

ANALYSIS OF PHOTOVOLTAIC ENERGY IN THE EASTERN KENTUCKY REGION
AND THE RESIDENTIAL FINANCIAL FEASIBILITY

A Thesis Proposal

Presented to

The Faculty of the College of Business and Technology

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In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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Joshua A. Johnson
Morehead State University, 2018

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The major problem with many energy sources is the pollution that is exerted to the environment. There have been several ways for many years now to produce clean renewable energy, one of them being solar energy. The problems associated with solar energy are costs for system and solar energy available in the demographic area. This research proves that solar energy is a feasible source of energy in eastern Kentucky. By doing an analysis of solar radiation emitted and finding a system with the proper solar panel capacity, there are photovoltaic systems that are feasible in Kentucky.

In this thesis, the data from Lexington, Kentucky were obtained by using the energy management software's SAM and RETScreen. After calculations it is estimated that a 15.95kW DC panel array, slightly smaller or larger, will be able to generate the energy needed to power a house of 973kWh per month. The cost one will pay per kilo watt hours (kWh) of electricity is

majorly reduced. Using a 345 panel Sun Power solar 4.139 DC array, a potential of 7.75 cents one will pay per kWh compared to the utility companies at 10.41 cents.

The payback period for a system from savings after installation is about 15 years. Financially, this is a feasible option to have solar energy in eastern Kentucky. This is a feasible power source option in terms of money but also decreases pollution emitted into the environment.

Accepted by: _____, Chair
Dr. Ahmad Zargari

Dr. Nilesh N. Joshi

Dr. Qingzhou Xu

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Chapter I - Introduction

1.1 Introduction

In the past one hundred years there have been many different sources of energy that have provided power for citizens throughout the world. With technology advancing exponentially, engineers have found several ways to create power through various forms of energy. These forms include: wave propulsion, fossil fuels, burning of coal, burning of wood, wind, geothermal, and many more. The major problem with many energy sources is that they happen to be extremely pollutant to the environment. One source of energy that does not emit pollutants, and caught the attention globally, is solar energy.

The issue that arises with solar energy is whether it is a feasible source of energy. In many parts of the world, solar energy may not be a viable source because of limited sunlight. Just like anything being developed, solar energy does require money to develop. Solar cells are energy harnessing devices, which means there has to be a minimum amount of sunlight to determine if it would be practical for cost. In eastern Appalachian Kentucky, it is not sunny out year round. Solar energy, may or may not, be a feasible source of energy in terms of cost for this particular location.

1.2 Overall Area of Concern

In this study, the area of concern is that solar energy will be too expensive for the amount of power that it may be able to provide to consumers. There may also be a major flux in the data that is generated because of the difference in years. The data is collected from NASA's software, known as RETScreen, from the year 2016. Due to the fact there is never the same exact amount of solar radiation emitted ever single month, this may cause a variance which will be considered.

1.3 Importance of Study

This study is extremely important for the sake of reducing pollutants released in the environment. For several years, pollution has been a rising issue in many places, including eastern Kentucky where several manufacturing plants generate enormous amounts of pollution. In 2012, a Toxic Release Inventory (TRI), which is fully regulated by the federal government by conducting standardized testing at every industrial manufacturing and chemical plants, reported some pollution statistics. The TRI that was reported claimed Kentucky's power plants released over forty million pounds of toxic pollution into the ozone. This makes Kentucky the highest for air pollution in the United States (Peterson, E. 2014). Determining if solar energy is a feasible method of energy for eastern Kentucky, may be the first step in eliminating or majorly reducing greenhouse gasses that are being emitted into the ozone by corporate industrial plants.

After researching about solar energy, most of the energy absorbed by the photovoltaic devices comes from the wavelengths of the visible light spectrum. Since ultraviolet rays (UV) are outside the visible light spectrum, most of the UV rays are not used in the harnessing of solar energy. This means that most of the energy collected for solar energy comes during daylight hours.

1.4 Statement of Problem

The major problem is that eastern Kentucky has coal wasteland that is not being used. Coal is a very unclean source of energy, but solar energy could potentially be used, assuming feasibility, in the place where the coal waste land is located. Solar Energy is not being used to power residential homes on a large scale.

1.5 Research Objectives

- 1) In this research, a cost analysis on solar energy will be conducted to determine if a transition from fossil fuels to renewable energy is feasible using similar studies.
- 2) There will be a strong focus on how a solar system works to convert sunlight into electric power.
- 3) Installation research will be collected to help determine if the transition will be feasible to the residential and commercial quantity.
- 4) Analysis of solar radiation emitted in eastern Kentucky will be collected using an Energy Management Software, Solar Advisory Model (SAM), and RETScreen.

1.6 Assumptions

- 1) The solar radiation emitted is approximately the same every year throughout the years on average. The data in this paper will come from an average monthly solar radiation, even though in the past years the sun rays may have emitted more, or less, energy.
- 2) The data from the National Renewable Energy Laboratory does not include this year. Instead, an average of several past years is used. There is variance in cost no matter what the estimate may be due to variance in solar radiation.

Definitions

Solar Electric System- Including PV system or solar power system, is a power system designed to supply usable solar power by means of photovoltaics. (Wikipedia)

Photovoltaic Effect - The creation of voltage and electric current in a PN junction upon exposure to light. (Wikipedia)

Global Warming – The temperature increase of the earth’s atmosphere. (Marriam-Webster)

Solar Energy – Energy that is emitted from the sun. (Marriam-Webster)

DOE (Department of Energy)–Is a federal executive division responsible for coordinating and administering national energy policy. The department promotes energy efficiency and the use of renewable energy through various research and financial assistance programs. Its national security and environmental management programs serve to develop nuclear energy resources, including nuclear power plants and weapons, while its Office of Environmental Management oversees waste management and cleanup activities at inactive facilities, including sites with chemical and nuclear waste. Its Office of Fossil Energy develops policies and regulations concerning the use of natural gas, coal, and electric energy, and its regional power administrations transmit electric power produced at federal hydroelectric projects. The DOE also conducts investigations in cases involving whistle-blower reprisal complaints, and it holds hearings and listens to appeals in cases involving complaints about its regulations. Included in the DOE is the Federal Energy Regulatory Commission (FERC)

NREL (National Renewable Energy Laboratory)– Specializes in renewable energy and efficiency research. NREL is a government-owned, contractor-operated facility, and is funded through the United States Department of Energy. (Wikipedia)

Solar Tracker - is a device that orients a payload toward the Sun. Payloads are usually solar panels, parabolic troughs, Fresnel reflectors, lenses or the mirrors of a heliostat. (Wikipedia)

Solar tracers are usually single or double axis tracking system. (Marriam-Webster)

Greenhouse Gas – the gas that comes from radiation pollution and is increasing the temperature that is trapped in the atmosphere. Contributing gas comes from burning of fossil fuels, wood, coal, and much more. (Marriam-Webster)

Semiconductor – any of a class of solids (such as germanium, silicon, III – V Compounds, and II – VI Compounds) whose electrical conductivity is between that of a conductor and that of an insulator and is nearly as great as that of a metal at high temperatures and nearly absent at low temperatures. (Marriam-Webster)

Band Gap – the difference in energy between the valence band and the conduction band of a solid material (such as an insulator or semiconductor) that consists of the range of energy values forbidden to electrons in the material. (Marriam-Webster)

Energy Levels – one of the stable states of constant energy that may be assumed by a physical system —used especially of the quantum states of electrons in atoms and of nuclei. (Marriam-Webster)

RETScreen – An energy management software used for determining several different physical features inducing solar radiation, temperature, pressure, UV index and much more in demographic location

Irradiance (Solar Radiation Value) – the density of radiation incident on a given surface usually expressed in watts per square centimeter or square meter. (Marriam-Webster)

Insolation- the rate of delivery of direct solar radiation per unit of horizontal surface. (Marriam-Webster)

Electric Diode – An Electronic device that has two electrodes or terminals and is used for especially as a device for converting alternating current into a direct current. The terminal may only send the current in one direction. (Marriam-Webster)

Anode- the positively charged electrode by which the electrons leave a device. (Marriam-Webster)

Cathode- the negatively charged electrode by which electrons enter an electrical device (Marriam-Webster)

Standard Test Conditions (STC) – this is the test conditions at which the solar panels were tested inside the manufacturer. Typically they are set at an air temperature of 77 Fahrenheit and a 1,000 watts per square meter of replica solar radiation on the panels. (Durrenberger, 2015)

Photovoltaics for Utility Scale Applications (PVUSA) Test Conditions (PTC) – This is a testing condition that the NREL developed to make the system more closely to the real environment. They tested solar panels solar panels at a 113 degree Fahrenheit, with a 68 degree Fahrenheit ambient temperature, and also a 2.2mph wind speed breeze. Under these testing condition there is actually about an 8-10% decrease generated in power from the panels at STC. This is closer to a real setting. (Durrenberger, 2015)

Chapter II - History of Solar Energy

2.1 History of Solar Energy

The history of solar energy, also known as photovoltaic energy, is not very old and happens to have been discovered in the late 1800s by William Gyrus Adams (The History of Solar Power, 2017). Williams Gyrus Adams was a physicist who taught at Kings College in London. He did extensive research on solar heat. Adams believed that the energy emitted from the sun could be harnessed into usable energy for various different applications, but one in particular was heating steam boilers. The first discovery of solar energy was conducted by using the element Selenium, which did prove that the energy of the sun could be harnessed into useable electric power. (The History of Solar Power, 2017)

Adams' work caught attention globally, especially when the New York Times wrote about how this may be the future of energy. The problem that had to be understood was that solar energy was outrageously expensive. It was not practical to mass produce solar cells because it was way too expensive to use even on a commercial scale. In the 1950's, other scientists began doing research on solar cells and how to increase efficiency by using different materials. The material that seemed practical to use was discovered by Calvin Fuller, Gerald Pearson, and Daryl Chapin. They found using silicon as the semiconductor was much more efficient and could actually produce much more electrical power. By the year 1956, the first solar cell to be put on the market for the public would cost \$300 for a 1-watt solar cell (The History of Solar Power, 2017). This was not a practical mean of energy even though it was the first truly clean renewable energy source.

2.2 Fundamentals of Solar Energy

Solar energy is not a complex system in understanding how it functions to produce electricity. The complex portion of solar cells is the chemistry of knowing which materials to build the solar cell with. Essentially, the sun is the energy source that is emitting energy through several different rays that are, and are not, visible to humans. UV rays are not visible to humans because they fall outside the solar visible spectrum of 400 to 700 nanometers, which has a minimal effect on solar energy. The sun emits photons that transfer through a transparent panel to a negative and a positive semiconductor. The photons that shine through excite the semiconductor to generate electron-hole pairs, which are converted to a current by the built-in electric field. The electricity is the energy that is now able to be used as electrical power. Using a wire that is attached to the negative and positive ends of the solar panels, which comes from the semiconductor, completes a circuit where the energy can be stored in a battery. This can be seen in the diagram below.

$$\text{“Photon” Energy} = \text{Planks Constant (h)} * \text{Frequency (gamma)}$$

Where h is 6.626×10^{-34} joule·s, and v is frequency in Hz

$$\text{Power (P)} = \text{Voltage (V)} * \text{Current (I)}$$

A man named Rick Contrata of Renewable Edge published some very simple to follow solar diagrams about how solar energy works. Below are diagrams of basic flow charts showing how solar energy is harnessed through solar panels.

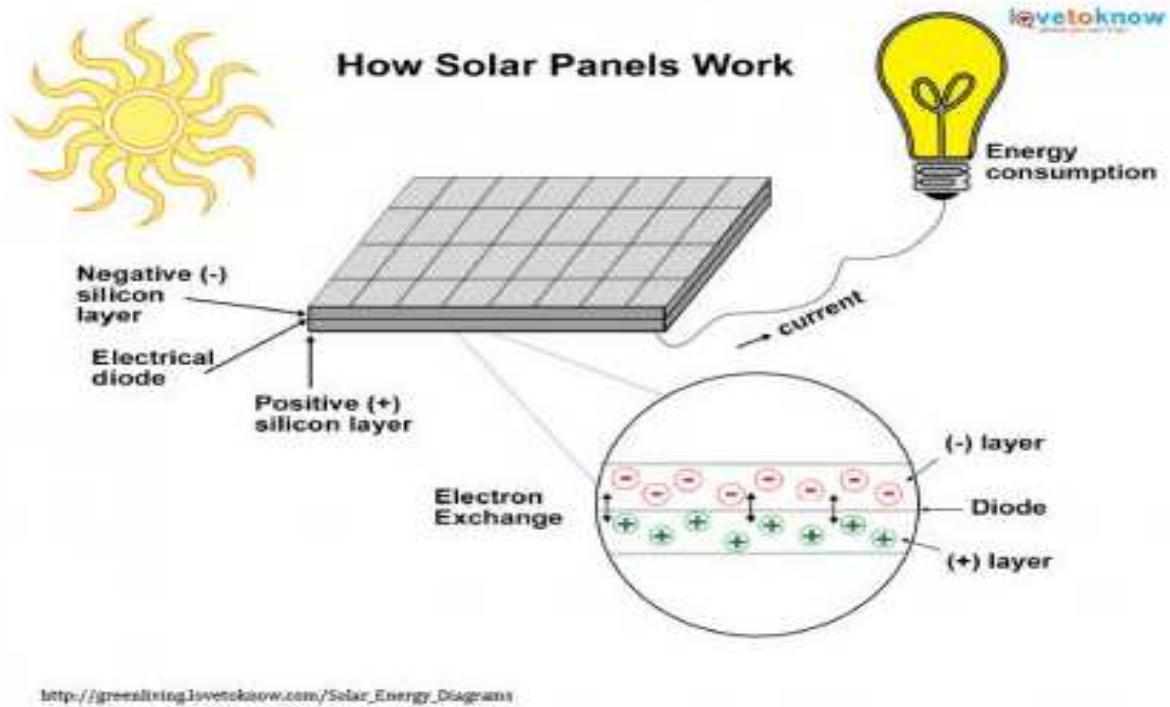


Figure 1: How solar panels work

Source: Warren, C. (2013, July 01). PV BASICS. Retrieved April 23, 2018, from <https://www.shop.eco-navitas.com/blogs/news/pv-basics>

