CONVERTING INDIANA UTILITY FOSSIL FUEL USAGE TO SOLAR ENERGY TO REDUCE CARBON EMISSIONS

by

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LIST OF ABBREVIATIONS

CO_2 – Carbon dioxide

EDR – Erythemal dose rate

kW – Kilowatt

kWh – Kilowatt hours

kWh/m^2/day – Kilowatt hour per meter squared per day

kWh/year – kilowatt hour per year

L – Liters

m - Meter

m^2 – Meters squared

MW – Megawatt

mWm^{-2}- Milliwatts per meter squared

PV - Photovoltaic

SW - Southwest

TWh – Terawatt hours

TWy – Terawatt year

UV Index – Ultraviolet Index

vs - versus

GLOSSARY

Anderson-Darling Normality Test	A statistical measure for inferential statistics (Anderson-Darling Test, n.d.)
Carbon Sequestration	Limiting the amount of carbon emitted into the atmosphere (Xiong et al, 2016)
Erythemal Dose Rate	A metric for the sun's solar energy (Moshammer et al, 2016)
Escalation rate	The rate in which a price increases over time (Purdue University, n.d.)
Fossil Fuels	Natural resources formed from the fossils and remains of buried plants and animals (Helm, 2017)
I-MR chart	A graphical representation of the values with the mean and the upper and lower control limits (Statistical & Data Analysis Software Package 2021, n.d.)
Matlab	Engineering software used to do complex engineering analysis (Kumar, 2019)
Matrix Plot	An array of scatter plots to maximize the number of values on a single graph (Statistical & Data Analysis Software Package 2021, n.d.)
Neotholic Chenese	Ancient Chinese cultures (Szabo, 2017)
NAE Grand Challenges	National Academy of Engineering Grand Challenge (NAE, n.d.)
N-Type Double sided cell structure	A high lifetime cell structure used in solar panels (Newstex Trade & Industry, 2016)
Planta Solar 10	A large movable mirror solar array power plant in Seville, Spain (Szabo, 2017)
PV	Photovoltaic cells used connected together in a solar panel system

Return on Investment	The amount of time to gain money back on a cost saving project after initial costs and upkeep expenses (Purdue University, n.d.)
Simulink	A portion of Matlab used to simulate various engineering systems (Kumar, 2019)
Therms	A unit of measure for energy that equals 100,000 Btu (U.S. Energy Information Administration, n.d.)
UV Index	Erythemal dose rate used to measure solar energy (Moshammer et al, 2016)

ABSTRACT

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Indiana is currently ranked eighth in total CO_2 emissions and eleventh in energy consumed per capita (Indiana Solar, n.d.) with only 0.56% from solar energy (U.S. Energy Information Administration - EIA – Independent Statistics and Analysis, n.d.). Indiana estimates that 84% of all electricity is from coal power plants and will exhaust resources by 2153 (Dillon, 2016). The problem was measured by quantitatively comparing Indiana households to lower 25%, 50%, 75%, and 100% of energy sources to solar energy. Producing and deploying solar energy in Indiana is linked to the NAE Grand Challenge of Developing Carbon Sequestration Methods (National Academy of Engineering, 2019). The data collected provided a path to homeowners to get a six or seven year return on investment depending on the supplementation. The return on investment along with the reduced carbon emissions provided proves to be beneficial. Utilizing additional research and commitment from government officials, Indiana can be a major contributor in renewable energy.

Keywords: Energy, Carbon Sequestration, Indiana, CO_2, Electricity, Coal

CHAPTER 1. INTRODUCTION

1.1 The Problem

Indiana has an ongoing problem of not utilizing renewable energy. Minimal efforts have been utilized to help Indiana move towards renewable energy such as solar, wind, or hydro-electric power. Indiana is currently ranked eighth in total carbon emissions and eleventh in energy consumed per capita (Indiana Solar, n.d.) with only 0.56% from solar energy (U.S. Energy Information Administration, n.d.). Local Indiana power companies have committed to continue to use non-renewable energy in the future. Vectren has committed to building an 800 to 900 MW gas plant that would replace old coal-burning power plants (United States: Vectren proposal commits SW Indiana to fossil fuel dependence, 2018). Large commitments by large power plants in Indiana to avoid using renewable energy is a large concern for sustainability over the next 50 years.

Carbon dioxide emissions are the primary driver of climate change in 2021 (Roser, n.d.). Because the United States is the second-largest emitter globally, CO_2 emission reduction is needed (Mohlin et al, 2019). More than 30% of emissions are from the power sector (Mohlin et al, 2019). Indiana is in the top 10 of CO_2 emissions and ranked 17th of all states in population. Indiana is among the bottom in renewable energy (Mohlin et al, 2019).

1.2 The Impact of the Problem

The impact of CO_2 emissions has become a significant problem throughout the United States and Indiana. Indiana has 183 million tons of carbon dioxide emitted per year. Indiana estimates that 84% of all electricity is from coal power plants and will exhaust resources by 2153 (Dillon, 2016). Since only 5% of the power is generated by renewable energy, Indiana must improve to protect the environment (Raymond et al, 2019).

At the current rate, Indiana could face many problems by the turn of the century. Indiana could face record high temperatures a couple of times during each summer that could kill hundreds of people, similar to the heatwave in Chicago in 1995. Figure 1.1 below shows with higher emissions, the number of days over 90 degrees Fahrenheit greatly increases. Air quality would deteriorate as the temperatures continue to increase. Public health would be greatly affected by lower air quality causing respiratory issues and more asthma attacks (Fitzpatrick, Freese, & Wadsworth, 2009).

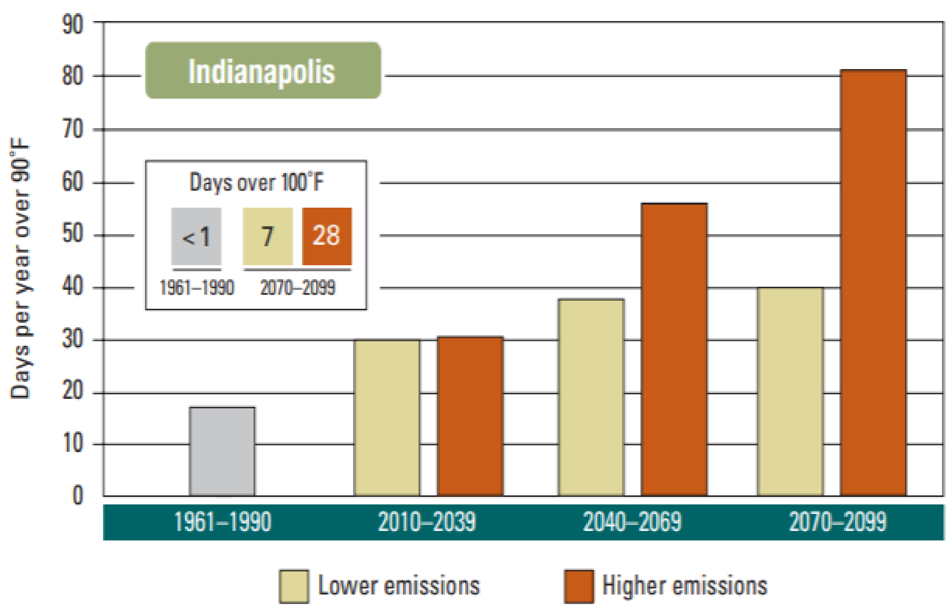


Figure 1.1: Indianapolis Temperature with Varying Emissions (Fitzpatrick, Freese, & Wadsworth, 2009)

Having lower emissions can make a tremendous impact on the heat throughout the Indianapolis area. Figure 1.1 on page two shows that a 50% increase by the year 2099 in days over 90 degrees Fahrenheit. Days over 100 degrees Fahrenheit are projected to be four times the current rate.

Floods and storms would also be more prevalent with greater CO_2 emissions. Over 30% more precipitation would occur during the winters and springs (Fitzpatrick, Freese, & Wadsworth, 2009). More precipitation and flooding could have a devastating impact on the land and homes of people all over the state.

Agriculture would also take a significant negative impact due to warmer temperatures. Crops and livestock would get more heat stress with higher temperatures (Fitzpatrick, Freese, & Wadsworth, 2009). The warmer winters could cause pests to expand their range and cause more impact (Fitzpatric, Freese, & Wadsworth, 2009). Crop production would also be affected by the changing rain patterns (Fitzpatrick, Freese, & Wadsworth, 2009). More rain would be experienced during the spring, but less precipitation would happen during the summer months when increasingly hotter (Fitzpatrick, Freese, & Wadsworth, 2009).

1.3 How the Problem was Measured

The problem was measured by quantitatively comparing Indiana households to lower 25% energy sources to solar energy. Knowing that Indiana generates 114.7 Terrawatt-hour (TWh) of electrical power per year, 28.7 TWh must be generated by solar panels. Indiana has 87 power plants. Having only 12 of the 87 power plants being renewable energy, room for improvement can easily be obtained (U.S. Department of Energy, 2016).

1.4 Connectivity of the Problem with The NAE Grand Challenge

The NAE Grand Challenges comprise fourteen different challenges that engineers face in today's world. Producing and deploying solar energy in Indiana is linked to the National Academy of Engineering Grand Challenge of Developing Carbon Sequestration Methods (NAE, n.d.). Developing more solar panels throughout Indiana could provide new opportunities for research to create more economical solar panels. Having more solar panels will provide electricity for Indiana that will lower fossil fuel needs to generate electric power. Lowering the amount of fossil fuel usage will lower carbon emissions throughout the state.

1.5 Summary Introduction

Creating a clear path for Indiana power plants to move into renewable energy is needed. Having a plan set forth for solar panels to be utilized among the state is needed. Locating areas of low usage, plans for implementation, and return on investment are all part of the proposed plan. Finding the most efficient solar panel at the best cost while also trying to get real data from solar energy trends throughout Indiana will be necessary. Using real data, researchers can determine what locations and costs are needed to achieve a 25% solar energy usage throughout Indiana.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Carbon Sequestration

Throughout the United States, the carbon footprint is an ongoing problem. Each year the amount of CO_2 emissions from burning fossil fuels is analyzed. Policies have been made to mitigate CO_2 emissions. The policies have been created to limit global warming and protect the ecosystem (Arrari et al, 2019). Changing the way electrical energy is obtained is a way to limit the burning of fossil fuels.

2.2 General Solar Energy

Solar energy has become a key topic in renewable energy. The sun generates a potential of 23,000 Terawatt-year (TWy) every year (Szabo, 2017). Earth is estimated to use only 1,600 TWy for 100 years to put into perspective how much solar energy is available (Szabo, 2017). Solar energy has a nearly endless supply that can be tapped for years to come.

