective way of achieving the same benefit of reduction in electricity. In either way, these methods work effectively towards reduction in carbon emissions and greenhouse gas emissions.

- **Performance of LCCA on application of solar PV:**

The analysis includes various uncertainties. Based on module tilt, module orientation, Irradiance and percentage of shading on solar modules the sun hours are available for balancing electricity from utility, in schools. In spite of these details required, the PV systems manage to work effectively on cloudy days, in state of Washington.

As determined in the life cycle analysis, avoided costs from solar PV are dependent on demand savings and usage savings. The more sun hours received by the system, more it offsets electricity. Considering the variable nature and difficulty in tracking demand savings from solar PV, schools approximate estimates of demand savings, during installation plans developed by schools. In order to track exact demand savings, it is essential to measure these savings accurately as highest peak demand in every fifteen minute interval on PV production meter as is measured for conventional electricity, by the utility company. This identifies precision in highest demand measurement. On account of disclosure restrictions, on part of actual electricity bills, non-availability of detailed demand data offset by solar PV, net metering savings from utility the analysis had difficulty posing calculation of demand savings and net metering savings. Conversely, this difficulty along with uncertainties identified as risks like inflation, costs of PV are evaluated by performing scenario analysis manually, probability distribution, and Monte Carlo simulation by application of @risk software tool and by observation of monthly electricity usage from schools, before and after solar PV implementation.

- **Incentives:**

There are various incentives available for commercial buildings. As identified in chapter 3 and chapter 4 of analysis, public schools comparatively receive fifty percent of available incentives. This has caused major drawback in determination of benefits implied for schools. For example the federal credit and MACRS bonus depreciation alone offsets more than forty percent of costs of solar PV. Hence efforts should be made by the federal, state and local government to identify the need of the present situation and provide appropriate new incentives, additional funds every school year especially - diverted and meant for schools. Hence, it can be concluded that, this effort is extremely essential for newly constructed schools and for retrofitting existing schools.

Net metering –

In analysis of life cycle costs, for one of the schools, the school identified net metering savings during summer vacation. After understanding the utility company's policy, utility credits the solar production to next month's solar production and accounts net savings, at end of its yearly cycle. With PV system installed in school, just one year old, this posed difficulties in receiving data of incentives for schools net metering savings. On an average the utility applies the same/retail rate of electricity for excess solar production, produced by the PV system. Availability of more specific breakdown of net metering production and its dollar savings, exhibited by utility company would have been helpful in analyzing the financial benefits of the system.

<u>Carbon equivalents or Green tags or Renewable energy certificates –</u>

Renewable energy certificates (REC's) in state of Washington amongst public schools are available, in increments of single megawatt-hours of electricity. However, in the case studies presented none of the schools have sold their REC's and generated green power income. These green tags as also called if, effectively sold by schools with major solar PV installation could generate good amount of benefits, at present rate anywhere between 1.25cents/kWh till 2cents/kWh. Schools need to explore this segment, with utilities, government to develop green source of income, as benefit for specific school.

- **<u>Social benefits:</u>**

With more percentage of public schools, installing solar PV as demonstration projects along with major installations, it is clear that schools are enthusiastic about the renewable solar energy, understand the risks behind solar PV installation, are determining the costs for future implementations, and are observing the performance of solar PV on regular basis via data monitoring system. Equally these schools, based on observation have implemented changes in school curriculum, incorporated science experiments, competitions and more. As a result, this has helped to develop critical analyzing capability with creative outlook amongst students, create understanding to conserve fossil fuels, the need for change, develop interests in green environment and explore new ventures. Moreover, building a positive opinion about the schools movement, amongst its school community goes beyond saying a word automatically.

5.2 Recommendations

Following are suggestions recommended, to enhance implementation of Solar PV in state of Washington – for public schools.

1. Based on priority, divert good portion of capital bonds, state and federal funds provided for public schools, in state of Washington. These funds when utilized for schools for renewable solar projects would start earning incentives and offsetting electricity almost immediately. Again, looking forward towards implementation of whole building design, high performance school building methods, it would be suggested that schools begin the conversation, bring the thought to school stake holders and at the minimum implement a demonstration project. The survey initiated shows clearly the positive responses and enthusiasm shown by the school community. Indirectly, it brings positive note for school in public opinion, increases the school enrollment, provides wide exploration for study curriculum, and incorporates career interests with creative outlook at a very early stage. This stage can be as early as any grade in elementary level.
2. Those schools unable to install either demonstration or major solar PV installation, can look forward to purchasing green power – again this helps schools socially in countless ways. Utilities are eager to sell electricity through their green programs. The need is exploring these viable possibilities. Though not a public school, but University of Washington is one of the large buyers of green power from Seattle city light, in state of Washington.
3. After good thought and reviewing of available literature on solar PV, It's understood that, solar dealers in United States are providing interesting solar leasing, solar power PV and financial solutions, for its customers. This is also one of the many alternatives that, schools based on their financial capability should look for. This would be made possible with power purchase agreement for schools with any interested utility company, or power generating organization. Eventually this should lead growth in on site renewable solar energy generation.