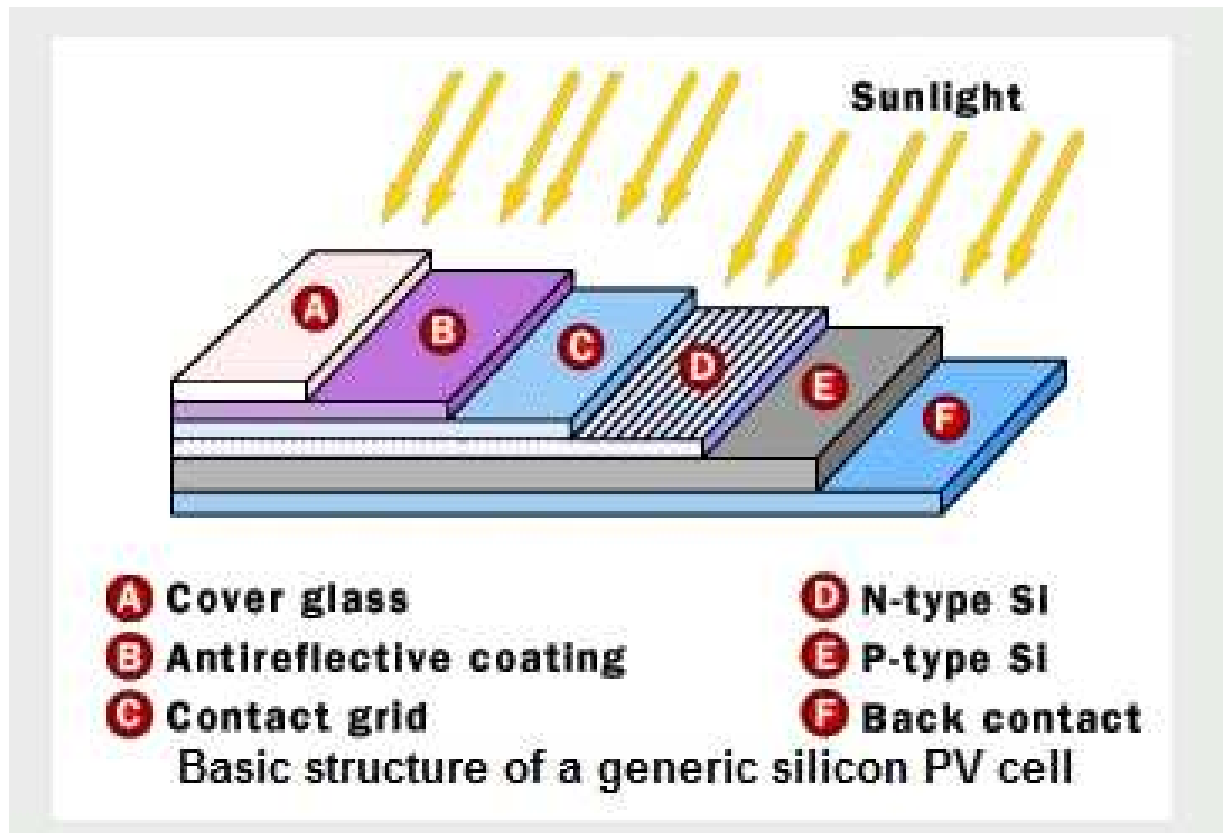


Figure 2: Basic Structure of a generic silicon PV Cell

Source: Contrata, R. (2015, May 30). How Solar Works - Basics of Photovoltaic Solar Power.

Retrieved April 19, 2018, from

http://www.renewableedge.com/how_solar_works_photovoltaic_basics.html

- A) Cover plate or glass- This is to protect the system from damage. This is system is located outside and may experience some harsh weather conditions depending on location. It is typically robust but a thinner material.
- B) Antireflective coating – this is used to keep the photons from reflecting out of the panel. The photons are the energy that is needed to excite the electron inside the cell.

- C) Contact grid – This is used to shorten the distance that the electron has to travel. The contact grid is a metal that is able to keep a steady flow of electron which results in a strong electrical current.
- D) N-type Si – This is a semiconductor doped with donor atoms and with electrons as the majority carriers.
- E) P-type Si - This is a semiconductor doped with acceptor atoms and with holes as the majority carriers.
- F) Back Contact – This is the end of the cell that has to be made of some sort of metal so it can transfer the DC electric current to a battery. (Contrata, 2015)

Understanding the Internal Components, P/N Junction

In *Figure 2* above, it does a great job of showing the six key components that comprise a solar panel; however, there are some parts of the solar cell that are happening at the microscopic level. Two things that are very important to understand inside a solar cell is the P/N junction and the Band Gap. These two factors are what determines how efficient the solar panel may be. The above diagram, *Figure 2*, is lacking the P/N junction. That is because it only displays the parts of the solar panel. So what is the P/N junction? In the below diagram, *Figure 3*, shows where the P/N Junction is located.

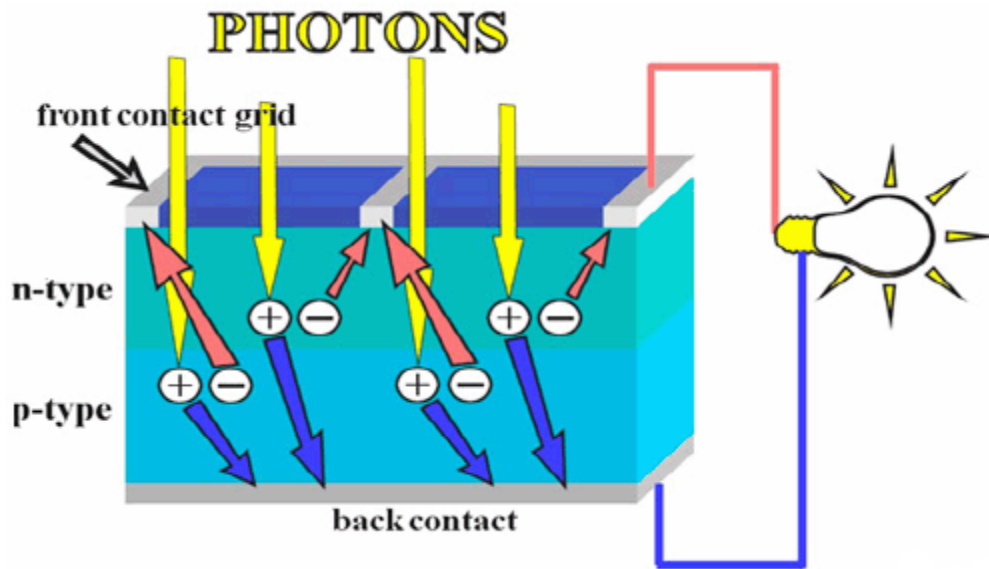


Figure 3: A diagram that is displaying the P/N Junction and which way the electrons and holes travel.

Source: <http://nothingnerdy.wikispaces.com/PHOTOVOLTAIC+CELLS+-+Yvonne>

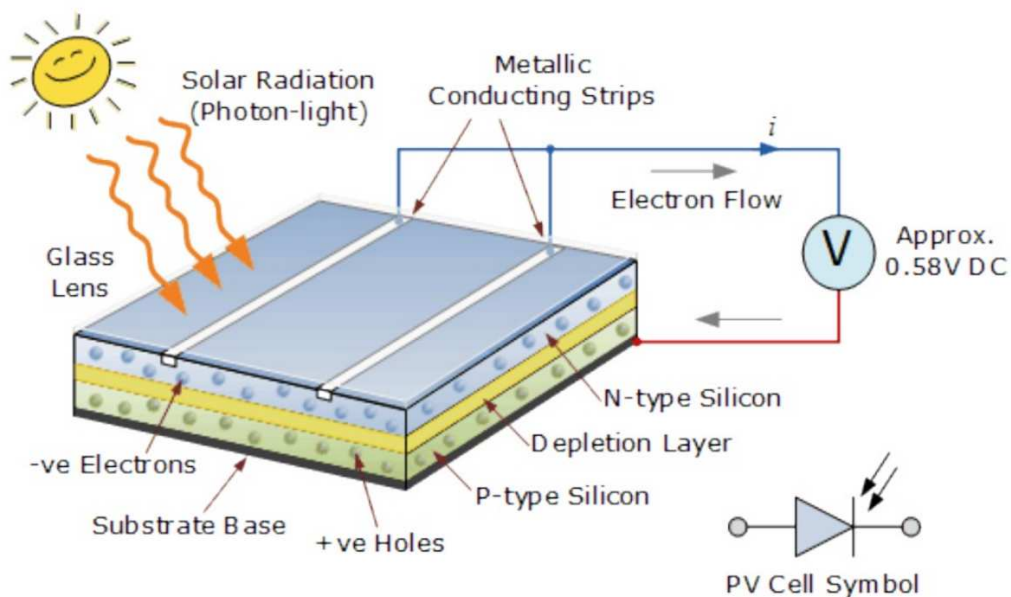


Figure 4: A diagram that displays the photovoltaic process

Source: <https://www.slideshare.net/vasistatiruveedi/solar-cell-47447105>

The P/N junction is also known as the semiconductor diode. This is where the p-type semiconductor material and the n-type semiconductor material are together. In order for there to be a P/N junction of these materials, they have to be doped. They will have specifically modified atoms that are inserted in the semiconductor material. For example, a silicon panel may be negatively doped with a phosphorus atom. This will allow an extra electron in the valence band to be excited and be free to move. Below is an example of what it would like in an n-type semiconductor. (G. G., & J. D. n.d.).

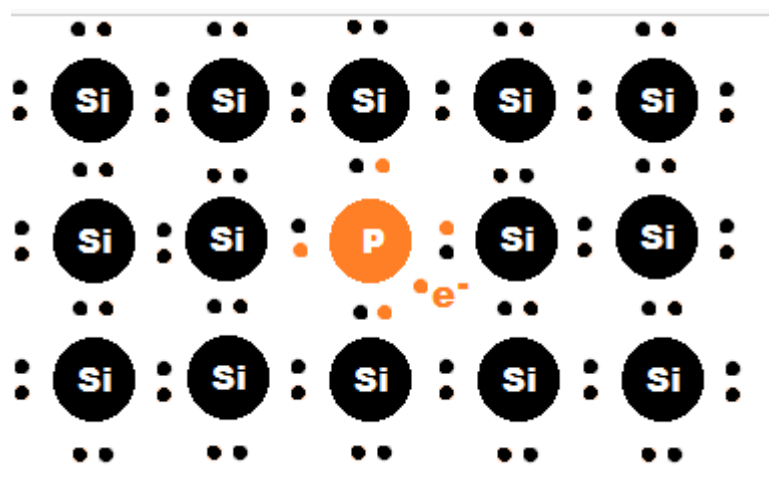


Figure 5: Diagram of a doped n-type semiconductor

Source: G. G., & J. D. (n.d.). Doping - Energy Education. Retrieved April 2, 2018, from

<http://energyeducation.ca/encyclopedia/Doping>

For Silicon to be positively doped, a Boron atom may be inserted. This creates what is called a “hole,” which is a spot in the valence energy shell where an electron should be. This hole is free to move. Below is a diagram that shows an example of this. (G. G., & J. D.n.d.).

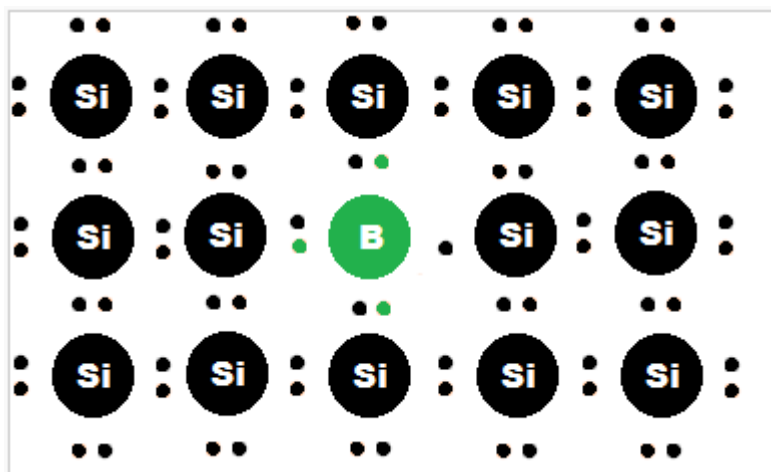


Figure 6: Diagram of a doped p-type semiconductor

Source: G. G., & J. D. (n.d.). Doping - Energy Education. Retrieved April 2, 2018, from

<http://energyeducation.ca/encyclopedia/Doping>

In the electrical diode, the p-type material is that of the anode and the n-type material is that of the cathode. (G. G., & J. D.n.d.).