2.2.1 Solar Energy History

Solar energy has been utilized for thousands of years. Neotholic Chinese utilized solar energy to ensure help in heating their homes (Szabo, 2017). Chinese homes were built facing south to get warm sun rays coming in during the winter months. A thatched roof in China was created to keep away the warm sun rays during the summer months (Szabo, 2017). Using solar energy has been used for thousands of years, even today (Szabo, 2017).

Sun rays were also used to dry and preserve food. Dehydrating food allowed for stored grain to be kept for several years before going bad (Szabo, 2017). Ancient Egyptians would even use the sun's rays to help get salt to prepare and conserve food (Szabo, 2017). Using the sun's rays to evaporate seawater was a quick and easy way to obtain salt (Szabo, 2017).

Leonardo da Vinci was an early pioneer in solar energy research. Da Vinci began testing the reflections' geometry to determine how sun rays could reflect on a curved metal plate (Szabo, 2017). During the research that da Vinci conducted, he created the first industrial application using a concave mirror to be used for heating water (Szabo, 2017). Utilizing the sun's energy proved valuable in heating bathtubs and even operating textile machines (Szabo, 2017).

During 1912, Frank Shuman became the first person to create solar thermal power (Szabo, 2017). The solar panels comprised 1,200 square meters (m^2) of an area consisting of several 62 meters (m) long cylindrical-parabolic cylinders to collect sunlight. With the solar energy collected from the panels, more than 20,000 liters (L) of water per minute could be pumped, as shown in Figure 2.1, on page number seven. The water was taken from the Nile River to nearby agriculture fields (Szabo, 2017).

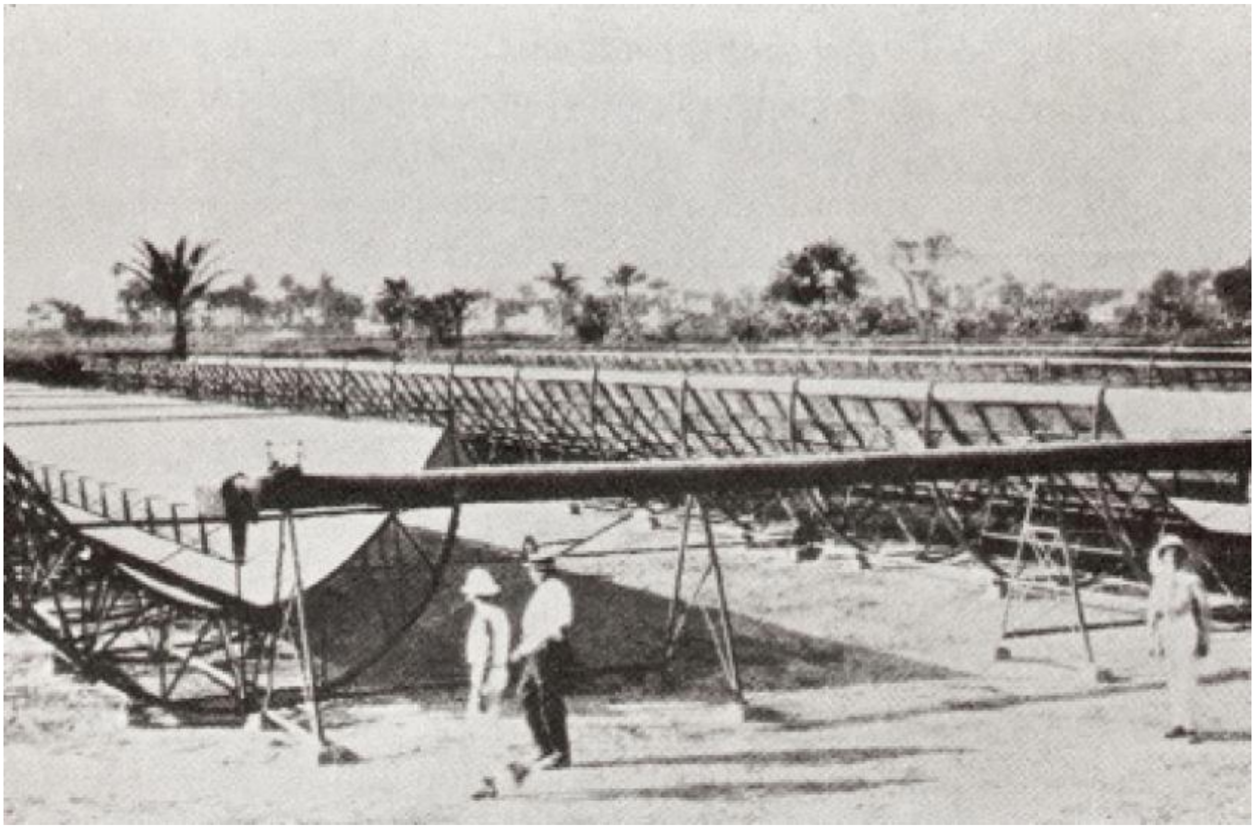


Figure 2.1: Frank Shuman's First Solar Thermal Power Station (Szabo, 2017)

Having large cylinders allowed the solar energy to be collected from different angles. The solar thermal power station in Figure 2.1 above, could generate up to 45 kW of power continuously for nearly five hours a day. Having the ability to utilize power from the sun made a huge impact on the agriculture community. The supply of water to nearby fields allowed the farmers to build more fields that were larger and more sustainable (Szabo, 2017).

The first commercial solar power plant was set up in 2004 (Szabo, 2017). The Planta Solar 10 near Seville, Spain was built with 624 large movable mirrors (Szabo, 2017). The mirrors were on top of a 115-meter tall tower with a solar receiver, steam turbine, and generator. The power collected from the Planta Solar 10 generated 10 MW of electricity. 10 MW of electricity is enough to power 5,500 homes a year (Szabo, 2017).

The current largest solar power plant was opened in 2014 in California (Szabo, 2017). The Ivanpah Solar Electric Generating System generates 377 MW of electricity (Szabo, 2017). The power collected is enough to power 140,000 homes (Szabo, 2017). Over 300,000 software-controlled mirrors are tracking the sun (Szabo, 2017). Boilers are on top of three towers that are 140 m tall (Szabo, 2017).

Over thousands of years, humans have been trying to capture the resources of the sun's power. Innovations and technology have put solar energy as one of the top renewable energy resources (Liu et al, 2019). Having renewable energy is vital in the preservation of life (Moorman et al, 2019).

2.3 Calculating Solar Energy

Solar energy can be calculated very quickly and easily. The three key factors for solar panel output are the solar panel efficiency, location, and direction the solar panels face (Geagea et al, 2018). Each system will have other factors, but a quick start can be done with the three key factors.

The first factor to take into consideration is the solar panel output. Each solar panel is generally rated between 250 watts and 370 watts (How to measure solar panel output, n.d.). The ratings are measured in ideal conditions at 77 degrees Fahrenheit and 1000 watts of sunlight per square meter (How to measure solar panel output, n.d.). A 300-watt solar panel in the ideal conditions will create 300 watts of electricity (How to measure solar panel output, n.d.).

After knowing the output rating, the solar panel efficiency is needed. The solar panel efficiency means that if the solar panel has a rating of 15%, 15% of the sunlight hitting the solar panel will be turned into power (How to measure solar panel output, n.d.). The power can be converted to powering a home. The efficiency can be changed by clouds, shade, dirt, snow, or any other obstruction.

The location of the solar panel also makes a vast difference in the savings. Living in a high sunlight area closer to the equator will have a much larger impact than Alaska. Figure 2.2 below, compares different areas throughout the United States and their erythemal dose rate (EDR). The erythemal dose rate is further simplified as the UV Index (Moshammer et al, 2016). The more sunlight, the more power generated. Longer summer hours will generate a lot more power than shorter days during the winter.

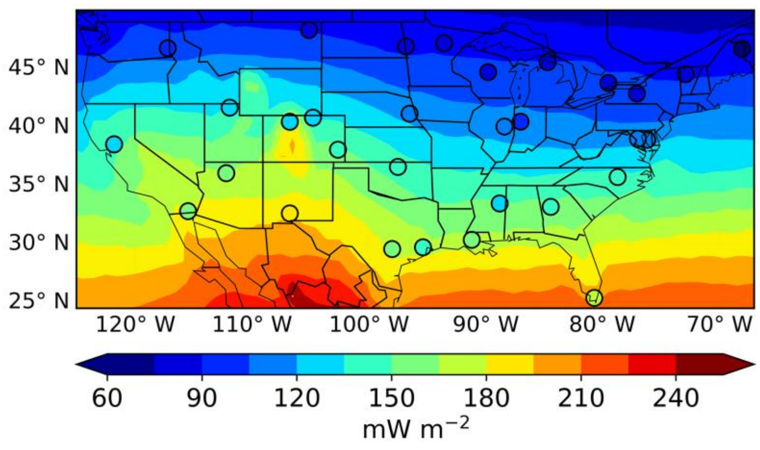


Figure 2.2: United States EDR Rates at Solar Noon Under Full Sunlight (Zhang et al, 2019)

Figure 2.2 on page nine shows the closer people are to the equator, the higher the EDR becomes. In central Indiana, the EDR is 110 milliwatts per meter squared (mWm^{-2}) in comparison to Florida, which receives 200 mWm^{-2} (Zhang et al, 2019). Having a higher EDR leads to greater energy output (Zhang et al, 2019).

The direction the solar panels are facing is another key factor. Facing the south or west will get the most sunlight. Having a direct angle to get the most sunlight is the best way to get power. Direct sunlight allows for more intense sunlight.

When calculating the solar panel output, the solar panel watts, average hours of sunlight, and a multiplier to accommodate imperfections must be attained. The imperfections are the location, direction, and efficiency of the panel. The basic equation for calculating daily watt-hours can be seen in Figure 2.3 below (How to measure solar panel output, n.d.).

Solar Panel Watts x Hours Sunlight x Imperfection Percentage = Daily Watt-Hours

Figure 2.3:: Solar Panel Daily Watt-Hours Calculation (How to Measure Solar Panel Output, n.d.)

Using the formula, a 300-watt system with five hours of daily sunlight and a 75% imperfection rate can be calculated (How to Measure Solar Panel Output, n.d.). Having 1,125 daily watt-hours is equivalent to 1.13 kWh per solar panel per day (How to Measure Solar Panel Output, n.d.). The average home uses almost 11,000 kWh per year (How to Measure Solar Panel Output, n.d.). Dividing by 365 days, the total usage is 30.14 kWh per day. For example, a house has just thirty panels, a house could be powered completely by solar panels (How to Measure Solar Panel Output, n.d.).

2.4 Residential Solar Power Systems

As home solar panel systems are becoming more common every day with showing a 49% annual growth over the last decade (Solar Industry Research Data, n.d.), many home builders include new solar panels with the build's cost. Including solar panels in a home can improve sales by roughly 4% more than homes without (Wynder, 2019). Solar panel options for homeowners have become increasingly easier to afford, averaging $1.05 per watt in hardware costs (Solar Industry Research Data, n.d.).