Finally, I would conclude with following statement by St. Francis of Assisi, in a green essay contest written by Rockville High school green team (Team 2011).

***"Start by doing what is necessary, then what is possible, and suddenly You are doing the impossible."* –St. Francis of Assisi**

As truly the above words say, to do impossible, the public schools in state of Washington should initiate the beginning.

5.3 Future study

The report concludes that, more data needs to be available from different public schools, to look forward as future case studies, of useful implementations of solar PV. This is just the beginning. As these solar PV's become older, meaning at least 2-3 years' worth of valid data, to shed light on net metering, carbon equivalent, demand savings and avoided costs of electricity could be used for more authentic and detailed life cycle cost presentation, by future analysts. Presently, distributions of costs in percentages, for various solar PV components are difficult to obtain from dealers, articles or papers, as either detailed cost or as thumb rule percent. Continued research with old and new solar PV projects, co-operation from dealers could overcome this difficulty and present a detailed overview of solar PV costs and its installations.

Forthcoming projects on solar PV could be investigated for positive experiences, reductions in life cycle costs, internal rate of return, benefit cost ratio, net present value and levelized cost of solar electricity, to establish as practical case studies – providing positive encouragement for schools for PV installation.

More extensive research on social acceptance of solar PV projects, amongst school community, in future is required. This would include involving students directly in the survey, rather than limited to school science staff, teachers and project managers associated with the project. This could help to give more valid presentation of sample population explored.

Finally, PV installations being comparatively new to public schools, the schools are equally understanding and checking the prior estimations and projections made for solar PV, to its actual performance. Considering degradation of solar PV along it useful life is another important aspect to be explored. Hence with more installations to offset electricity, increased data on reductions in costs of PV, older data being available to explore, best practices used for high performance of school buildings, for implementation of renewable solar projects, in design and construction would provide more enhanced and systemic analysis, in future.

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Appendix

Appendix A

Following are the excel spread sheets for four public schools in state of Washington:

a) A_Eastlake High School_LCCA and Risl

b) B_Evergreen Junior High School_LCCA an

c) C_Redmond High School_LCCA and Risl

d) D_Hayes Freedom High School_LCCA an

Appendix B

Electricity bills before and after solar PV is installed:

Electricity usage before and after sola

Appendix C

Survey Questions:

Survey_WebQ_Questions.pdf

Appendix D

Interview Questions:

1. State the brand of solar Photovoltaic systems and inverters?
2. Can I request to have data from years' worth of electricity bills before and after the solar PV system was installed?
3. State the incentives provided by the state of Washington?
4. Explain the motivation behind installing the solar PV projects at your school?
5. Are photovoltaic installations effective in long run? Do they work in state of Washington? How are the observations made?
6. Express practical opinion regarding benefits observed?
7. How are avoided costs of electricity calculated?
8. State the electricity rate applied to Hayes Freedom School and its demand savings?
9. What are demand savings? Why are they applied a different electricity rate?
10. State the electricity rate applied to Eastlake, Evergreen junior high and Redmond high school?
11. Did the public schools receive tax credit and MACRS depreciation and Why?
12. Explain in brief the Btu units for Electricity, Gas and Total energy?
13. Can I request to have agreements made with Clark public utility and Bonneville foundation?
14. It would be appreciable to have the power point presentation link for solar art work, by Sarah Hall at Grass wood elementary school, to include in my Thesis.
15. State the purpose behind, using energy model created by in-house staff, using eQUEST v3.64 modeling software?
16. Would like to explain any other issues, topics, cases regarding practical implication of solar PV systems?
17. Do you have any questions for me?

Appendix E

Survey results:

Results_pdf_Catalyst WebQ.pdf

Appendix F

Subsequent excel sheets represent the energy use and energy cost data from four public schools:

1. EastlakeHS Energy Cost 07-10.xlsx | EastlakeHS Energy Use 07-10.xlsx
2. EvergreenJH Energy Cost 07-10.xlsx | EvergreenJH Energy Use 07-10.xlsx
3. RHS Energy Cost 05-10.xlsx | RHS Energy Use 05-10.xlsx
4. Hayes Freedom_11-1027 En

Appendix G

Following is the energy model created using eQUEST v3.64 modeling software based on 2009 Washington State Energy Code for Hayes Freedom HS:

Hayes Freedom Baseline Energy.pdf

Appendix H

Following is an Net metering explanation document from Clark Public Utility:

Customer Generation
Metering Explanation

Appendix I

Power point presentation from artist Sarah Hall:

Sarah Hall Solar Art
Glass _ Grass Valley E