Band Gap

The reason that solar energy is possible is because of materials that have a band gap. Band gap is the energy differential in an element from its valence energy level to its conduction energy level. For a long time, scientists did not know how to utilize materials that had a band gap. Many scientists thought that materials with bandgaps were useless materials because of the different properties they were able to express. Three of the main types of materials are insulators, conductors, and semiconductors. With a conductor, there is no gap from the conduction band to the valence band. The electrons can flow freely without a needed outside energy source to excite the electron inside the orbital. With an insulator, there is an enormous gap from the conduction band to the valence band. Typically this gap is larger than 3.0eV in current. An electron is not

able to be excited to the conduction band because of the large gap between the conduction band and the valence band, known as the band gap. The semiconductor is a material with a narrow band gap. This means that the conduction band and the valence band are not very far apart. This allows for electrons to jump across from the valence band to the conduction band when they are excited from an outside energy source causing a flow of current. (Chandler, D. L. 2010).

The flow of electrons, that semiconductor materials can possess, is why proper band gap sizes are needed for feasibility. With conductors there is no direct flow. The electrons can roam freely in the material not allowing us to know which state the electron is in. The semiconductor allows for a one way current flow from an electric diode once a photon excites the electron. The insulator has too far of a band gap for an electron to jump across. This means that a semiconductor is the only material that can be used for solar energy because of its narrow gap between the valence and conduction band. (Chandler, D. L. 2010).

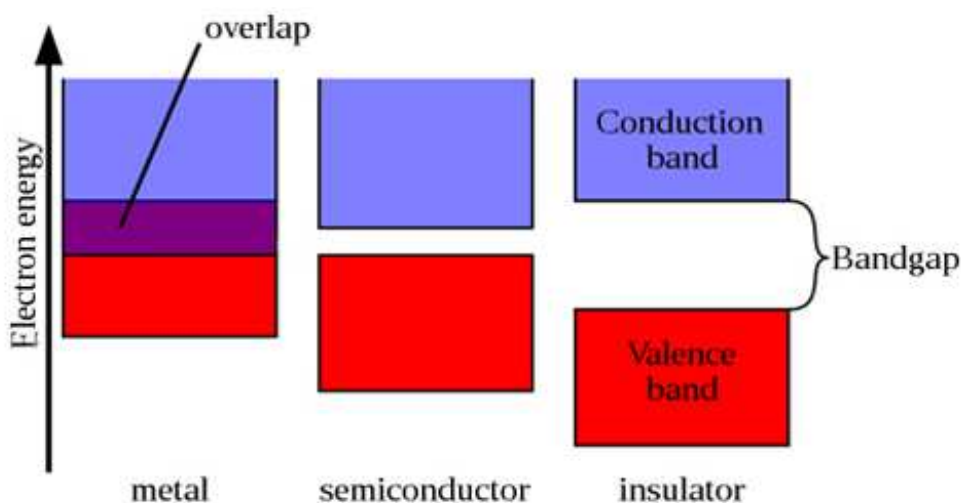


Figure 7: A chart of where a band gap is located in the solar panels semiconductors

Source: http://solarcellcentral.com/junction_page.html

Solar panels have an enormous range in price, from very cheap panels to very expensive panels.

The separating factor that distinguishes expensive solar panels from cheap solar panels is the

manufacturing cost and the materials. According to Solarcellcentral, ““band gap” is the energy difference between the top of the valence (outer electron) band and the bottom of the conduction (free electron flow) band.” (P/N Junction and Band Gaps.n.d.).

In a solar panel, it is important to know that a band gap cannot be zero because there must also be a voltage source, which makes more efficient energy when transmitting. According to many different scientist, solar panels are most efficient when the band gap is in the range of 1.0 to 1.7 eV. As stated earlier, power is equal to the product of current and voltage. This limits the materials available to be used for making solar cells because it is not just about having a semiconductor. A semiconductor with a band gap in the range between 1.0 - 1.7eV is needed for maximum efficiency. The PV system also has to meet those specifications of public retail affordability. The larger the voltage source, the more energy can be used. Because of band gaps, solar cells cannot be 100% efficient, meaning not all of the solar radiation emitted can be harnessed by the sun. Many different materials are used in solar panels for semiconductors and the materials used have a major impact on the price of the solar panel. One of the best materials used is silicon. Silicon has a band gap of 1.11 eV which allows harnessing a good portion of the solar energy available within the radiation spectrum of the sun. (P/N Junction and Band Gaps.n.d.).

2.3 Review of Literature

When calculating the feasibility of solar energy in eastern Kentucky, this study is dependent of several different factors, including: PV efficiency, space, cost of system, and insolation (amount of solar radiation emitted geographically). The solar radiation has probably what many people

think to be the biggest factor in feasibility of solar energy. There are three different type of solar radiation that is emitted which constitute of direct radiation, diffused radiation, and reflected radiation.

Direct radiation is solar radiation that is emitted from the sun directly to the solar panel. Diffused radiation is radiation that may be dispersed to the solar cell from interceptions in the atmosphere. This may be due to clouds or other gas materials. Reflection is the solar energy that is reflected off of the ground. Sometimes there is a high solar radiation reflection that may be seen with snow. There may also be a very low solar radiation reflection from materials such as asphalt. (Watson, 2011). Below is a figure that shows the three different solar radiations.

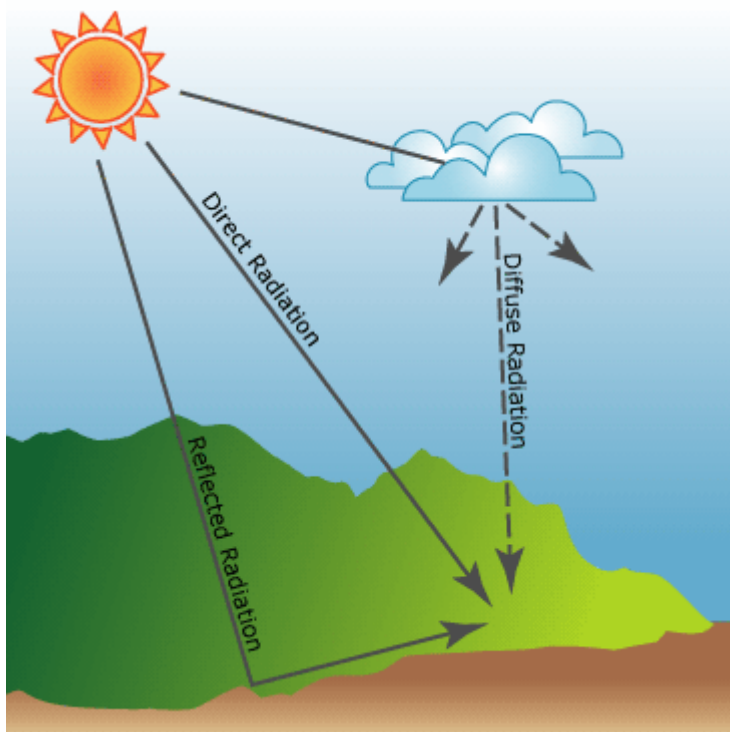


Figure 8: Showing three different interception solar radiation may have as direct, diffuse, or reflected components.

Source: Consulting, F. G. (2012, May 03). Differentiate between the DNI, DHI and GHI? Retrieved April 19, 2018, from <https://firstgreenconsulting.wordpress.com/2012/04/26/differentiate-between-the-dni-dhi-and-ghi/>

Adam Stanley's Research

One of the first people that did effective research on feasibility in eastern Kentucky is Adam Stanley. Stanley graduated from Morehead State University where he did research in photovoltaics with Dr. Sanghyun Lee. Stanley published a paper called *Photovoltaics in Eastern Kentucky: The Feasibility Study Of Abundant Renewable Energy Resources*, at the University of Memphis in the Proceedings of The National Conference.

According to Stanley, a 325-Watt panel array should have the potential to power an average size household, assuming that the average house uses 975 kWh per year. Stanley also completed generated diagrams to show what a 325-Watt panel array potential may have using diagrams for comparison to average daily usage. He also concluded for future plans, an algorithm that may be used to help track the sun in this specific demographic area. By using a two axis tracking system, it may enhance the direct beam solar radiation to the solar panels allowing for maximum energy potential. (Stanley, 2017)

JJ Augenbraun Research

One of the research studies that was conducted, that is similar to this study, is that of JJ Augenbraun, from Sydney Australia at Macquarie University. In JJ Augenbraun's research, the data that is analyzed for feasibility purposes came from data taken from Sydney, Australia. Since this is done in Sydney, Australia, it is no surprise that solar energy is a feasible source of energy. The analysis that Augenbraun completed shows substantial evidence of solar energy

being feasible in that specific location. The data that JJ Augenbraun analyzed would be significantly different than that of data from Kentucky for the purpose of different insolation data. Monetary wise, Australia uses a different currency than the United States, which will make the price different. The methodology on how Augenbraun conducted the research is well developed and used valuable sources. Augenbraun used data from NASA to generate cost and expected energy potential. By using the solar insolation data, he was able to use the equation below. (Augenbraun, 2010)

$$E = i * s * d \quad (1)$$

Where E represents electricity production in kWh, i represents the daily solar insolation in kWh/m² /day, s represents the capacity of the system, and d represents the adjustment for inefficiencies associated with inverting the electricity from DC to AC, temperature, cleanliness of panels, downtime for maintenance, and other sources of inefficiency (National Renewable Energy Laboratory 2010a).

From there, Augenbraun used the widely known solar energy software, SAM, to generate data on the inefficiencies to be able to calculate an electricity production of the system. In SAM, the solar data analysis was completed and a cost data analysis was able to be completed using the amount of electric production needed and the potential electric production generated of the PV system. (Augenbraun, 2010)

RETScreen

There are quite a few different energy management software's that may be a great source for data analysis when calculating the feasibility of solar energy. It is important to know what sources to utilize in order to get the insolation numbers. Due to many different contributing factors, there is a lot of variance in insolation data. Some of the contributing factors, that may cause variance in the data, include: industrial corporation pollution, direct or diffused solar radiation

measurements, and size of data sample. That being known, the source of where the data comes from needs to be reputable and take into consideration the loss of solar radiation for the location. By using RETScreen to generate the insolation data, this allows for more accurate data.

RETScreen uses data from NASA (National Aeronautics and Space Administration), which is a very recognized organization internationally. The data from NASA is collected over many years and several factors are taken into consideration for the loss of energy. An average is determined with several years of daily data collection, allowing for this to be a closer data number.

SAM (System Advisor Model)

In order to determine many of the feasibility questions, data have to be provided and accounted for to receive an accurate analysis. SAM is a software that is able to generate data that helps determine the feasibility of renewable energy. SAM uses the data from NREL (National Renewable Energy Laboratory) and calculates the system costs off of the module and inverter one needs. SAM calculates losses of energy, energy lifetime, incentives by state and federal, shading and snow, electricity rates of what one pays per month and annually. It also is able to generate very detailed graphs in a simulation portion.

Chapter III - Methodology

3.1 First Objective Approach

There will be a strong focus on how the solar system works to convert sunlight into electric power.

Approach: In order to understand how solar energy works to convert sunlight into electric power, research was done by using books, websites, and articles. Research was conducted to determine which materials in the solar panels to research regarding cost. Research on how solar energy is conducted is used to determine which solar panel is the best price for how much power it is able to harness. It is also important to know and understand the components that make a PV system.

3.2 Second Objective Approach

Analysis of Solar Radiation admitted in eastern Kentucky will be collected using an Energy Management Software known as RETScreen and SAM.

In finding if solar energy is even feasible, the first known thing that has to be determined is a collection of solar radiation emitted. Without solar radiation, power may not be able to be harnessed from the sun. Using the RETScreen allows for well generated data to be used for analysis. In this study, an average is used in RETScreen. SAM is another software that is able to generate insolation data collected from the NREL. SAM is used to generate charts that may show comparisons of which PV system would be more feasible for financial reasons, but also efficiency.

3.3 Third Objective Approach

In this research, a cost analysis on solar energy will be conducted to determine if a transition is feasible using similar studies.

Approach: When determining the financial feasibility of solar energy being used in eastern Kentucky, a variety of different research was conducted. In order to understand if solar energy is even a feasible source of energy, a history of solar energy was researched to understand how it was developed. After a thorough understanding of the development of solar energy was researched, a detailed understanding of how solar energy works needed to be understood. The research was composed of many different sources including: web articles, books, journals, websites, and other research papers that involved similar studies from different locations. Once the research is conducted on the history of solar energy, data will be collected using a few different sources. The data that will be used in this study mostly will come from energy management software, RETScreen, and SAM.

The cost data of PV systems are generated inside SAM. By getting several different PV systems costs, a comparison graph is generated by the name of system and the cost. Also another graph is able to be generated by the name of the system and the payback period.

Using the equation that JJ Augenbraun used, which he obtained from NASA to generate cost and expected energy potential, the electricity production was calculated. By using this solar insolation data, it helps enable the use of the equation below. (Augenbraun, 2010)

$$E = i * s * d \tag{1}$$

Where E represents electricity production in kWh, i represents the daily solar insolation in kWh/m² /day, s represents the capacity of the system, and d represents the adjustment for inefficiencies associated with inverting the electricity from DC to AC, temperature, cleanliness of panels, downtime for maintenance, and other sources of inefficiency (National Renewable Energy Laboratory 2010a).

After data is collected of the size of the PV system, a correct cost of the system is able to be generated. A list of the sizes the PV system will be analyzing by cost is inside the software SAM.