California has passed laws that require all homes, apartments, and condos built beginning in 2020 to have solar panels on their roofs (Fingas, 2020). Having solar panels added to the homes will increase construction costs by roughly $25,000. The panels' estimated savings would have an estimated savings of over $50,000 during the panels' lifetime. California is the first state to require solar panels.

Indiana is one state that has historically fallen behind in solar energy (U.S. Energy Information Administration - EIA – Independent Statistics and Analysis, n.d.). Using data for determining savings can be challenging based on two main reasons:

- The need for accurate estimates of solar production in kWh based on your location.
- Knowing an accurate amount of value for kWh rate is after 10, 20, and 25 years.

Table 2.1 below shows that Indiana can be a state that receives benefits from solar systems in residential areas (Sendy, 2020).

Table 2.1: Average Monthly and Lifetime Savings for Solar Panels

CITY	STATE	SPR COST	ANNUAL PRODUCTION OF 6 kW SYSTEM	AVERAGE MONTHLY SAVINGS YEAR 1	25-YEAR BILL SAVINGS
Indianapolis	Indiana	0.12	7068	$70.68	$30,842

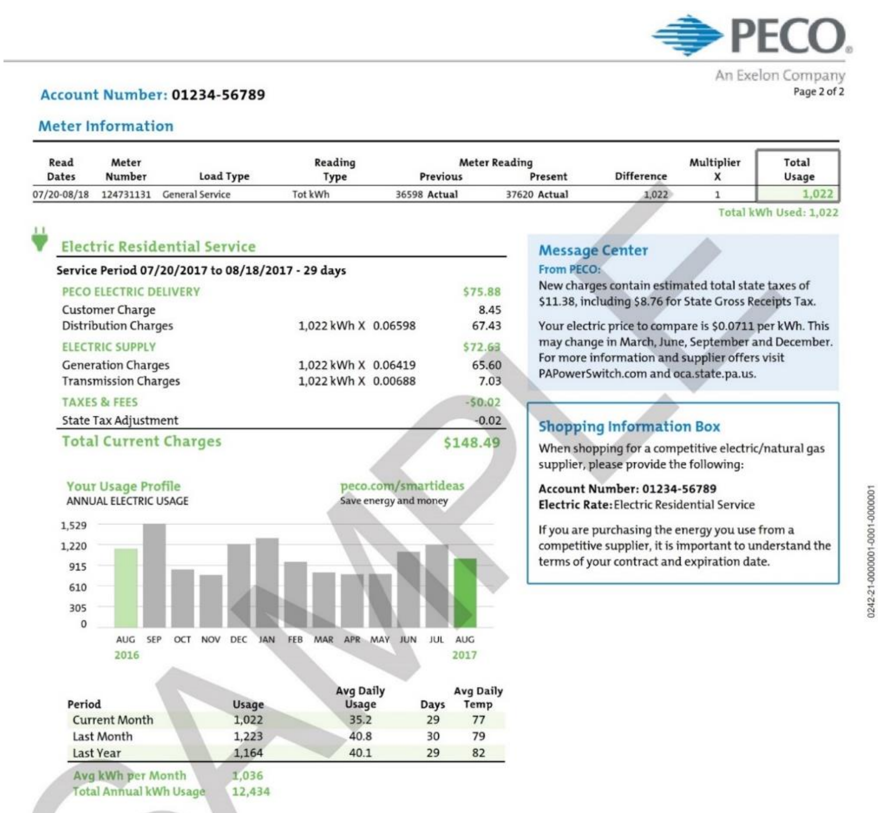
Indianapolis has shown possibilities of having significant savings after a 25 year period by leveraging renewable energy, as shown in Table 2.1 above (Sendy, 2020). The typical size of a residential solar energy system is a six kW system (Sendy, 2020). Table 2.1 shows that a $30,842 savings can be acquired from a six kW system in 25 years (Sendy, 2020). A savings of $70.68 a month could allow funding for other energy savings efforts for each household.

Studies have been done to ensure that solar panels are affordable in residential areas (Sendy, 2020). In California, solar panels are used not only for energy savings but also for safety (Mass & Ovens, 2019). Having fewer high voltage transmission lines in California could drastically impact wildfires in the state (Spaulding, 2018). The wildfire in 2017 spread across nearly 250,000 acres and had over $10 billion of insured loss (Mass & Ovens, 2019). One fire can have a massive impact on the population as well as the economy.

Another simple way to make home solar panels more affordable is by increasing the term length of the mortgage. Adding a single year or two to a thirty-year mortgage would generate the same monthly mortgage bill with added energy savings. Solar panels would then be affordable to all homeowners and help save our fossil fuels and limit CO_2 emissions (Raymond et al, 2019).

2.4.1 Residential Utility Cost Impact

To better understand how a home utility bill can be impacted, researchers must know how to read the bill. The utility bill can be found from the local electric company. An example home electric bill is shown in Figure 2.4 below.



PECO
An Exelon Company
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Account Number: 01234-56789

Meter Information

Read Dates	Meter Number	Load Type	Reading Type	Meter Reading Previous	Meter Reading Present	Difference	Multiplier X	Total Usage
07/20-08/18	124731131	General Service	Tot kWh	36598 Actual	37620 Actual	1,022	1	1,022

Total kWh Used: 1,022

Electric Residential Service

Service Period 07/20/2017 to 08/18/2017 - 29 days

PECO ELECTRIC DELIVERY		$75.88
Customer Charge		8.45
Distribution Charges	1,022 kWh X 0.06598	67.43
ELECTRIC SUPPLY		$72.63
Generation Charges	1,022 kWh X 0.06419	65.60
Transmission Charges	1,022 kWh X 0.00688	7.03
TAXES & FEES		-$0.02
State Tax Adjustment		-0.02
Total Current Charges		**$148.49**

Message Center
From PECO:
New charges contain estimated total state taxes of $11.38, including $8.76 for State Gross Receipts Tax.

Your electric price to compare is $0.0711 per kWh. This may change in March, June, September and December. For more information and supplier offers visit PAPowerSwitch.com and oca.state.pa.us.

Shopping Information Box
When shopping for a competitive electric/natural gas supplier, please provide the following:

Account Number: 01234-56789
Electric Rate: Electric Residential Service

If you are purchasing the energy you use from a competitive supplier, it is important to understand the terms of your contract and expiration date.

Your Usage Profile
ANNUAL ELECTRIC USAGE

peco.com/smartideas
Save energy and money

Period	Usage	Avg Daily Usage	Days	Avg Daily Temp
Current Month	1,022	35.2	29	77
Last Month	1,223	40.8	30	79
Last Year	1,164	40.1	29	82

Avg kWh per Month 1,036
Total Annual kWh Usage 12,434

0242-21-0000001-0001-0000001

SAMPLE

Figure 2.4: Home Electricity Bill (Exelon, n.d.)

Referencing Figure 2.4 on page 13, the home electricity bill from Exelon Company, energy usage data points can be retrieved for analysis. The rates, usage, monthly usage from the previous year, and even last month's rates can be seen. Having the average daily temperature and the number of days can also make a difference in how much was consumed. At the top of Figure 2.4 on page 13, the reading type, meter reading, and the total amount used are key components.

Figure 2.4 on page 13, a total amount of 1,022 kWh was used in August of 2017. During that month, 29 days were recorded, and the average temperature was 77 degrees Fahrenheit. A total of $148.49 for the month is critical in knowing how much the rate is and how solar panels can effectively save money. To find the cost that was charged per kWh, we used the formula from Figure 2.5 below:

$$Cost\ per\ kWh = \frac{Monthly\ Bill\ Chares\ in\ Dollars}{Total\ kW \cdot hr\ Used}$$

Figure 2.5: Formula to Determine Price Per Kilowatt-Hour

Looking at the bill in Figure 2.4 on page 13, the researcher can determine the exact rate charged per kilowatt-hour in Figure 2.6 as seen below.

$$Cost\ per\ kWh = \frac{\$149.49}{1{,}022\ kW \cdot hr} = \frac{\$0.1427}{kW \cdot hr}$$

Figure 2.6: Example of Calculating Price Per Kilowatt-Hour

The bill in Figure 2.4 on page 13, the charges show calculations of the rates that are being charged per kWh. The rates that are shown are being charged for the supply and delivery of the electricity. To get a full comprehensive cost of the rate that is being charged, researchers must consider the amount that was used and the amount that was charged.

Knowing how to read the usage for a home electricity bill allows for a visual to determine how much solar energy is needed for each home. Having a good understanding of the usage and rates at homes could allow power companies to utilize solar energy on private properties.

2.5 Commercial Systems

Throughout recent years, commercial buildings are starting to realize the benefits of creating solar panel fields to supplement energy costs. LG's flagship NeON™ boasts a 72 cell solar panel for commercial application (Newstex Trade & Industry, 2016). The N-Type double-sided cell structure allows the panels to produce more energy in a smaller footprint (Newstex Trade & Industry, 2016). Having a smaller footprint provides opportunities for greater value for land in a solar panel field. The LG375N2W-G4 offers 375 W of power in a 40" x 77" panel (Newstex Trade & Industry, 2016). A six-acre lot could provide enough energy for one MW of generating capacity (Hyder, 2020).

2.6 Simulation Tools

Simulation tools have been utilized to create solar energy systems. The systems can range from Simulink in Matlab to C# programing (Er, 2016). Simulations allow for the design to be done without investing large amounts of money in a physical system.

Using Simulink in Matlab, modeling can be used to predict the outcomes of a system. Matlab can provide an extensive list of options to be able to fine-tune any system. Using the program, exact components for the system can be placed. Figure 2.7 below shows a photovoltaic system with several different key components.