The financial data will be used from variety of different solar energy companies for cost analysis. Data are gathered from the companies cost of their systems through the software SAM. After making a table of the different PV systems, graphs are able to be generated comparing the companies. An average size of a PV system in eastern Kentucky is confirmed from speaking with Solar Energy Solutions Company that is based out of Ohio. RETScreen is used to generate the data for the solar radiation along with a graph of the months for a comparison of the potential solar energy from the PV systems in eastern Kentucky. The RETScreen graphs of solar irradiance are able to be compared to the potential electricity production graphs that were generated in SAM. Using an average by month of the solar radiation will give a better result, or closer result, of feasibility for money that the consumer will pay.

In order to know if the transition would be financially feasible, a cost comparison has to be compared to what customers are currently paying for electricity in eastern Kentucky. This data is easily obtainable through the federal government's data on the US Energy Information Administration.

3.4 Fourth Objective Approach

Installation cost research will be collected to help determine if the transition will be feasible to the residential and commercial quantity.

Approach: After understanding how solar energy works, a price analysis will be completed by researching PV cell's cost of installation in comparison to price costumers pay per watt of electricity from power companies. Some calculations will be performed from using the amount of solar radiation that is emitted from the software RETScreen and/or SAM, which bases its data from NASA and NREL. These calculations were used to get a price per watt a consumer would pay if they were to install a 3,000 watt solar system into their home.

Some of the estimation costs were received from different companies. Many of the companies require one person to buy the PV system and they require one person to pay for installation costs on that PV system.

The cost of installation of PV systems is also generated in SAM. There is a list of costs for installation associated with the specific PV systems.

Chapter IV - Findings

4.1 Results and Data

Electric Power Costs

Below is a chart that shows the average household income price per kilowatt per hour (kWh) that customers pay from Kentucky's eastern power companies. Many residents in eastern Kentucky pay for their electric through Kentucky Utilities (KU) or Louisville Gas and Electric. The average price per 1 kWh of power the consumer pays is nearly 10 cents through KU Corporation. This data was taken directly from the US Energy Information Administration government website. (U.S. Energy Information Administration - EIA - Independent Statistics and Analysis, 2017).

2016 Utility Bundled Retail Sales- Residential

(Data from forms EIA-861- schedules 4A & 4D and EIA-861S)

Entity	State	Ownership	Customers (Count)	Sales (Megawatthours)	Revenues (Thousands Dollars)	Average Price (cents/kWh)
Kentucky Power Co	KY	Investor Owned	137,013	2,128,530	254,059.9	11.94
Kentucky Utilities Co	KY	Investor Owned	426,225	6,047,873	596,749.9	9.87
Licking Valley Rural E C C	KY	Cooperative	16,231	190,959	21,100.0	11.05
Louisville Gas & Electric Co	KY	Investor Owned	356,424	4,215,244	438,833.4	10.41

Figure 9: Utility bundled sales for residential prices

Source: U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (2017, November). Retrieved December 09, 2017, from https://www.eia.gov/electricity/sales_revenue_price/

In order to understand what this means in terms of time and money spent by power companies, an average monthly kilowatt hour had to be determined. This is where it may vary because depending on which state the electric consumption may range from about 900-1200 kWh per month. In the state of Kentucky, according to the US Energy Information

Administration government's website, the average residential home spent \$117.65 per month in the year of 2016 on their electric bill.

In order to understand how much solar energy that is needed to be produced in Kentucky, a software called RETScreen Expert was used for the town Pikeville, Kentucky. That happened to be the closest town to Morehead, Kentucky where the weather is likely to be the most similar. This software is a clean energy management software that can produce several different sets of data. RETScreen has the ability to generate the average air temperature, humidity, precipitation, daily solar radiation, atmospheric pressure, wind speed, and much more for several North American cities. The application that is the most interesting is the RETScreen, which has the ability to generate data on the daily solar radiation.

Once the data was analyzed in RETScreen, a graph was plotted that shows daily solar consumption vs. month vs. average air temperature. This data is crucial because a comparison between months of daily solar radiation consumption vs. price of solar cells can be conducted. The below diagrams show the data produced in RETScreen. It is interesting to see that solar insolation is directly proportional to that of temperature. As temperature increases, so does solar insolation.

Due to the fact that solar insolation can be reflected or diffused, this actually reduces the amount of solar radiation able to be harnessed in winter months. As one can see in the months of November, December, January, and February, the solar irradiance is the lowest while humidity is the highest. This may be associated with the diffused solar radiation. The gas particles in the atmosphere are intercepting the solar radiation and not allowing for a direct beam to the solar panels.

The other part that the data includes is temperature. This is what shows the reason for low reflection radiation. The temperature in the months of December and January happen to hover slightly above freezing, forcing snow to melt. If snow was able to stick during those months, there could potentially be an increase in solar radiation from the reflection radiation. *Figure 10* shows the data that were generated of data from NASA. *Figure 11* is a graph that shows the proportion to that of temperature.

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m ² /d	kPa	m/s	°C	°C-d	°C-d
January	0.2	74.1%	100.59	2.01	96.7	3.8	-0.1	552	0
February	2.1	73.1%	77.85	2.62	96.6	3.8	2.0	445	0
March	6.3	70.1%	106.74	3.67	96.5	3.8	6.5	363	0
April	12.0	64.0%	112.15	4.68	96.4	3.5	12.2	180	60
May	17.2	64.5%	118.33	5.07	96.5	2.9	17.4	25	223
June	21.4	66.4%	127.59	5.81	96.5	2.7	21.7	0	342
July	23.1	69.5%	125.94	5.54	96.6	2.5	23.3	0	406
August	22.3	70.0%	91.50	5.12	96.7	2.4	22.4	0	381
September	18.8	67.8%	86.79	4.40	96.7	2.8	18.8	0	264
October	13.1	65.7%	70.38	3.43	96.8	3.1	12.9	152	96
November	7.4	71.3%	90.96	2.30	96.7	3.6	7.0	318	0
December	1.8	73.8%	93.43	1.78	96.8	3.7	1.4	502	0
Annual	12.2	69.2%	1,202.25	3.87	96.6	3.2	12.2	2,537	1,773
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Figure 10: Energy analysis of Pikeville, Kentucky generated in RETScreen

Source: Analysis was created in RETScreen

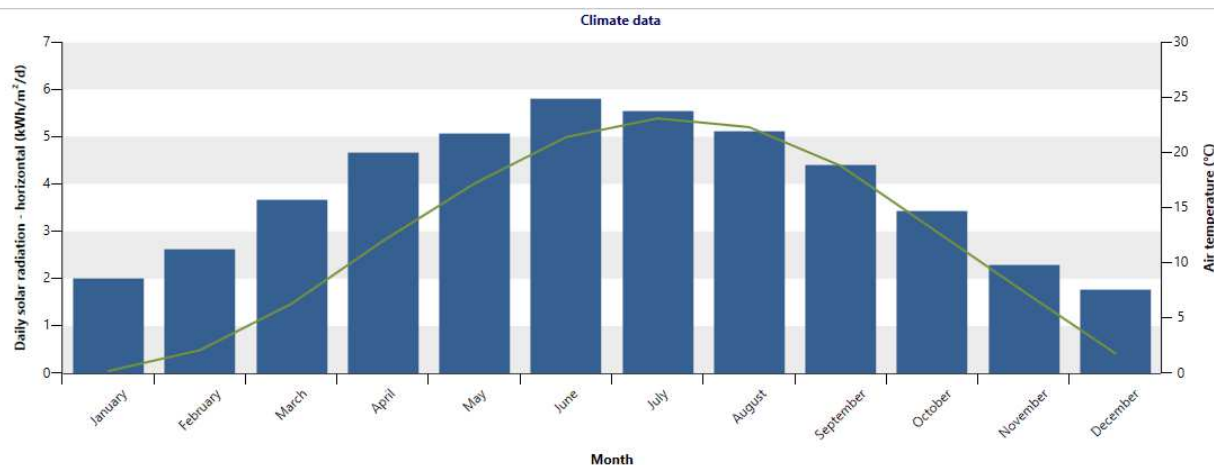


Figure 11: Graph of Solar Energy Analysis of Pikeville, Kentucky generated in RETScreen

Source: Graph was created in RETScreen

The above graph shows that solar radiation increases in the summer months and its peak month is in June. The month of December has the least amount of solar radiation that is emitted.

Solar Panel Prices

After using the software RETScreen, the daily solar radiation that is emitted in a horizontal position was produced. In the highest month of June, 5.81 kWh/m²/d was emitted on a flat horizontal surface. In the lowest month of December, 1.78 kWh/m²/d was emitted on a horizontal surface. The average annual solar radiation emitted monthly is around 3.87 kWh/m²/d. If the unit of watt is used it is 1,780 Watt hours per one square meter per day that is being emitted in the lowest months. The most expensive solar panels capture 25% of the solar radiation, which means that the most energy to be harnessed in the month of December is 445 Watt hours per square meter per day.

Math calculations for determining how many one meter square panels would be necessary for an average home to use in the month of December on a horizontal surface:

Average home kWh used = 1,200kWh = 1,200,000 Wh Per Month

= 30,000 to 40,000 Wh per day

Solar radiation in December = 1.78 kw/m²/d

= 1,780 W/m²/d

Useable solar radiation = 0.25 * 1,780 Wh/m²/d

= 445 Wh/m²/d

(Average Home kWh Used) / (Maximum efficiency solar Panel)

(40,000 watt/day) / [(445 Watts/m²/day) = 89.88 m²

This means that with a 0.25 solar panel efficiency that three 1,800 Watt PV System would be needed to fully power the average house demands

30days * 0.25 * 1800 Watt PV System = 13,500 Wh/month

3 systems * 13,500Wh = 40,500Wh/month

Math calculations for determining how many one meter square panels would be necessary for an average home to use in the month of June on a horizontal surface:

Average home kWh used = 1,200kWh = 1,200,000 wh Per Month

= 30,000 to 40,000 Watt per day

Solar radiation in December = 5.81 kw/m²/d = 5,810 W/m²/d

Useable solar radiation = 0.25 * 5,810 W/m²/d = 1,452.5 W/m²/d

(Average Home kWh Used) / (Maximum efficiency solar Panel)

$$(40,000 \text{ Watt/day}) / (1,452 \text{ Watt/m}^2/\text{d}) = 27.54 \text{ m}^2$$

If it takes about ninety square meters of panels in the month of December, the lowest solar radiation to generate 1200 kWh for this month is feasible for space on a residential quantity. According to the renewable energy world, the average rooftop in the United States consists of 2,700 square feet which converts to 250.8 m². This constitutes the materials used for band gap between 1.0eV to 1.7eV to get the maximum efficiency of solar energy harnessed. (Anthony, 2011).

This means that if you used your very best solar panels, which are extremely expensive, it would be enough to power an average home during the month of December with just the solar panels on a horizontal surface. In order to know if solar panels are feasible in eastern Kentucky, a few price analysis had to be completed on how much it would cost to buy a solar panel and install them for the lowest month average payment.

One of the best solar panels that was found on The Inverter Store's website was the 3000 Watt solar with 12,000 Watt pure sine power inverter charger 48VDC 120/240VAC off grid kit. This can be bought for \$10,968.08 directly from The Inverter Store.

Features:

- Easy to connect and use
- Works with medium size devices up to 10,000 watts/ 83 AC amps 120VAC or 41.5 amps at 240 VAC
- Ideal for large appliances, tools, pumps, compressors, AC units, freezer, refrigerators, heaters and electronics
- Ideal for large homes or businesses that need 120 and 240 VAC power

The solar panel array will recharge a 50% depleted 600 amp battery bank in 5 hours with full sunlight.



Photo: 3000 WATT SOLAR WITH 12,000 WATT PURE SINE POWER INVERTER CHARGER 48VDC 120/240VAC OFF GRID KIT

Source: <https://theinverterstore.com/product/3000-watt-solar-with-12000-watt-pure-sine-power-inverter-charger-48v-off-grid-kit/>

One of the better PV systems to purchase is a kit that includes the full assembly to install. This PV system is usually cheaper for the quality because the customer is buying the full package all at once. This allows the customer to be able to pay a contractor to install the kit if they choose not to install it. If the customer were to install it, help of a licensed electrician for the permit would be needed to ensure it was assembled to electrical safety standards.

Some states require a licensed electrician for any electrical work, while other states can get away with buying a handyman license from the local courthouse. If one is to obtain a

handyman license, they would still need a licensed electrician to inspect and approve that it has been done to industrial safety standards.

When hiring an outside contractor, according to *go green solar*, the resident will pay about one dollar per watt in installation. That means that if a 3,000 watt system is being installed, the cost will be approximately 3,000 dollars.

Amount of solar potential on this system

$$3,000 \text{ watts} * .25 = 750 \text{ watts is useable daily}$$

$$750 \text{ watt} * 8 \text{ hr} = 6,000 \text{ watt hours}$$

$$6,000 \text{ wh} * 30 \text{ day} = 180,000 \text{ watt hours}$$

$$= 180 \text{ kWh produced per month}$$

This means that on the average month of solar radiation this system can generate enough electricity to power nearly twenty percent of a house hold demands. The average household uses about 900-1200kwh per month

$$10,968.08 + 3,000 = 13,968.08$$

Louisville gas and electric average cost per kilowatt is approximately 10.41 cents as shown in *Figure 3*. This is what is being broken down, the cost of how much per kilowatt one will pay for converting to solar energy.

This system did not have a capacity of what solar radiation emitted, which was needed, to operate and generate the watt hours. The assumption of minimum solar radiation is needed for the maximum capacity of the PV system and 25% efficiency was assumed.

Table 1: Cost comparisons in cents of solar vs LG&E utilities.

Average Life Span Years	LG&E Average Price (cents/kWh)	Average Price (cents/kWh) Solar Panel over Life Span
25	10.41	25.86

Average Month Solar Panel lifespan Price (cents/kWh)

$$\begin{aligned}
 &25 \text{ years} * 12 \text{ months} * 180 \text{ kilowatts hours/month} \\
 &= 54,000 \text{ kilowatts} \\
 &= \$13,968.08 / 54,000 \text{ kilowatt hour} \\
 &= 25.86 \text{ cents/kWh}
 \end{aligned}$$

According to the company Solar Energy Solutions, the average house in eastern Kentucky would probably need a power system that can generate 1,200 kWh of electricity monthly. The PV system that they generally recommend to customers in eastern Kentucky is 24 panels of 290 watts, which is a 6,960 watt PV system. Solar Energy Solutions does not manufacture their solar panels, but they do install the PV systems. They also require a purchase of solar panels through their company and they buy the products directly from SEnergy or Canadian Solar.

By using the equation from the National Renewable Energy Laboratory. An estimation of size of the PV system was able to be generated.

$$\begin{aligned}
 \text{Electricity Production in (kWh)} &= \text{Solar Insolation Number} * (365 \text{ days}) * (\text{Capacity of System}) * \\
 & (5.5 \text{ hours} * \text{Percent of inefficiencies} * \text{Size of System})
 \end{aligned}$$

$$1,200 \text{ kWh} = (3.8 \text{ kWh/m}^2/\text{d}) * (30 \text{ days}) * (0.15) * (5.5 \text{ hours} * 0.8 * X)$$

X = 15.95kW Array

Using the average insolation number that was generated in RETScreen and estimated size of a 15.95 kW DC PV System would be needed to power an average home of 1,200kWh monthly. Because of the cost of the system, the sizing systems that were considered were in the range of 4 to 6 kW DC arrays. Even though this will not fully power the home it still may make the electric bill cheaper.

Upon looking through hundreds of different PV systems through SAM software, several of the systems were able to be eliminated for size. SunPower system seemed to be the best system. There were hundreds of systems right away that did not meet the capacity requirement to be a feasible option. Below is a table of the feasible systems that were considered for residential use in eastern Kentucky. This data was taking from SAM software.

Table 2: Comparison of PV Systems generated in SAM that are feasible with solar data from Lexington, Kentucky.

Company Name	Product Name	System Total Cost in dollars	System Size DC (kW Array)	Pay Back Period in years	Electric bill with system in dollars	Electric bill without system in dollars
SunPower	SPR-X21-345	12,136	4.139	13.7	296	973
SunPower	SPR-X21-335-BLK	13,758	4.693	15.1	248	973
Trina Solar	TSM-295PA14A.08	17,299	5.901	17.3	152	973
Topsun	TS-S420TA1	17,241	5.881	17.5	156	973
Shenzhen Topray Solar	TPS105S-300W(72)	12,340	4.209	14.1	301	973
Schuco USA	MPE 360 AL 01	14,749	5.031	18.2	295	973
REC Solar	REC310PE 72 Q3	12,734	4.343	11.5	163	973
SOLON	SOLON BLACK XT 295	12,137	4.140	14.0	307	973

Canadian Solar	CS6X-350-FG	14,368	4.901	15.5	229	973
1Soltech	1STH-350-WH	14,349	4.894	16.0	247	973

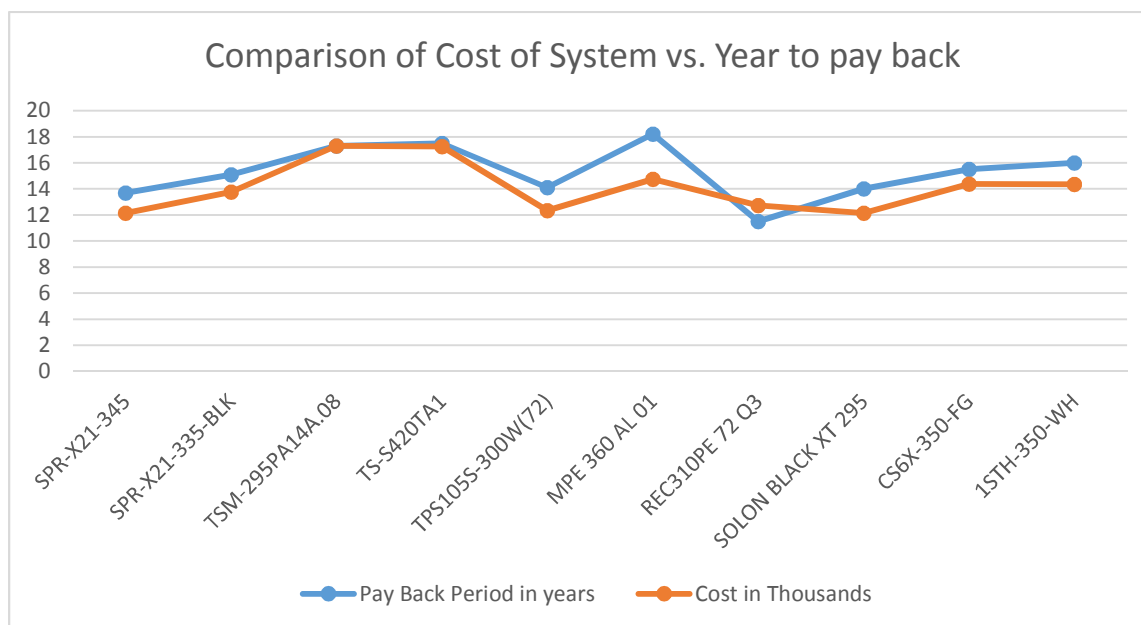


Figure 12: Comparison of Cost of Systems vs. years to pay back

Source: Created in excel from SAM data

The best PV system that was found was SunPower SPR-X21-335-BLK, which is able to generate enough power for an average house in eastern Kentucky. More data was provided for this system, through SAM, allowing stronger evidence of why this would be a feasible option. The capacity factor of this system is 15.4%, which is extremely important for sizing the correct system. On average for most of the systems analyzed was about 15%. This system has a 3.8kW AC total capacity, which is feasible because of the average solar radiation emittance of 3.87 kWh/m²/d. The DC total capacity of this system is 3.92 kW.

This PV system is a 335 watt DC power panels with module area of 1.631m². The material compromised the semiconductor in Mono-c-Si. This PV system generates a very high

nominal efficiency of 20.5521%. This is very good because of low solar irradiance that Kentucky receives some of the months.

Table 3: Summary of the SPR-X21-335-BLK PV System fully simulated in SAM

Metric	Value
Annual energy (year 1)	6,349 kWh
Capacity factor (year 1)	15.4%
Energy yield (year 1)	1,353 kWh/kW
Performance ratio (year 1)	0.82
Levelized COE (nominal)	9.80 ¢/kWh
Levelized COE (real)	7.75 ¢/kWh
Electricity bill without system (year 1)	\$973
Electricity bill with system (year 1)	\$250
Net savings with system (year 1)	\$723
Net present value	\$2,897
Payback period	15.1 years
Discounted payback period	NaN
Net capital cost	\$13,758
Equity	\$0
Debt	\$13,758

Source: Created in SAM software

As one can see in the above table, it would not take long to pay off the \$13,758 debt. The annual electricity savings of \$723 is occurring after the first year. The payback period of this system is expected to be 15.1 years. Many of these systems are very robust and can last for much longer than the 25 year guarantee.

In order to show a better visual understanding of what this system would cost, the table below is broken down. There is a direct correlation in this table with cost in electric bill and demand peak in kW/month that this PV system may display.

Table 4: A comparison to peak demand in kW/month and cost of electric

	Demand peak with system (kW/mo)	Electricity bill with system (\$/mo)
Jan	0.879051	23.8746
Feb	0.857659	20.6125
Mar	0.889821	16.68
Apr	1.1931	16.68
May	1.38801	16.68
Jun	1.77159	16.68
Jul	1.87966	20.2986
Aug	1.94032	30.7122
Sep	1.67033	27.9698
Oct	1.43306	21.6774
Nov	0.807116	20.6722
Dec	0.899462	17.3575

Source: Created by SAM software

As you can see in the graph below, there is an increase in the monthly bill without the system. The increase is an inflation rate that system advisory program calculated into the next 25 years. The appendix shows the data numbers that were calculated into this graph.

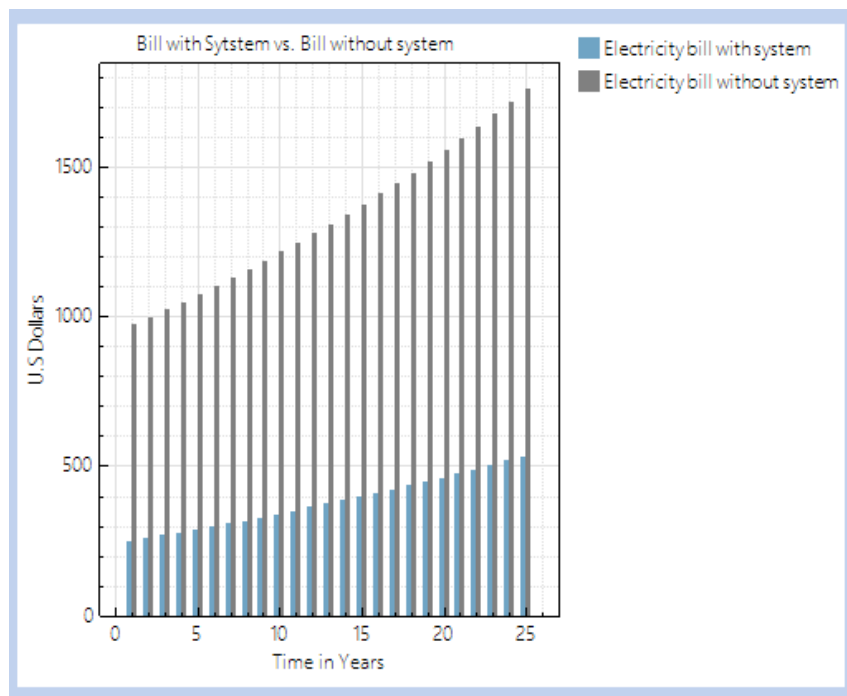


Figure 13: Graph comparison of the SPR-X21-335-BLK with vs without the system

Source: Created by SAM Software

A better visual is shown above in the graph that was generated in the software SAM. With this PV system, in 15.1 years the cost can be paid off from the savings money that has accumulated from the purchase of this system. In theory, this system should be very cheap after 15 years. The graphs show that the annual electric bill after 15 years will be under 500 dollars as compared to 1,400 dollars from the electric company without calculating inflation.

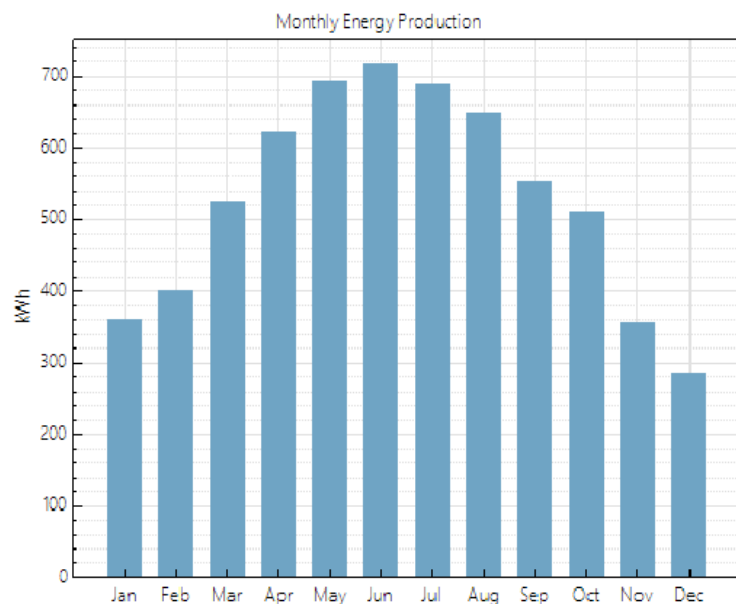


Figure 14: Graph showing the estimated energy production of the SPR-X21-335-BLK 335watt panel array

Source: Created by SAM Software

This graph shows the estimated production of kWh that may be produced using this PV system. This is on a 20 degree fix angle. This data is very similar to the trend of what the horizontal irradiance is monthly, which was expected.

Chapter V - Conclusion

5.1 Summary

Solar Energy is a great source of clean renewable energy. The problem that is associated with solar energy is the efficiency of panels. There are specific locations that lack enough solar radiation. In this particular demographic area, solar panel efficiency, capacity of system, and cost are the determining factors in feasibility. After the thorough research, it would take an estimation of 15.1 years to get the solar PV system paid off from monthly savings that are generated from the system. This does mean that solar energy is a feasible option in eastern Kentucky. This is due to the minimum of solar radiation in kWh/m²/d, the 15.4% capacity factor of the system, and the 20% efficiency of the Sunpower PV 335 watt array panel PV System. Other demographic states are able to pay off the system much faster from savings.