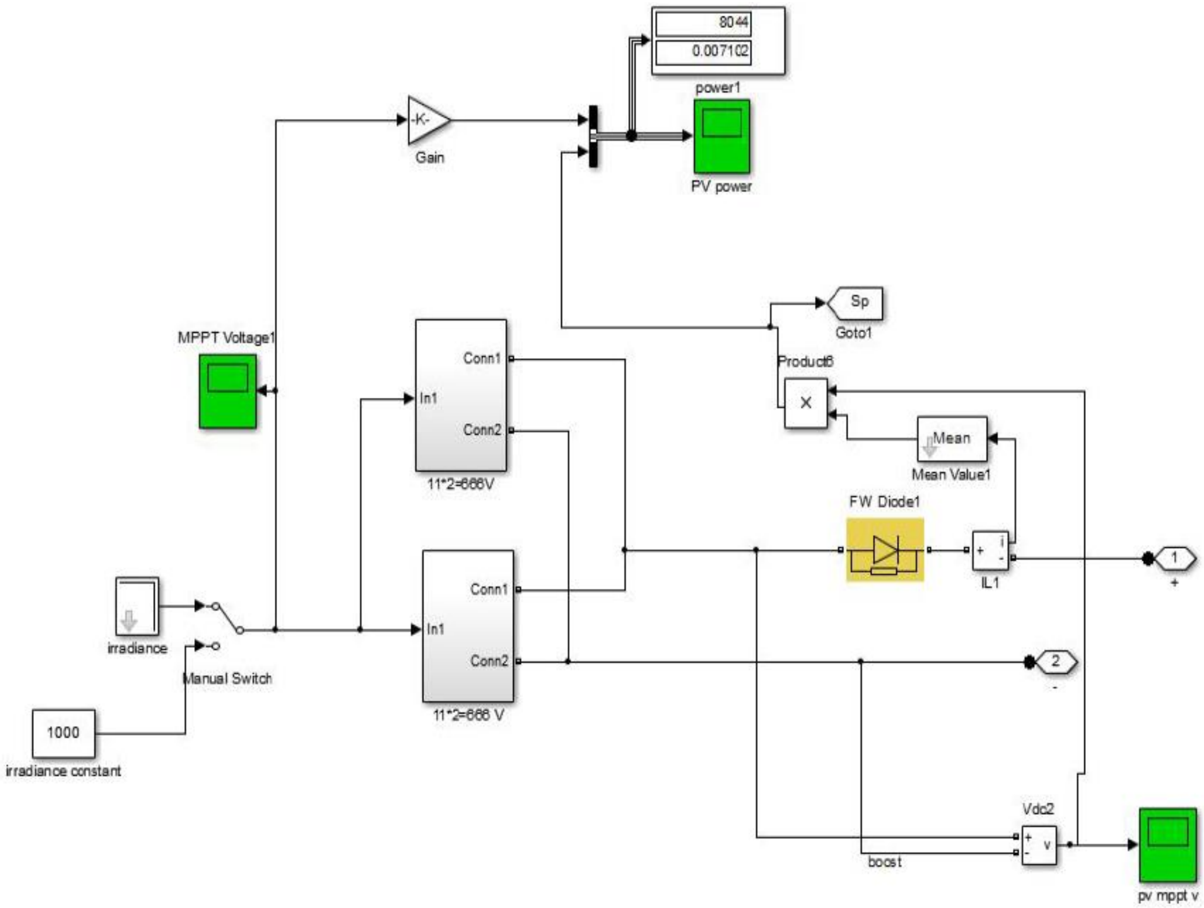


Figure 2.7: MATLAB Simulink Model for Photovoltaic System (Kumar, 2019)

The system shown in Figure 2.7 above, several inputs are given to get an output of power in the model. Using connections, diodes, and mathematical equations, an output can be given on the expected power that is produced by the system. Using models has proven to be a valuable resource to obtain an estimate before the system is built.

Other variations of the mathematical simulation are available. Some such as Homer Pro, PV F-Chart, pvPlanner, and PVsyst are used worldwide (Allam, 2017). Each program has a different interface that interacts with the user to be able to simplify data collection. The programs take the weather data and the system data to accurately output the information for the user to build a model.

2.7 Conclusion

Solar systems can be seen as one way to provide renewable energy. Both commercial and residential applications of solar energy allows for different applications. Each application lowers the carbon footprint for all. Having a lower carbon footprint allows for sustainable living for humanity.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Research Methodology Overview

Comparing capital cost versus the savings provided from implementing solar energy throughout Indiana. A sample size of ten different residential buildings was used to determine power consumption. Each sample included various specific data points to measure and conduct the research analysis. Sample data points include residential facility's square footage, energy usage, and the number of occupants. Each sample participant was selected from a group that information was easily obtained.

3.1.1 Research Environment

The study's research environment was focused on Indiana utility companies that use fossil fuels as an energy source to produce electricity. Indiana was chosen because of the central location in the Midwest and having access to specific data such as utility information and building information. The methodology of the research was the same throughout the Midwest but with minimal variable changes. A study of ten homes was utilized in the research study.

Throughout the research, the utility company, rates, and even location were taken into account. Some locations offered better locations for installation and proximity to nearby solar energy installers.

3.1.2 Sample Population, Participants, and Validation

The sample size was comprised of ten residential structures ranging from 1,050 square feet to 4,500 square feet. Each residential structure was located in central Indiana. All have electricity as the primary energy source. Some of the homes have a supplemental energy source of natural gas or propane. Each home was comprised of one to five occupants.

Several variables were included in the research. One variable was the heat source. Having electric vs. propane vs. natural gas requires different levels of energy. The number of people in the household also factored into the amount of energy needed. Square footage of the home also had a significant level of impact on how much energy is required. The solar irradiance at each location was different due to the property's obstructions and the property's exact location. The outside temperature also factored into the requirement for heating and cooling of the home.

A total of six data points were collected for each of the homes. The data points included electrical usage in kWh per year, gas or propane usage in therms or gallons, square footage of the home, number of occupants, home location, and how much money was spent for energy usage. Each of the six data points collected was vital in getting a clear understanding of the homes' energy requirements.

3.1.3 Statistical Measures

The research study's statistical measures were compared and contrasted with fossil fuel energy values and renewable energy values to test the hypothesis. The sample size of ten residential households in Central Indiana whose source energy was generated by fossil fuels emitting CO_2 was analyzed against a hypothetical renewable energy source provider (solar) applied at 25%, 50%, 75%, and 100% values. Inferential statistics were utilized in the form of an Anderson-Darling Normality Test (Anderson-Darling Test, n.d.). The test was used to recognize the significance of the data collected. A matrix plot was also utilized to recognize how each variable interacts with one another in a visual setting. Each of the statistical analyses was created on Minitab (Statistical & Data Analysis Software Package 2021, n.d.).

3.1.4 Limitations and De-limitations

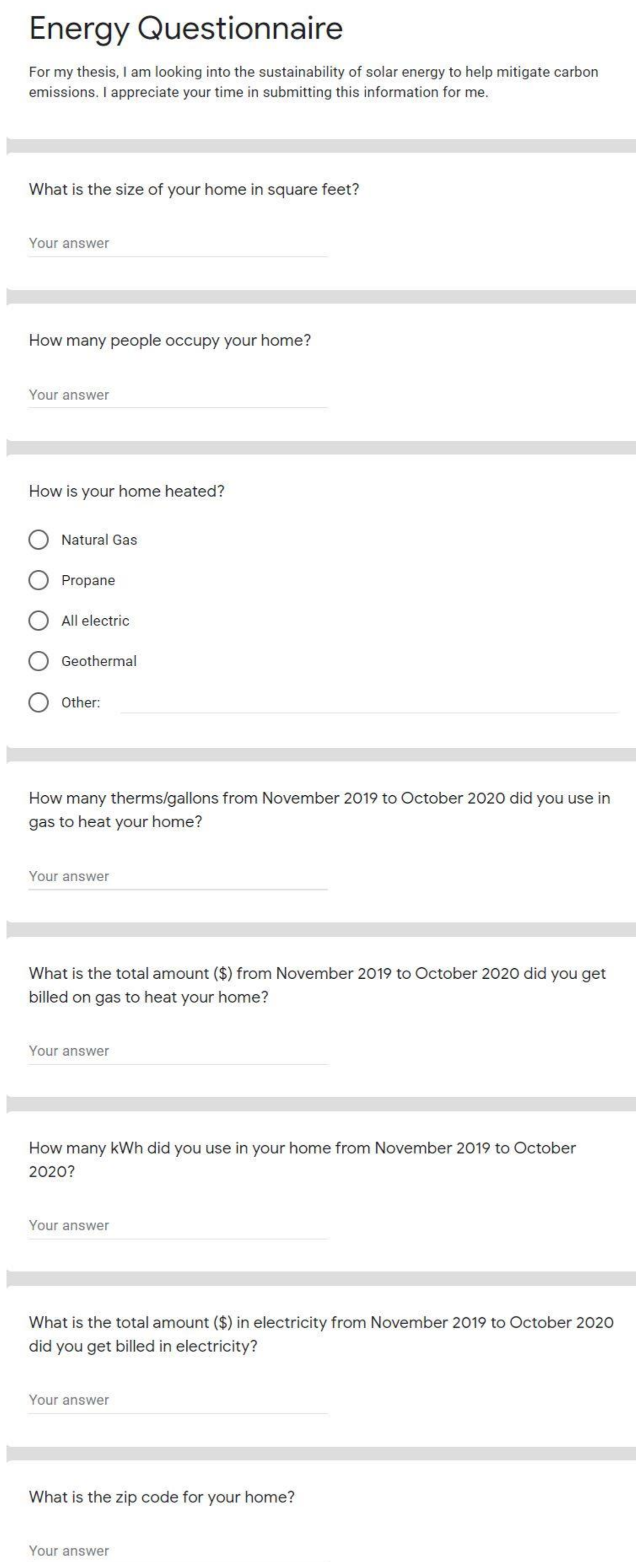
Some of the limitations were access to billing information, locations, and solar panel information availability. Having access to billing information probably was the biggest limitation. Homeowners would not readily give up their billing information. The chosen groups were all people that were willing to give up how much they were invoiced and the electricity usage they incurred. The locations of the places chosen were pre-set by who was willing to release information for the research. Throughout Indiana, solar energy is not as useful as in much warmer climates such as the southern United States (U.S. Energy Information Administration - EIA – Independent Statistics and Analysis, n.d.).

Another limitation of solar panels is the dust and dirt on the solar panels. Having dust on solar panels can reduce efficiency by up to 35% (Dusty Solar Panels Slash Power Output by Over 35%, 2019).

De-limitations were made during the research. To minimize the volume of the study, a chosen set of ten locations were selected. Each household had a basic understanding of construction and electricity in the ten locations to do their own installation.

3.2 Research Instruments

Throughout the research, various methods were employed. Surveys, the internet, and the Purdue Library were utilized. The large majority of the information utilized was used within five years of the final research. A questionnaire was utilized to gather data among people who live throughout central Indiana. Figure 3.1 on page 22 is an example questionnaire that was used.



Energy Questionnaire

For my thesis, I am looking into the sustainability of solar energy to help mitigate carbon emissions. I appreciate your time in submitting this information for me.

What is the size of your home in square feet?

Your answer

How many people occupy your home?

Your answer

How is your home heated?

- Natural Gas
- Propane
- All electric
- Geothermal
- Other:

How many therms/gallons from November 2019 to October 2020 did you use in gas to heat your home?

Your answer

What is the total amount ($) from November 2019 to October 2020 did you get billed on gas to heat your home?

Your answer

How many kWh did you use in your home from November 2019 to October 2020?

Your answer

What is the total amount ($) in electricity from November 2019 to October 2020 did you get billed in electricity?

Your answer

What is the zip code for your home?