From research on solar websites, using a 3,000 watt solar system in eastern Kentucky would cost about 25.86 cents per watt on average over 25 years. If one is to use LG&E utilities, one will pay 10.41 cents per watt. With the power company's prices per watt, inflation was not taken into consideration. The price of utilities from power companies will increase in cents per watt throughout the years. The rate of solar is a flat 25.86 cents per watt. It is important to know that solar panels may last much longer than the estimated twenty-five year life span. The longer it lasts, the cheaper it ultimately is on the consumer. Even if the efficiency decreases, it will still generate electric.

From the research on SAM, a 96 cell of 335 watt panel mono-c-Si PV System is the most efficient system. This is the system that would have a 15.1 year debt to pay off. This system is estimated to cost 13,758 dollars and that includes installation. This system is called the SPR-X21-335-BLK, which is from the company Sun Power. In the data, the loss of energy was taken

into account along with a 0.5 system degradation being calculated into the years. The comparison price of energy to the power companies in SAM did include an inflation rate.

In this research, there were things that were not taken into consideration. Something that may help modify the prices with possible price reduction is an analysis done for each month. With SAM, a tracking system to follow the sun was not used. A fixed 20 degree tilt south was used. Using a tracking system to follow the sun may help to increase amount of useable energy as stated in Adam Stanley's research.

The last thing to consider might be using a less expensive solar panel for short term gain. This would cost less, but the ability to convert solar radiation into useable electric power would be less. The material used would be less expensive meaning the band gap of the semiconductor may not fall into the most efficient range of 1.0 to 1.7 eV. This could still be majorly beneficial and would in theory take less time in years to pay the debt.

5.2 Recommendations

After looking at hundreds of different PV systems, there are several different compatible systems that are feasible for eastern Kentucky. The one that is recommend is the, SPR-X21-335-BLK, 96 cells of 335watt panel mono-c-Si PV System. This is recommended because of the size capacity of the system, its excellent efficiency, and the price. It has a cost of 7.75cents per kilowatt hour. This would be compared to the price the consumer pays which is 10.41 cents per kilowatt hour through LG&E. After speaking with companies that are in the area, it is pretty much essential to have a minimum of a 290 watt 24 array of panels for an average house. This SunPower system has the potential to pay itself off in 15.1 years assuming that solar radiation emitted stays the same.

One of the factors that may increase the amount of potential solar energy is an axis tracking system. The data for this research was from a fixed horizontal surface. There have been several experiments done on one-way and two-way axis tracking to maximize solar radiation input to the panels. Using tracking collectors doubles the amount of solar radiation absorbed directly by a panel. This is another option to add to the solar panel system which may increase the solar radiation obtainable to absorb.

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.7	3.7	4.8	6.3	7.3	7.8	7.6	7.1	5.9	4.7	2.9	2.3	5.3
	Min/Max	2.1/3.5	2.9/4.7	3.8/6.1	4.6/8.2	5.6/8.7	6.8/10.2	5.9/8.4	6.4/8.3	5.1/7.2	3.4/6.4	2.0/3.9	1.9/3.0	4.9/6.0
Latitude -15	Average	3.3	4.2	5.3	6.6	7.3	7.8	7.6	7.4	6.4	5.4	3.5	2.8	5.6
	Min/Max	2.4/4.4	3.2/5.4	4.1/6.7	4.8/8.6	5.6/8.8	6.8/10.1	5.8/8.5	6.6/8.6	5.4/7.8	3.8/7.3	2.3/4.7	2.2/3.8	5.2/6.4
Latitude	Average	3.5	4.4	5.4	6.5	7.1	7.5	7.3	7.2	6.4	5.6	3.7	3.1	5.7
	Min/Max	2.5/4.8	3.3/5.8	4.1/6.8	4.7/8.6	5.4/8.5	6.5/9.7	5.6/8.1	6.4/8.5	5.4/7.9	4.0/7.7	2.4/5.1	2.4/4.2	5.2/6.4
Latitude +15	Average	3.7	4.5	5.3	6.2	6.7	7.0	6.9	6.9	6.2	5.6	3.8	3.2	5.5
	Min/Max	2.6/5.1	3.3/5.9	4.0/6.7	4.5/8.3	5.0/8.0	6.0/9.1	5.2/7.6	6.1/8.1	5.2/7.8	3.9/7.8	2.4/5.3	2.4/4.4	5.1/6.3

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	3.7	4.5	5.4	6.6	7.4	8.0	7.7	7.4	6.4	5.7	3.9	3.2	5.8
	Min/Max	2.6/5.1	3.4/5.9	4.1/6.8	4.8/8.7	5.7/8.9	6.9/10.4	5.9/8.6	6.6/8.7	5.4/7.9	4.0/7.8	2.4/5.3	2.5/4.5	5.4/6.6

Figure 15: 1 Axis and 2 Axis tracking solar radiation collector of Lexington KY data from the NREL

Source: National Renewable Energy Laboratory

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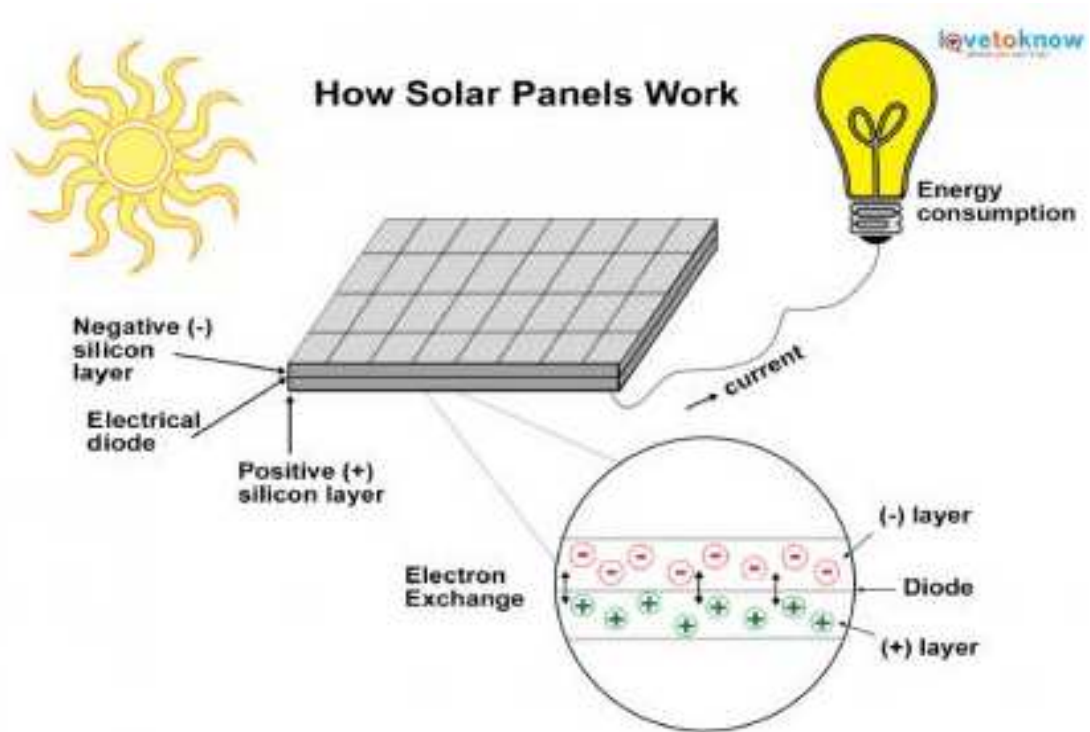
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Appendixes

Figure 1: How solar panels work



http://greenliving.love2oknow.com/Solar_Energy_Diagram/

Figure 2: Basic Structure of a generic silicon PV Cell

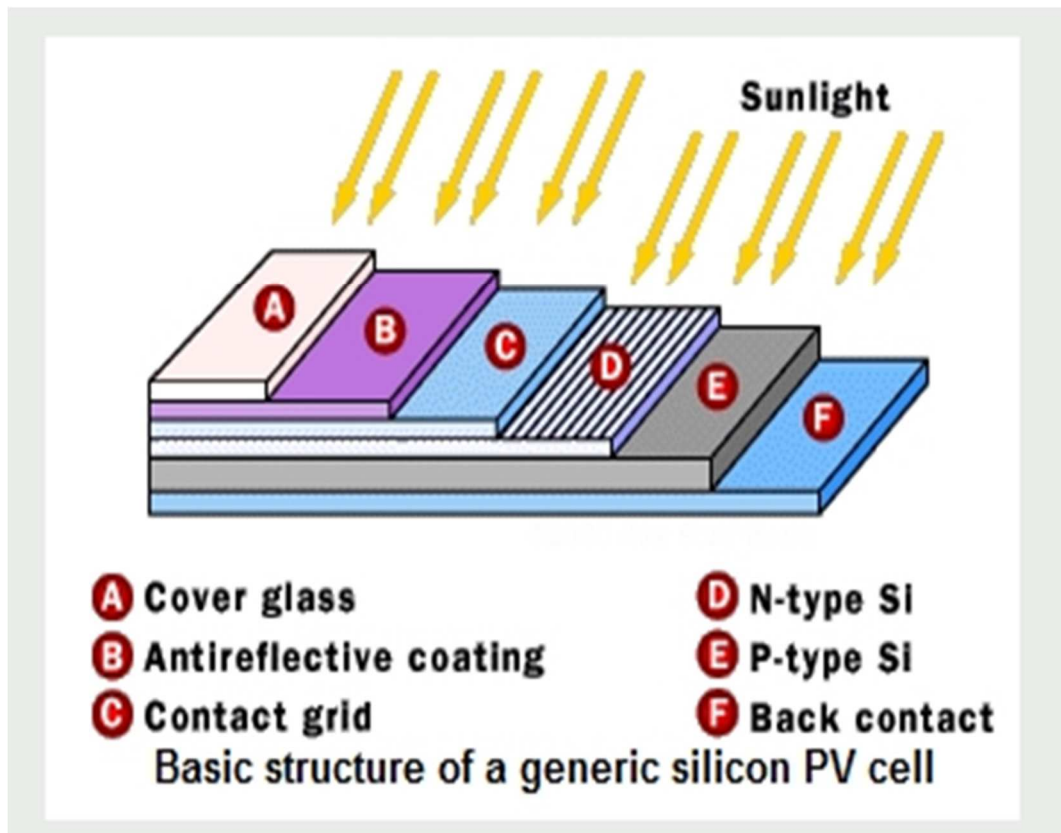


Figure 3: A diagram that is displaying the P/N Junction and which way the electrons and holes travel.