Your answer

Figure 3.1: Sample Survey Questions

Using a survey provides valuable information for understanding the amount of energy used in homes throughout Indiana. Through an anonymous survey shown in Figure 3.1, each person can state their bills and how much energy their house used without knowing each person's expenses.

The National Renewable Energy Laboratory was also used (National Renewable Energy Laboratory, n.d.). Within the National Renewable Energy Laboratory (NREL), a PVWatts calculator was offered to create a solar energy system at any home or business. Figure 3.2 below shows a sample of solar radiation and energy data that was easily attainable by location at the NREL PV Watts calculator (National Renewable Energy Laboratory, n.d.).

RESULTS

9,338 kWh/Year*

System output may range from 8,938 to 9,578 kWh per year near this location.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.80	525	54
February	3.51	580	60
March	4.63	834	86
April	5.53	919	95
May	5.67	934	96
June	6.44	1,017	105
July	6.73	1,080	111
August	6.10	967	99
September	5.52	865	89
October	4.16	709	73
November	2.92	494	51
December	2.25	413	43
Annual	4.69	9,337	$ 962

Figure 3.2: Solar Radiation at Sample Location (NREL, n.d.)

Figure 3.2 on page 23 shows data at a location using a seven kW system. In the system, an average of 4.69 kWh/m^2/day was obtained. Through solar radiation, a total of 9,337 kWh was gained by the system and could save $962 per year.

3.3 Procedures for Data Collection

The data was collected from various areas throughout Indiana. The selection of the homes was random, but the residential homeowners that were selected were not random. Selecting the proper homes and people was difficult due to the nature of the required information. Volunteers were generated through social media sites than the originally anticipated participation of four homes, brought in ten homes.

Once the homes were selected, a 12-month analysis was done to include usage in kilowatt-hours, billing fees, and consumption charges. Knowing billing information and the demand offered a good idea for determining the size of the required system. Each location had a different need based on their energy consumption. For simplicity of the project’s scope, the homes were averaged on usage to get an overall savings of 25%, 50%, 75%, and 100% in energy savings.

The locations and the amount of space were researched. Each location had its own set of challenges that were analyzed. Having more people in a home or a different heat source was examined for possible trends.

After the system's size was completed, determining the parts required to construct each system was pursued. Utilizing various sources, the size of panels, number of panels, and the components were all selected. After the components were selected, a payback analysis was pursued in each system.

3.4 Presentation of Data

Data collected were presented in a table showing the residential households with the data points collected from the survey. Table 3.1 below shows how the data was presented.

Table 3.1: Initial Data Collection Presentation

Residential Household (N)	Aver. Outside Air Temp. (deg. F)	Number of Occupants	Square Feet	Therms/gallons per year	Natural Gas/Propane	Amount in Gas ($)	kWh/year	Amount in Electricity ($)	Converted to kWh	CO2 Tonnage
1										
2										
3										
4										
5										
6										
7										
8										
9										
10										

Table 3.1 above organizes the key components used to begin the evaluation. The average outside air temperature was collected from a database from the home location (Climate – Indiana, n.d.). The carbon dioxide (CO_2) tonnage was calculated, incorporating the energy used for each energy type. The conversion for gas is 0.0053 metric tons CO_2 per therm, and electricity is 7.07×10^{-4} metric tons CO_2 per kWh (Greenhouse Gases Equivalencies Calculator, 2020).

Using the conversions, the tonnage of CO_2 was determined. The remaining data were all gathered from the survey sent out to various people throughout Indiana.

Using a 25% supplementation of energy usage was implemented next. Table 3.2 below shows the table that was used to calculate the information.

Table 3.2: 25% Renewable Energy Supplementation

Residential Household (N)	Aver. Outside Air Temp. (deg. F)	Number of Occupants	Square Feet	Converted kWh	25% Renewable kWh	CO2 Tonnage Saved
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Table 3.3 on page 27 illustrates a supplementation using 50% renewable energy. The supplementation is in the form of solar energy.

Table 3.3: 50% Renewable Energy Supplementation

Residential Household (N)	Aver. Outside Air Temp. (deg. F)	Number of Occupants	Square Feet	Converted kWh	50% Renewable kWh	CO2 Tonnage Saved
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Table 3.4 above illustrates an energy supplementation of 75% renewable energy. Using more energy supplementation lowers the energy bill and the CO_2 tonnage.

Table 3.4: 75% Renewable Energy Supplementation

Residential Household (N)	Aver. Outside Air Temp. (deg. F)	Number of Occupants	Square Feet	Converted kWh	75% Renewable kWh	CO2 Tonnage Saved
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Table 3.5 above utilizes 100% energy supplementation. The supplementation is theoretical as 100% supplementation will not be able to be fully achieved due to the location of Indiana and weather pattern changes.

Table 3.5: 100% Renewable Energy Supplementation

Residential Household (N)	Aver. Outside Air Temp. (deg. F)	Number of Occupants	Square Feet	Converted kWh	100% Renewable kWh	CO2 Tonnage Saved
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Each system was utilized in the data shown in Example 3.1 below to describe the initial cost.

The initial costs were gathered from a set of data collected from installation costs, the first year of savings, repair costs, and escalation and discount rates. Each set of information was gathered to input in to show the final cost analysis.

Life cycle of investment (years)	20
installation cost ($)	-37612
first year energy savings ($)	47168
annual maintenance/repair costs ($)	-188
energy escalation rate (%)	5
repair/maintenance escallation rate (%)	1
discount rate (%)	4

Example 3.1: Input Data for Payback (Purdue University, n.d.)

Having a set of input values allows, as shown from Example 3.1 on page 28, to make creating calculations possible. Calculating out the values of installation cost and first energy savings are very valuable. The values of the life cycle, maintenance, energy escalation, and discount rate are all assumed.

Example 3.2 below analyzes the output to show how the return rate was calculated. One of the most important factors when doing any energy savings project is the payback period. Another big factor is the amount of savings that would be offered over the life cycle.

year	install cost	energy savings	repair & maintenance	cumulative value
	$	$	$	$
0	-37,612	0	0	-37,612
5	0	60,199	-198	203,736
10	0	76,831	-208	456,171
15	1	98,059	-218	720,173
20	6	125,150	-229	996,245

Example 3.2: Example Output Data for Energy Savings Effort (Purdue University, n.d.)

The initial cost is always a critical factor to include in any project. Example 3.2 above shows that the initial cost on year zero is $37,612. Using energy savings and the repair and maintenance placed as an input on Example 3.1 on page 28, the payback will be made in the first year, and by the twentieth year, $1 million was saved.

3.5 Return on Investment

Return on investment is very critical in any project to determine viability. A simple payback can be looked into for any project, but a simple payback does not consider the time value of money. Including the energy escalation rates, repair escalation, and discount rate gives a more accurate representation. The energy savings were calculated as shown in Figure 3.3 below.

$$Energy\ Savings = Previous\ Year\ Accumulated\ Savings * \left(1 + \frac{Energy\ Escalation\ Rate}{100}\right)$$

Figure 3.3: Energy Savings Equation (Purdue University, n.d.)

The next step was calculating the repair and maintenance required. The repair and maintenance equation can be seen in Figure 3.4 below.

$$Repair\ and\ Maintenance\ Cost = Previous\ Year\ Repair\ \&\ Maintenance * (1 + (Repair\ and\ Maintenance\ Escalation\ Rate)/100)$$

Figure 3.4: Repair and Maintenance Costs (Purdue University, n.d.)

After calculating out repair and maintenance costs, a total annual cash flow can be determined. The total annual cash flow formula can be seen in Figure 3.5 below.

$$Annual\ Cash\ Flow = Energy\ Savings + Repair\ and\ Maintenance$$

Figure 3.5: Annual Cash Flow Formula (Purdue University, n.d.)

Present value annual savings is the most complex formula to find a return on investment. Figure 3.6 below shows how present value annual savings is calculated.

$$Present\ Value = \frac{Annual\ Cash\ Flow}{\left(1 + \frac{Discount\ Rate}{100 * compound\ rate}\right)^{Year\ in\ Life\ Cycle * compound\ rate}}$$

Figure 3.6: Present Value Annually Formula (Purdue University, n.d.)

The final equation to find the return on investment is finding the cumulative value. The formula for finding the cumulative value is shown in Figure 3.7 below.

$$Cumulative\ Value = Previous\ Year\ Value + Present\ Total\ Value$$

Figure 3.7: Cumulative Value Equation (Purdue University, n.d.)

Using all the figures to calculate the return on investment is critical not only in solar energy; but also in any investment project (Foster, 2017). Having an understanding of how the return on investment is calculated is very important. Each supplementation value had a separate analysis of how long the return on investment will take.

3.6 Research Methodology Summary

The research method has been laid out throughout Chapter Three. Creating a survey to determine the importance of each part of solar energy gets an initial understanding of the hurdles. After the survey, looking at each location, individual electricity needs, and availability were found. When a good understanding of each need is formed, a system was created. Finally, a return on investment was calculated to understand the feasibility of the project. The overall objective was to offer evidence that all homeowners will look to solar energy to lower carbon emissions.

CHAPTER 4. RESULTS

4.1 Results Summary

The research results illustrate the amount of solar energy that would be required to power a residential home at 25%, 50%, 75%, and 100% of the home's total energy usage. Having each level of supplementation provides different initial capital investments and a different return on investment. The ten homes that were researched all provided square footage, types of utilities the home used, and how much each home spent on utilities. All sources could be converted to a standard unit of energy in kWh, knowing the energy amount. Finding the average amount of kWh through the ten homes provided the information to determine the size PV panel system needed at each home.

The constraints of participation only allowed for ten homes, and most were near Lafayette, IN. As a result, the variance in needs between homes in the northern or southern parts of the state was not considered. Lafayette, IN does provide a city of 70,697 and is located in the central part of the state, which was assumed to be an average location (Lafayette, IN Population 2021).

4.2 Results Objectives

The research intended to show that solar energy can be an affordable alternative to burning fossil fuels with the current technology. The initial capital could be seen as an investment to any homeowner. Having data to show various home sizes and energy needs can allow the homeowner to decide whether a PV solar panel system is right.

4.3 Initial Findings

The data collected from all ten homeowners provided different occupancy levels, square footage, locations, and energy usage. A summary of the electrical demand and energy usage charts can be seen below in Table 4.1 below.