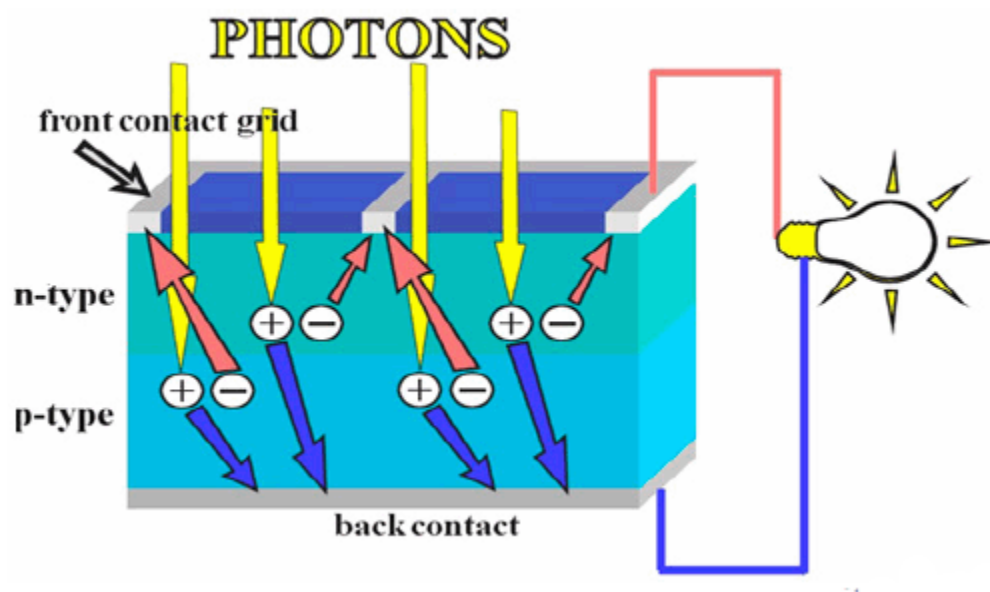


Figure 4: A diagram that is displaying the photovoltaic effect

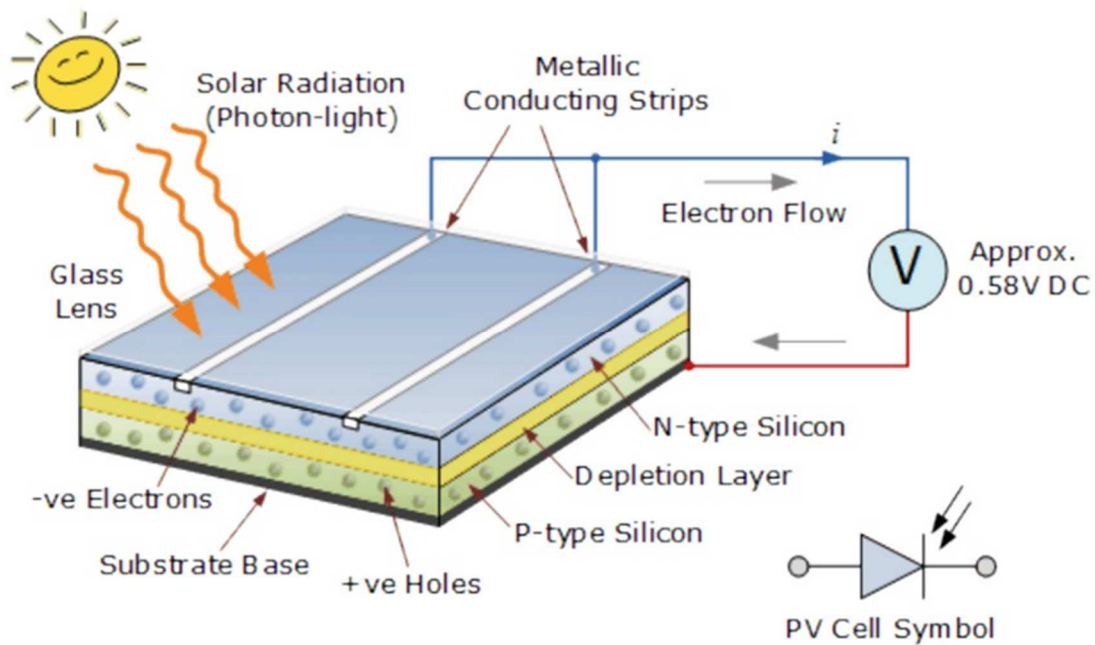


Figure 5: Diagram of a doped n type semiconductor

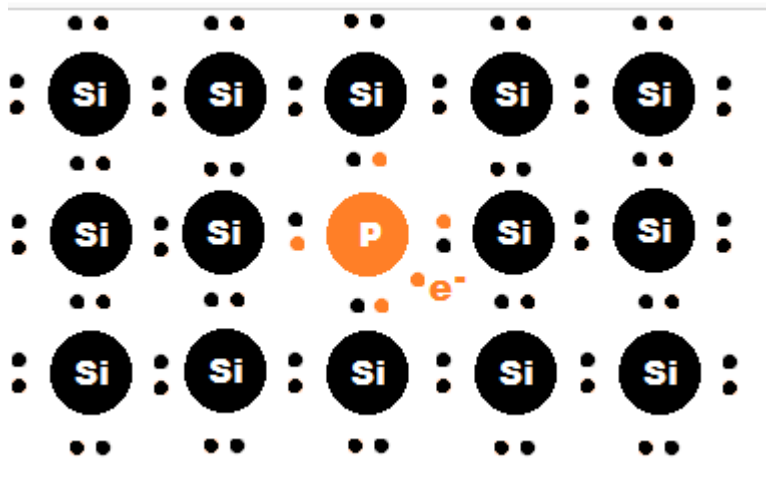


Figure 6: Diagram of a doped p type semiconductor

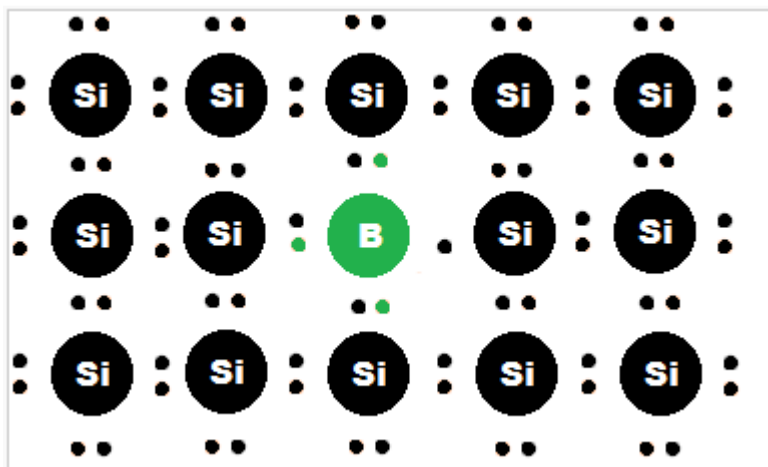


Figure 7: A chart of where a band gap is located in the solar panels semiconductors

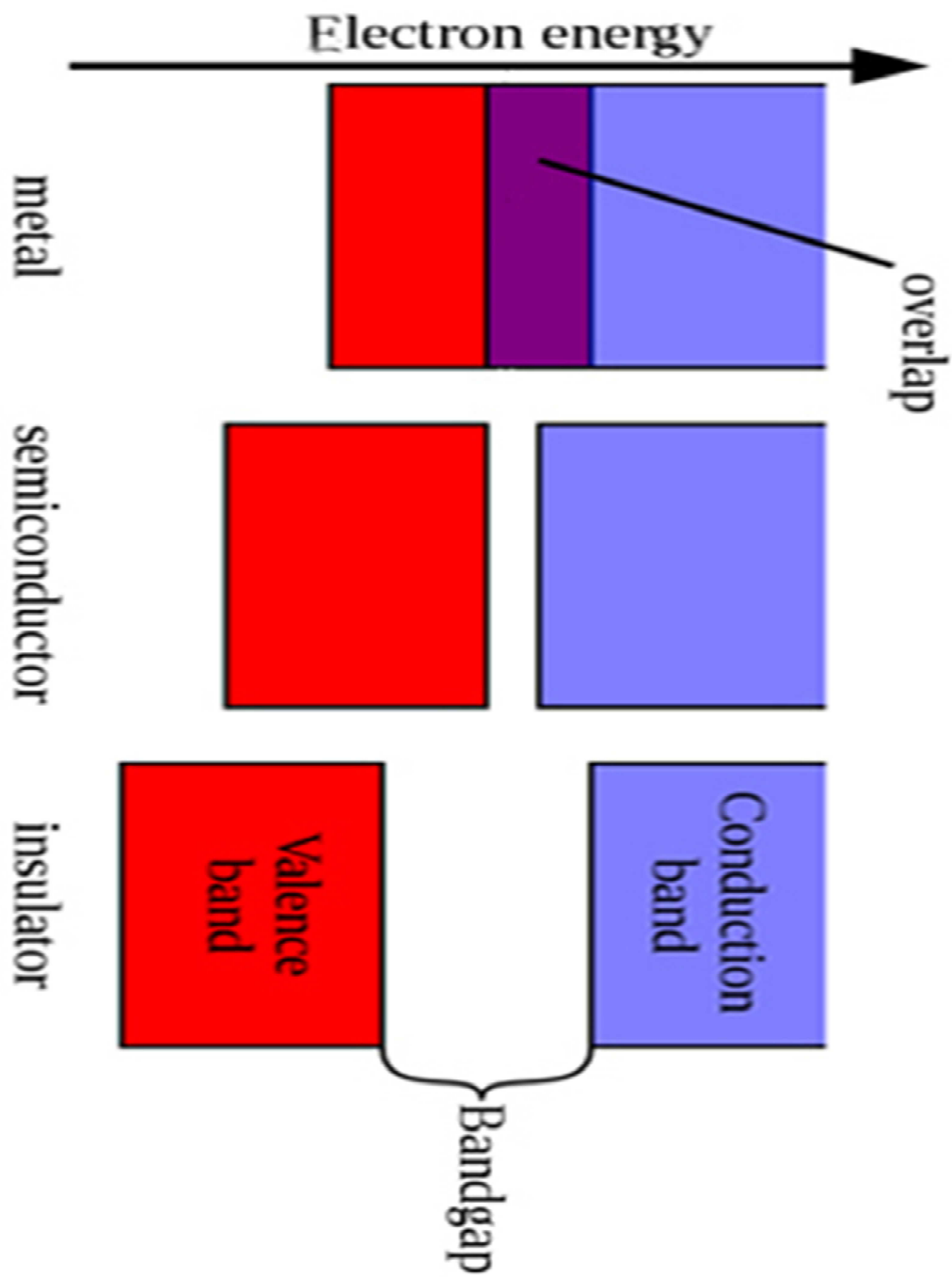


Figure 8: Showing three different interception solar radiation may have as direct, diffuse, or reflected components.

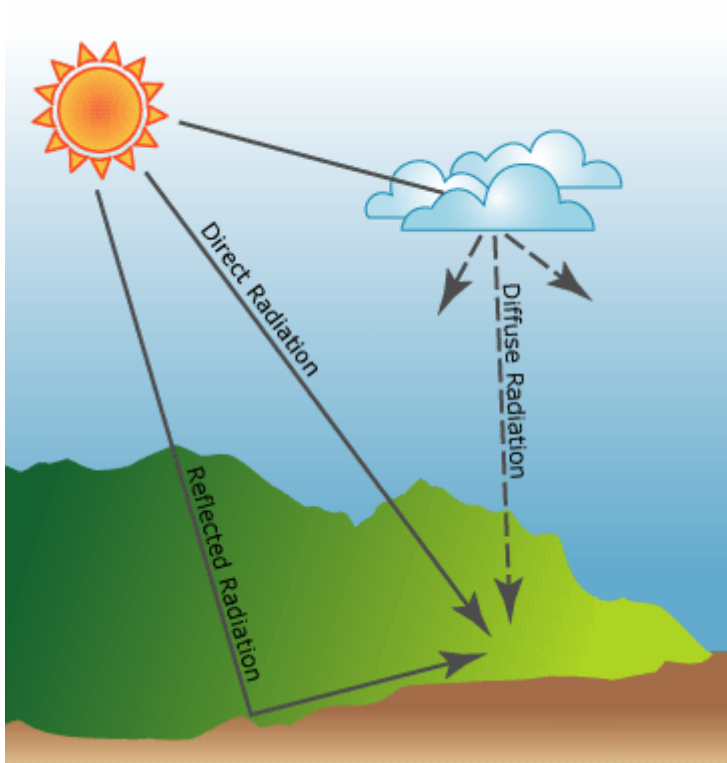


Figure 9: Utility bundled Sales for residential prices

2015 Utility Bundled Retail Sales - Residential

Colton Energy Services - Middle Atlantic Energy Services

City	State	County	Customer Count (by Metering)	Revenue (Thousands of Dollars)	Revenue (Millions of Dollars)	Revenue Per Customer (Dollars)
Verona Power Co	NY	Putnam County	07/10	2,085,500	24,000	11.94
Verona Utility Co	NY	Putnam County	08/28	6,067,172	98,740	16.27
Long View Power LLC	NY	Columbia	9/21	90,922	21,000	11.22
Putnam Gas Electric Co	NY	Putnam County	28/09	4,715,240	69,330	15.41

Figure 10: Energy analysis of Pikeville, Kentucky generated in RETScreen

Month	Air temperature °C	Relative humidity %	Precipitation mm	Daily solar radiation - horizontal kWh/m ² /d	Atmospheric pressure kPa	Wind speed m/s	Earth temperature °C	Heating degree-days 18 °C	Cooling degree-days 10 °C
January	0.2	74.1%	100.59	201	96.7	3.8	-0.1	552	0
February	2.1	73.1%	77.85	262	96.6	3.8	2.0	445	0
March	6.3	70.1%	106.74	367	96.5	3.8	6.5	363	0
April	12.0	64.0%	112.15	468	96.4	3.5	12.2	180	60
May	17.2	64.5%	118.33	507	96.5	2.9	17.4	25	223
June	21.4	66.4%	127.59	581	96.5	2.7	21.7	0	342
July	23.1	69.5%	125.94	554	96.6	2.5	23.3	0	406
August	22.3	70.0%	91.50	512	96.7	2.4	22.4	0	381
September	18.8	67.8%	86.79	440	96.7	2.8	18.8	0	264
October	13.1	65.7%	70.38	343	96.8	3.1	12.9	152	96
November	7.4	71.3%	90.96	230	96.7	3.6	7.0	318	0
December	1.8	73.8%	93.43	178	96.8	3.7	1.4	502	0
Annual	12.2	69.2%	1,202.25	3,87	96.6	3.2	12.2	2,537	1,773
Source	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA	NASA
Measured at	<div style="display: flex; align-items: center; gap: 10px;"> m <input type="text" value="10"/> 0 </div>								

Figure 11: Graph of Solar Energy Analysis of Pikeville, Kentucky generated RETScreen