Table 4.1: Residential Home Energy Usage

Residential Household (N)	Aver. Outside Air Temp. (deg. F)	Number of Occupants	Square Feet	Therms/gallons per year	Natural Gas/Propane	Amount in Gas ($)	kWh/year	Amount in Electricity ($)	Converted to kWh	CO2 Tonnage
1	49.5	1	1144	680	Natural Gas	$ 555.02	9,454	$ 1,242.34	29,378.08	36,135.03
2	51	3	2264	791	Natural Gas	$ 698.21	9,147	$ 1,216.16	32,327.28	39,762.56
3	51.5	4	1250	1,000	Natural Gas	$ 563.34	9,230	$ 1,322.66	38,530.11	47,392.04
4	51.5	4	1050	439	Natural Gas	$ 242.38	4,710	$ 1,120.03	17,599.12	21,646.92
5	51.5	5	1800	600	Propane	$ 900.00	9,865	$ 1,200.00	26,657.97	32,789.31
6	51	3	1130	444	Natural Gas	$ 459.39	4,738	$ 516.00	60,390.25	74,280.01
7	51.5	2	3500	1,280	Natural Gas	$ 710.34	11,234	$ 1,754.01	48,738.14	59,947.91
8	51	1	1305	540	Natural Gas	$ 579.12	6,178	$ 1,123.27	22,000.06	27,060.07
9	51.5	2	3400	837	Propane	$ 1,437.82	20,585	$ 2,810.65	44,000.00	54,120.00
10	51	4	4500	-	Geothermal	$ -	23,103	$ 2,601.70	23,103.00	28,416.69

Table 4.1 above reflects the amount of energy that each of the ten homes consumed. The average outside air temperature of each home was derived from the provided zip code (Climate – Indiana, n.d.). When other sources of energy utilized in each home, the gallons of propane (Convert Gallon of LPG to kWh, n.d.) and therms of natural gas (Therms to kWh Conversion, n.d.) were converted to kWh to find a total converted value. The $C0_2$ tonnage was determined using an equation as shown in Figure 4.1 above.

$$CO_2 \text{ tonnage} = \text{Converted to kWh} * 1.23$$

Figure 4.1: CO_2 Tonnage Calculation (Clayton, 2021)

Using the CO_2 tonnage calculation from Figure 4.1 determined the impact each home has on the environment. Averaging the overall amount of kWh and CO_2 tonnage gives a better understanding of the average house throughout Indiana and the impact a solar energy system can provide.

4.4 Statistical Analysis

The data collected illustrates interesting data characteristics. The analyzed characteristics were about square feet, CO_2 tonnage, and electricity usage, to name a few. Each set of data was analyzed through Minitab (Statistical & Data Analysis Software Package 2021, n.d.) to see the common trends among the data collected.

The first set of data that was analyzed was a graphical summary of the converted energy. The data collected can be seen in Figure 4.2 on page 36.

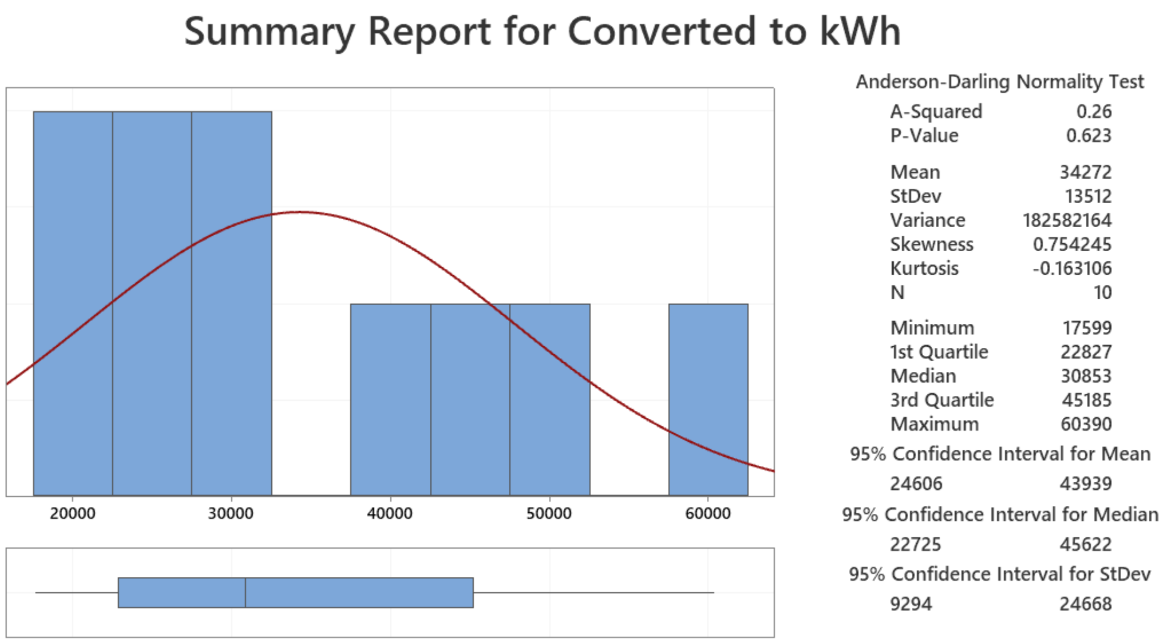


Figure 4.2: Graphical Summary of Converted kWh

As shown in Figure 4.2 above, the data shows the average kWh for all the homes is 34,272 kWh of converted energy. The data collected also shows the distribution among all the data is normal with a right skew.

Using an I-MR chart was also used to look at data collected. Figure 4.3 on page 37 illustrates the converted data to kWh.

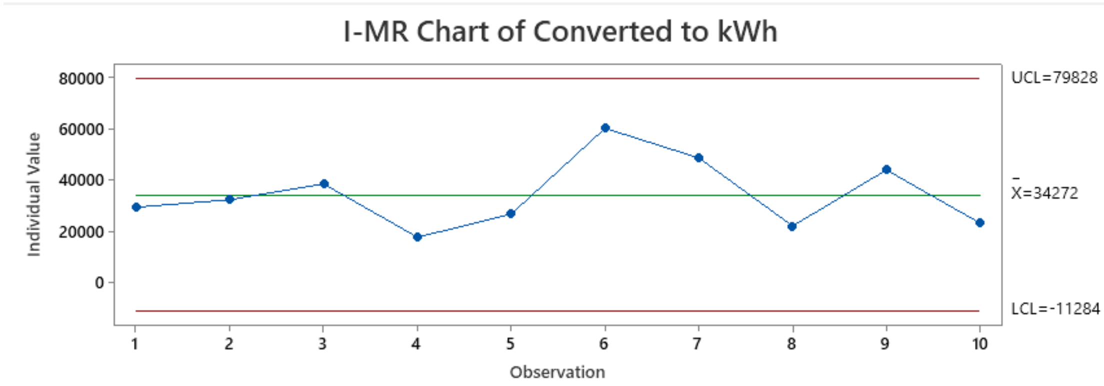


Figure 4.3: I-MR Chart of Converted to kWh

As shown in Figure 4.3 above, the I-MR chart's purpose was to see if the data was consistent. The data shows the upper control limit and lower control limits. The limits are three standard deviations from the mean.

The data collected were placed in a matrix plot to identify possibilities of direct correlations between data points. Figure 4.4 on page 38 shows the geothermal, natural gas, and propane and how they relate to the other variables collected.

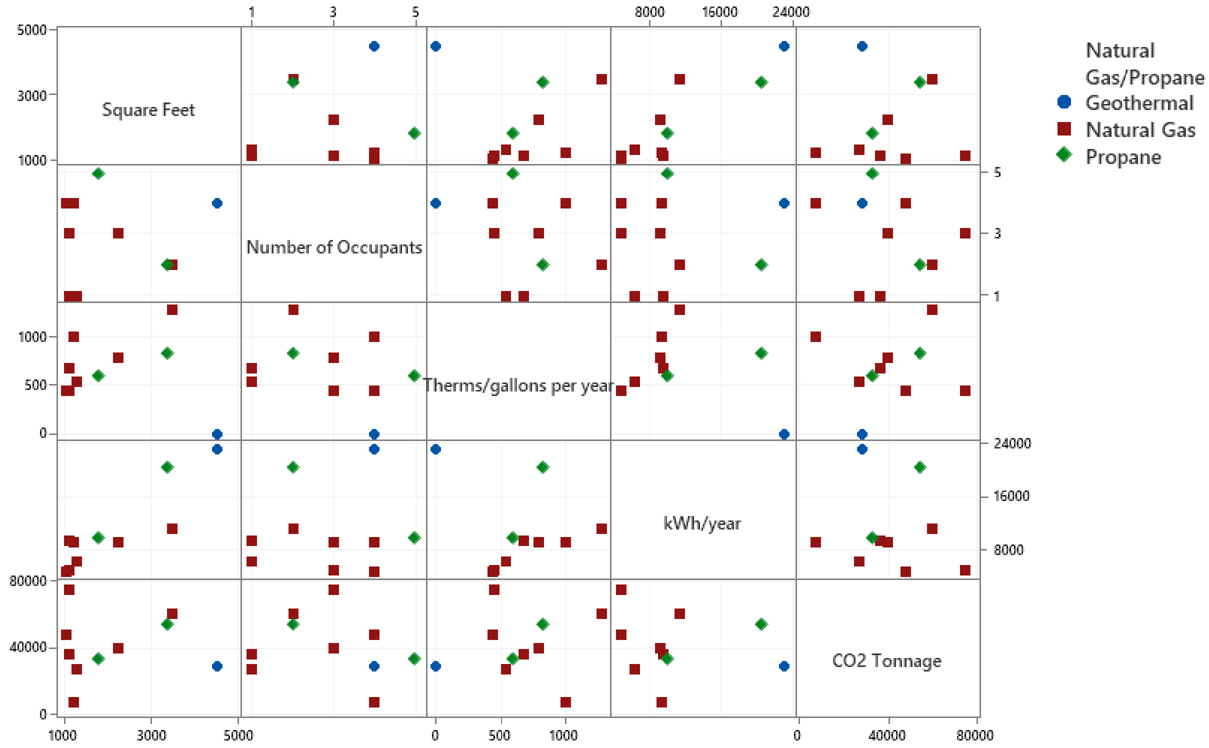


Figure 4.4: Matrix Plot of Collected Data

The analysis in Figure 4.4 above shows the geothermal home, and home number four are outliers. Through plot diagrams of kWh/year, a separation of the two data points are seen. Using the data from the two homes shows a skewed result in a direct comparison of the variables.

The final analysis analyzed was a second matrix plot. House number four and ten were removed as the two homes were considered anomalies due to variances in the plot diagrams including kWh/year and skewed the results. Figure 4.5 on page 39 shows a matrix plot of the data.

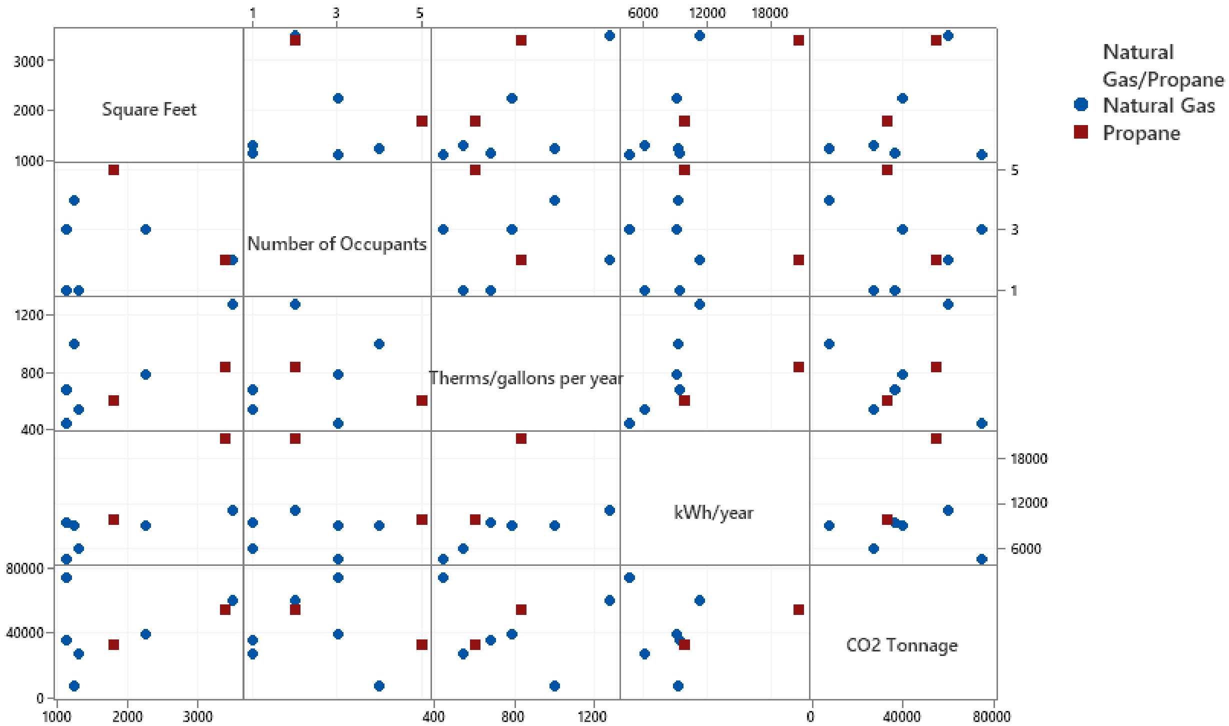


Figure 4.5: Matrix Plot of Collected Data Removing House Four and Ten

Looking at the matrix plot in Figure 4.5 above, the data can be compared through each variable of CO_2 tonnage, kWh/year, therms/gallons per year, number of occupants, and square feet. The bottom left box on the matrix plot, for example, compares CO_2 tonnage to square feet. Using the data can be a quick way to interpret the data from multiple different angles.

Statistical analysis such as matrix plots allows data in research to be quickly analyzed. The data can be interpreted to see how each variable interacts with one another and the data's validity. The data can then be objectively analyzed without subjective interpretation.

4.5 25% Supplementation of Energy

The initial investment of solar energy is to eliminate 25% of the energy required to power the set of homes. The home's energy usage was all averaged to a total of 34,272 kWh per year. With homes connected to the grid, some homes will overproduce the particular home's energy while others will under-produce. The overall amount of energy obtained from the solar panels will cover 25% of the homes' energy.

Table 4.2 below has a breakdown of the supplementation of energy used at each home.

Table 4.2: Converted Energy to 25% Renewable Energy

Residential Household (N)	Aver. Outside Air Temp. (deg. F)	Number of Occupants	Square Feet	Converted kWh	25% Renewable kWh	CO2 Tonnage Saved
1	49.5	1	1144	29,378.08	7,344.52	9,033.76
2	51	3	2264	32,327.28	8,081.82	9,940.64
3	51.5	4	1250	38,530.11	9,632.53	11,848.01
4	51.5	4	1050	17,599.12	4,399.78	5,411.73
5	51.5	5	1800	26,657.97	6,664.49	8,197.33
6	51	3	1130	60,390.25	15,097.56	18,570.00
7	51.5	2	3500	48,738.14	12,184.54	14,986.98
8	51	1	1305	22,000.06	5,500.01	6,765.02
9	51.5	2	3400	44,000.00	11,000.00	13,530.00
10	51	4	4500	23,103.00	5,775.75	7,104.17

The converted data in Table 4.2 above was gathered from the data collected on Table 4.1 on page 34 using the same method as Table 4.1. The data was then analyzed by averaging a 25% reduction in energy usage by supplementing solar energy.

Using 25% of the average of 34,272 kWh will require 8,568 kWh energy per solar panel system. Using an eight kW system in Indiana is projected to achieve 10,878 kWh/year, as shown in Appendix A (National Renewable Energy Laboratory, n.d.). Having an average of $0.138/kWh of the homes collected would allow each home to save $1,500 per year in energy costs.

The found solar kit for an eight kW system by GoGreenSolar (GogreenSolar.com, n.d.) is designed for the average homeowner to install the system without professional help. At the cost of $10,235.11, a system is an affordable option for any homeowner. The system has a 25-year warranty, full technical support, and permit approval. Using a 25-year warranty, the homeowner has 25 years to recover the system's cost.

The economic analysis tool was used to calculate if the solar energy installation is an attractive homeownership option. Table 4.3 below shows the data placed in the economic analysis tool (Purdue University, n.d.).

Table 4.3: Economic Analysis Tool for 25% Supplementation

Life cycle of investment (years)	20
installation cost ($)	-10235.11
first year energy savings ($)	1500
annual maintenance/repair costs ($)	100
energy escalation rate (%)	5
repair/maintenance escallation rate (%)	1
discount rate (%)	4

Using the tool can be very effective in quickly and easily understanding the economic impact of the project. Table 4.3 on page 41 shows the inputs in the economic analysis tool (Purdue University, n.d.). The repair and maintenance are shown as a low cost of $100 per year given the 25-year warranty. Energy rates, discount rates, and maintenance rates are escalating given the change in the economy.

Appendix B shows in year seven, money is recovered, and the solar panels are making money for the homeowner (Purdue University, n.d.). When the 20 year period is over, the homeowner will have a net value of $24,213 (Purdue University, n.d.). Each homeowner in the study should have a very similar payback period due to the homes' rates and proximity.

Having an eight kW system at each home would save 13,379 in CO_2 tonnage (Greenhouse Gas Equivalencies Calculator, 2018). Comparing the greenhouse emissions saved is equivalent to 2,890 passenger vehicles driven for one year or a total of 33,198,511 miles driven (Greenhouse Gas Equivalencies Calculator, 2018). Having the savings in CO_2 tonnage provides longer sustainability of the environment for years to come.

4.6 50%, 75%, and 100% Supplementation of Energy

The same process from 25% implementation were followed for 50%, 75%, and 100% supplementation. All data was collected in the same method as the 25% implementation. The results of the data can be seen in Table 4.4 on page 43.

Table 4.4: Output Results of 50%, 75%, and 100% Energy Supplementation

Supplementation Amount (%)	kWh Needed	Size System Needed (kW)	Actual Output (kWh)	Initial Cost	Annual Savings	Years to Pay Back	Net Value After 20 Years	Yearly Savings (CO2 Tonnage)
50	17136	15	20,395	$17,804.96	$ 2,814	6	$ 45,522	25,085.85
75	25704	20	27,194	$22,863.84	$ 3,752	6	$ 61,078	33,448.62
100	34272	30	40,791	$43,348.62	$ 5,629	8	$ 81,846	50,172.93

Table 4.4 above shows that as the supplementation amount increases, the net value over a 20 year period also increases. As the value increases, the more money the homeowner obtains from the energy savings.

The data collected provided three main takeaways. The first takeaway illustrated that in the four different levels of supplementation, the payback was less than ten years. The second takeaway was the savings in CO_2 emissions was evident by almost 13,000 tons with the 25% savings. The final takeaway from the data collected was the cost for installation. The $10,235.11 buy in for an eight kW system is affordable for homeowners.

CHAPTER 5. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

5.1 Summary

Solar energy over the last twenty years has become a topic for a renewable energy source. Cost savings and research are utilized more, with solar energy used more often. Utilizing government grants and the inherent benefits of using renewable energy instead of fossil-burning fuels makes the cost savings desirable.

Lowering CO_2 emissions to preserve the environment while saving money is another benefit of using solar energy. Indiana will face significant problems by the turn of the century. Public health could be significantly affected by low air quality causing respiratory issues and asthma attacks (Fitzpatrick, Freese, & Wadsworth, 2009). Agriculture would also be devastated due to a significant number of days over 100 degrees Fahrenheit and flooding (Fitzpatrick, Freese, & Wadsworth, 2009).

Using a research method of collecting data from homeowners is a critical path to completion. Google Forms was used to input the homeowner’s current energy rates of the last year. The home’s location also gave a foundation to start the research. Having the homeowner know how to read the bills and interpret them was a common struggle. Many of the homeowners required assistance in how to interpret their bills.

The data collected was transferred to a single unit of measure for ease of interpretation. Changing all the energy usage to kWh allowed a more straightforward analysis of the solar panel system required. After using the total energy, an analysis of each of the supplement levels could be determined.

When the energy requirements at each home were analyzed, the solar panel system was selected. Having the solar panel system selected allowed for a payback period to be analyzed. Using a more complex payback period using inflation rates, interest, and even maintenance costs provided the best investment return.

5.2 Conclusions

The Midwest is known for having a lack of solar energy. Throughout central Indiana, the EDR is 110 milliwatts per meter squared (mWm^{-2}) in comparison to Florida, which receives 200 mWm^{-2} (Zhang et al, 2019). Having a higher EDR leads to greater energy output (Zhang et al, 2019). Consumers have deemed Indiana's lack of solar energy to not being able to have a quick return on investment. While the return is not as much in states closer to the equator, such as Texas or Florida, a quick payback is possible.

Throughout the study, homes were selected strictly throughout Indiana. The homes selected were from various home sizes and locations. While the homes were selected at random, the group selected was not. Having a limited number of people willing to put forth the time and effort to give data was a problem.

After the homes' energy rates were added together, an average was created for the amount of energy needed to power the homes. Using a solar array of different sizes and heating sources provided a solid foundation for analysis. The homeowners were expected to mount the solar system on their roof, and the homeowner would install themselves.

The data collected showed the homes required an average of 34,272 kWh to power the home entirely. Table 5.1 below illustrates the four different supplementation levels, the payback period, the net value after 20 years, and the yearly CO_2 tonnage saved. Using the data from table one allows for a quick understanding of the data collected.