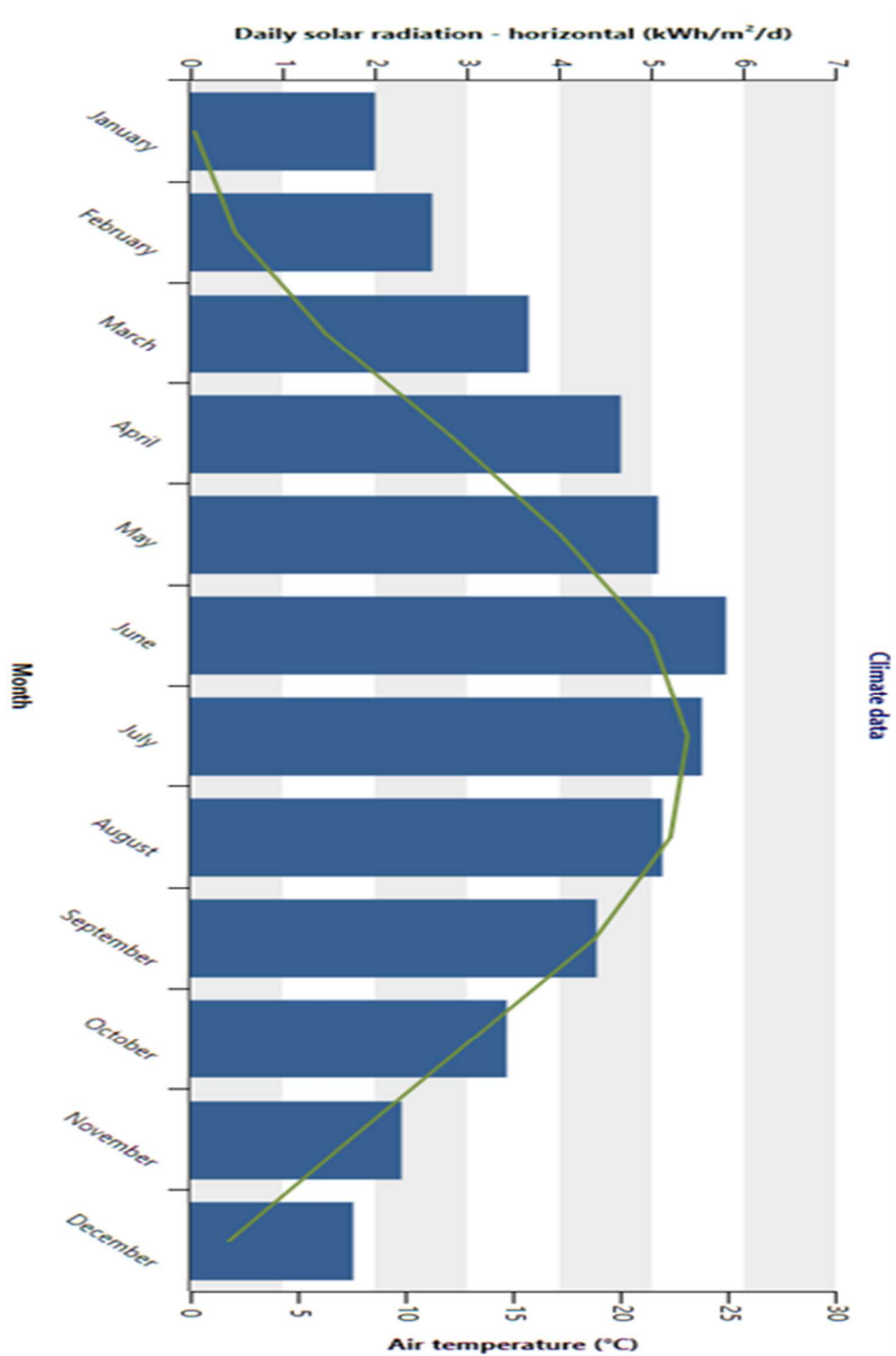


Table 1: Cost comparisons in cents of solar vs LG&E utilities.

Average Life Span Years	LG&E Average Price (cents/kWh)	Average Price (cents/kWh)Solar Panel over Life Span
25	10.41	16.89

Table 2: Comparison of PV Systems generated in SAM that are feasible with solar data from Lexington, Kentucky.

Company Name	Product Name	System Total Cost in dollars	System Size (kW Array)	Pay Back Period in years	Electric bill with system in dollars	Electric bill without system in dollars
SunPower	SPR-X21-345	12,136	4.139	13.7	296	973
SunPower	SPR-X21-335-BLK	13,758	4.693	15.1	248	973
Trina Solar	TSM-295PA14A.08	17,299	5.901	17.3	152	973
Topsun	TS-S420TA1	17,241	5.881	17.5	156	973
Shenzhen Topray Solar	TPS105S-300W(72)	12,340	4.209	14.1	301	973
Schuco USA	MPE 360 AL 01	14,749	5.031	18.2	295	973
REC Solar	REC310PE 72 Q3	12,734	4.343	11.5	163	973
SOLOON	SOLOON BLACK XT 295	12,137	4.140	14.0	307	973
Canadian Solar	CS6X-350-FG	14,368	4.901	15.5	229	973
1Soltech	1STH-350-WH	14,349	4.894	16.0	247	973

Table 3: Summary of the SPR-X21-335-BLK PV System

Metric	Value
Annual energy (year 1)	6,349 kWh
Capacity factor (year 1)	15.4%
Energy yield (year 1)	1,353 kWh/kW
Performance ratio (year 1)	0.82
Levelized COE (nominal)	9.80 ¢/kWh
Levelized COE (real)	7.75 ¢/kWh
Electricity bill without system (year 1)	\$973
Electricity bill with system (year 1)	\$250
Net savings with system (year 1)	\$723
Net present value	\$2,897
Payback period	15.1 years
Discounted payback period	NaN
Net capital cost	\$13,758
Equity	\$0
Debt	\$13,758

Table 4: A comparison to peak demand in kW/month and cost of electric

	Demand peak with system (kW/mo)	Electricity bill with system (\$/mo)
Jan	0.879051	23.8746
Feb	0.857659	20.6125
Mar	0.889821	16.68
Apr	1.1931	16.68
May	1.38801	16.68
Jun	1.77159	16.68
Jul	1.87966	20.2986
Aug	1.94032	30.7122
Sep	1.67033	27.9698
Oct	1.43306	21.6774
Nov	0.807116	20.6722
Dec	0.899462	17.3575

Graph 12: Comparison of Cost of Systems Vs. years to pay back

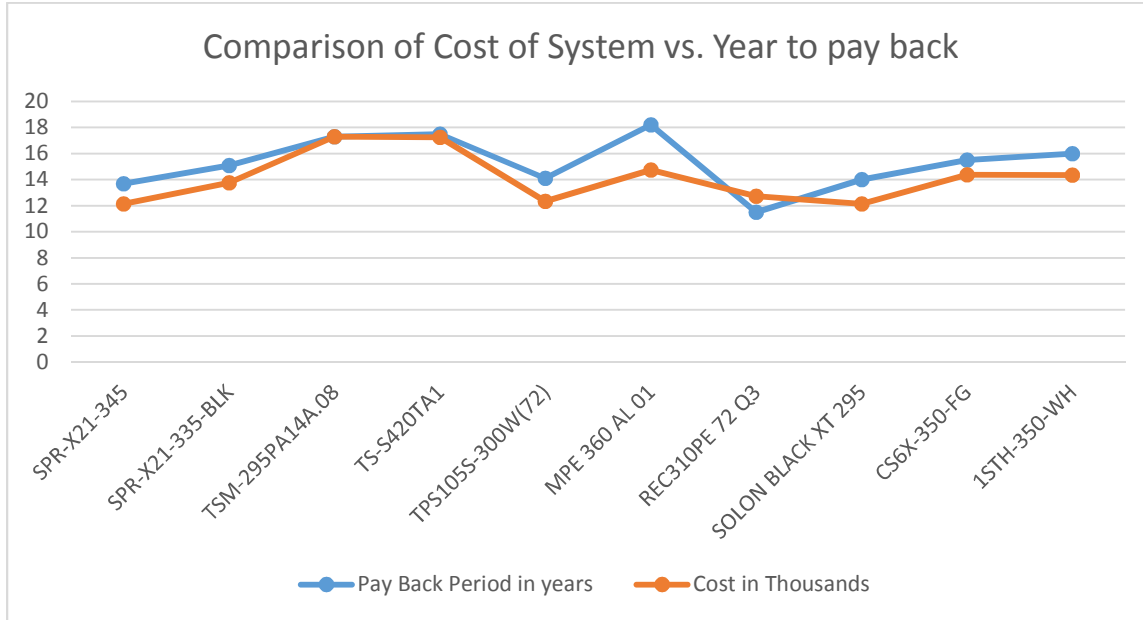


Figure 13: Graph comparison of the SPR-X21-335-BLK with vs without the system

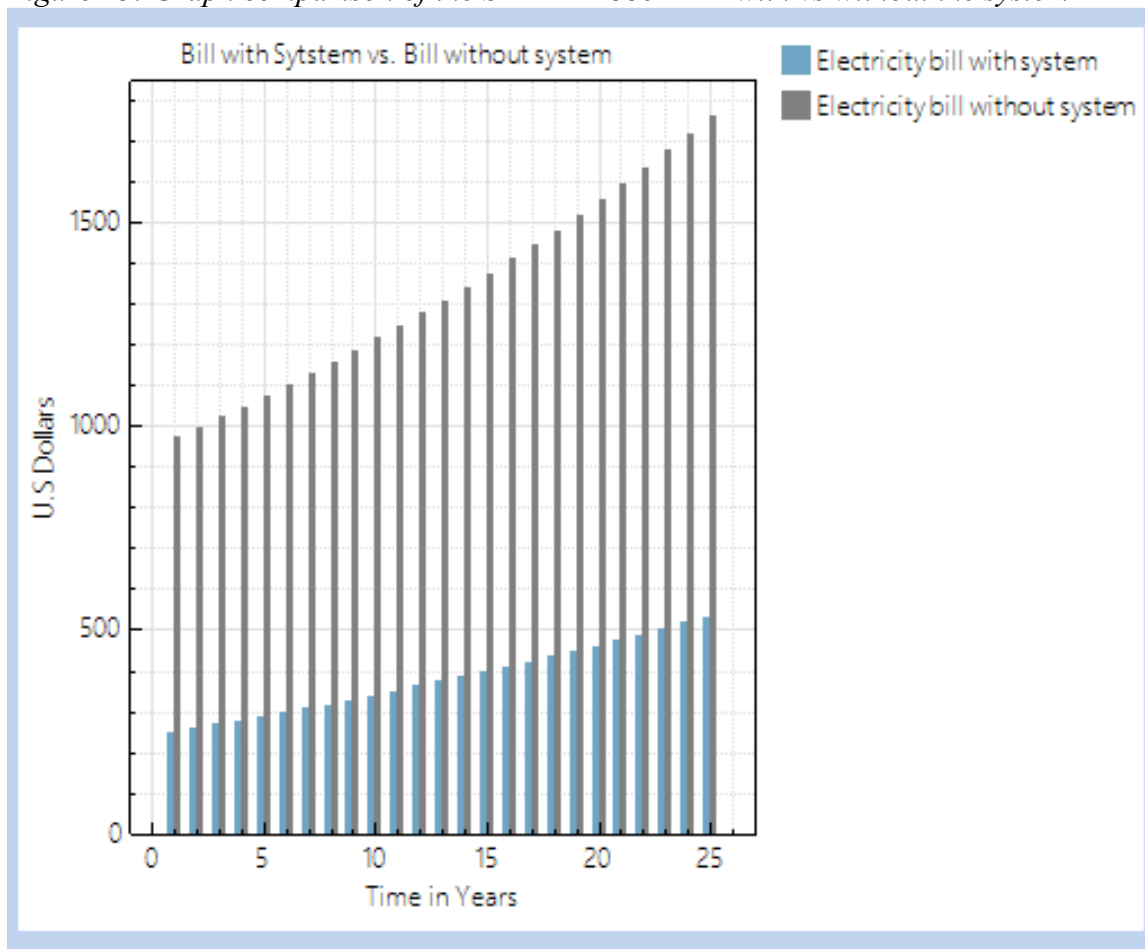


Figure 14: Graph showing the estimated energy production of the SPR-X21-335-BLK

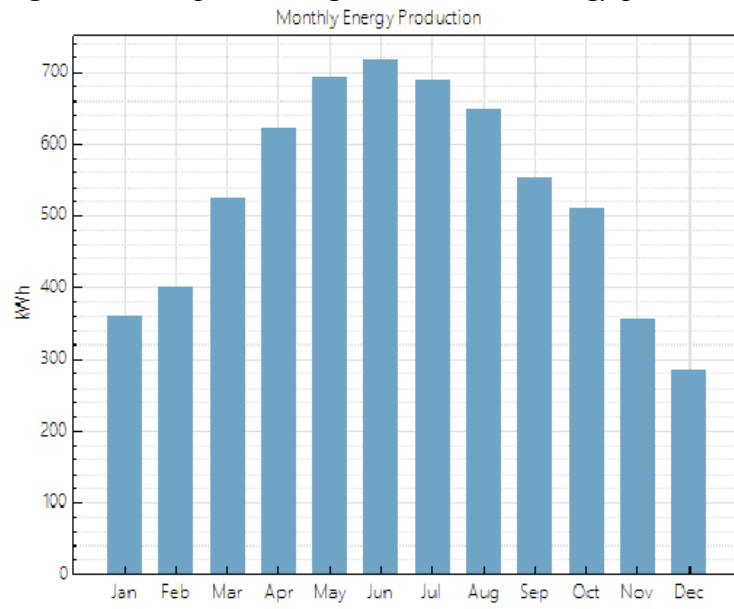


Figure 15: 1 Axis and 2 Axis tracking solar radiation collector data from the NREL

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m ² /day), Uncertainty ±9%														
Axis Tilt (°)	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year	
0	Average	27	37	48	63	73	78	76	71	59	47	29	23	53
	Min/Max	21/35	29/47	38/61	46/82	56/87	68/102	59/84	64/83	51/72	34/64	20/39	19/30	49/60
Latitude -15	Average	33	42	53	66	73	78	76	74	64	54	35	28	56
	Min/Max	24/44	32/54	41/67	48/86	56/88	68/101	58/85	66/86	54/78	38/73	23/47	22/38	52/64
Latitude	Average	35	44	54	65	71	75	73	72	64	56	37	31	57
	Min/Max	25/48	33/58	41/68	47/86	54/85	65/97	56/81	64/85	54/79	40/77	24/51	24/42	52/64
Latitude +15	Average	37	45	53	62	67	70	69	69	62	56	38	32	55
	Min/Max	26/51	33/59	40/67	45/83	50/80	60/91	52/76	61/81	52/78	39/78	24/53	24/44	51/63
Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m ² /day), Uncertainty ±9%														
Tracker	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year	
2-Axis	Average	37	45	54	66	74	80	77	74	64	57	39	32	58
	Min/Max	26/51	34/59	41/68	48/87	57/89	69/104	59/86	66/87	54/79	40/78	24/53	25/45	54/66