Table 5.1: Final Results

Supplementation Amount (%)	kWh Needed	Size System Needed (kW)	Actual Output (kWh)	Initial Cost	Annual Savings	Years to Pay Back	Net Value After 20 Years	Yearly Savings (CO2 Tonnage)
25	8568	8	10,878	$10,235.11	$ 2,815	7	$ 24,213	13,379
50	17136	15	20,395	$17,804.96	$ 2,814	6	$ 45,522	25,086
75	25704	20	27,194	$22,863.84	$ 3,752	6	$ 61,078	33,449
100	34272	30	40,791	$43,348.62	$ 5,629	8	$ 81,846	50,173

Table 5.1 above uses the data collected to analyze the amount saved in money and CO_2 tonnage. The table shows increasing the system size, a nearly proportional value of net value after 20 years and yearly savings. Figure 5.1 on page 47 illustrates the nearly direct proportion of system size versus the net value.

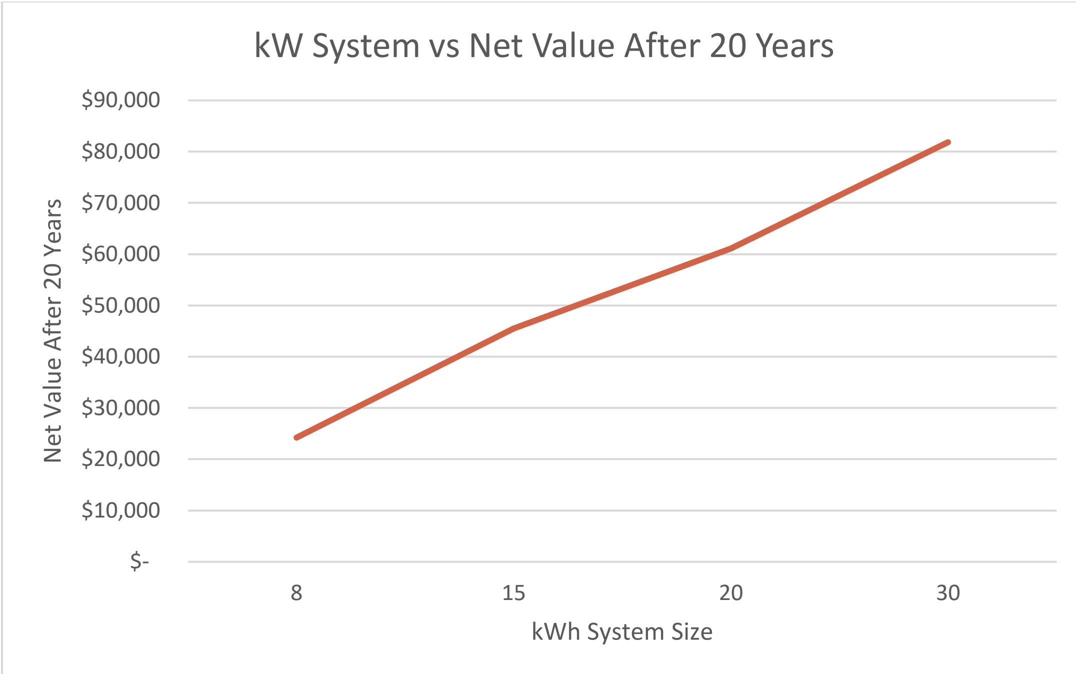


Figure 5.1: kW System Needed vs. Net Value After 20 Years

Having a direct proportion is expected for the size of the system and the net value. The values must adjust from inflation costs and maintenance costs over the lifetime of the panels.

Figure 5.2 on page 48 illustrates the comparison from the system size to the amount of CO_2 saved each year.

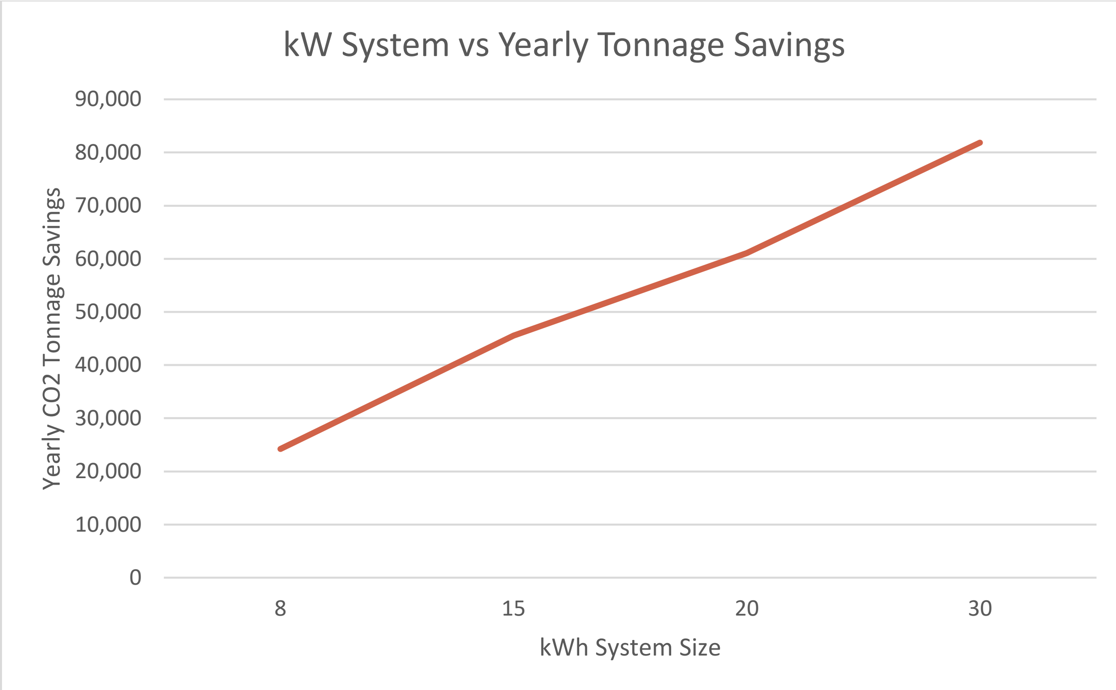


Figure 5.2: kW System Needed vs. Yearly Tonnage Savings

The direct proportion of size and tonnage savings is expected. The amount of tonnage is based on the number of kWh saved. Each system has a variance in the output based on the size of the system.

The final results of the research were similar to the expected results of seven years. Having a payback of six or seven years, depending on the system's size, is very attainable. To fully understand the results, more data must be collected to prove the results further. Larger sample size of more than 10 homes is going to provide more opportunities to eliminate outliers in the analysis.

Knowing the results provide an attainable payback period for most homeowners provides a more attractive path for lawmakers and builders alike. Government policies to try to implement in new building requirements and incentives could offer benefits to the future. Builders could also use the information as incentives for new homeowners to build solar systems in the initial build.

Researchers can also see the value in adding to the current systems. Having a lower payback period can entice more homeowners to buy solar panel systems. The continued evolution of energy-efficient products will continue, and researchers should see an opportunity to help. Lowered carbon emissions are an essential need for sustainability for the future (Fitzpatrick, Freese, & Wadsworth, 2009).

Having improved solar energy systems will have a significant impact on the homeowner's financials. From the eight kW system saving $24,213 in 20 years to $81,846 on the 30 kW system, an attractive financial benefit is found. Every homeowner capable of the initial investment should look at the possibility of solar systems for their homes.

5.3 Recommendations

Using a return rate of six or seven years provides an attractive and affordable option for all homeowners. Having a return on investment of less than ten years while protecting the environment is a positive in all facets. Everyone needs to help save the environment by limiting the carbon footprint. Having solar panels is one way to make an impact to reducing the carbon emissions.

Further research of solar panels with larger sample size of home energy data only provides better opportunities of reducing the carbon footprint. Homeowners will purchase solar panels with more efficient systems and more research available. Having efficient systems in the future will only further the argument to have more solar panel systems in residential areas. Each person needs to advocate for preserving the future for all, and solar energy is one solution.

LIST OF REFERENCES

Allam, Eslam. (2017). *7 Most Popular Solar PV Design and Simulation Software.* Retrieved October 25, 2020, from https://www.linkedin.com/pulse/7-most-popular-solar-pv-design-simulation-software-eslam-allam/

An Exelon Company. (n.d.). Retrieved October 27, 2020, from https://www.peco.com/MyAccount/MyBillUsage/Pages/HomeElectricBillpg1.aspx

Anderson-Darling Test. (n.d.). Retrieved February 27, 2021, from https://www.itl.nist.gov/div898/handbook/eda/section3/eda35e.htm

Clayton, J. (n.d.). *1 kilowatt-hour*. Retrieved February 21, 2021, from https://blueskymodel.org/kilowatt-hour

Climate - Indiana. (n.d.). Retrieved November 29, 2020, from https://www.usclimatedata.com/climate/indiana/united-states/3184

Convert gallon [U.S.] of LPG to kWh - conversion of measurement units. (n.d.). Retrieved February 21, 2021, from https://www.convertunits.com/from/gallon+[U.S.]+of+LPG/to/kWh

Dillon, Mathew. (n.d.). *The Long View: Indiana's Energy Outlook*. n.d.). Retrieved September 16, 2020, from https://www.ibrc.indiana.edu/ibr/2015/outlook/longview.html

Dusty Solar Panels Slash Power Output by Over 35%, Study Reveals. (2019, April 19). Retrieved November 29, 2020, from https://www.zmescience.com/ecology/renewable-energy-ecology/solar-panels-dust-output/

Gogreensolar.com. (n.d.). Retrieved February 27, 2021, from https://www.gogreensolar.com/

Er, Z. (2016). *A Study of Evaluation of Solar Energy Simulation and Modeling Systems*. Acta Physica Polonica, A, 130(1), 72-77.

Fingas, J. (2020, February 27*). California to require solar panels on most new homes.* Retrieved November 28, 2020, from https://www.engadget.com/2018-05-06-california-to-require-solar-panels-on-most-new-homes.html

Fitzpatrick, M., & Freese, B. (2009). *Confronting Climate Change in the U.S. Midwest* (996615267 769446531 B. Wadsworth, Ed.). Union of Concerned Scientists.

Foster, C. (2017). *Designing learning and development for return on investment* (First ed., Finance and financial management collection).

Geagea, Georges, Batache, Abdallah, El Zakhem, Henri, & Moufarej Abou Jaoude, Marie-Thérèse. (2018). *Enhancing Photovoltaic solar panel Raising efficiency of photovoltaic solar panel by preventive actions*. MATEC Web of Conferences, 171, 1005.

Greenhouse Gases Equivalencies Calculator. (2020, May 27). Retrieved November 29, 2020, from https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references

Helm, D. (2017). *Burn out : The endgame for fossil fuels*. ProQuest Ebook Central https://ebookcentral.proquest.com

How to Measure Solar Panel Output. (n.d.). Retrieved October 25, 2020, from https://www.vivintsolar.com/learning-center/how-calculate-solar-panel-output

Hyder, Z. (2020, September 10). *What is a solar farm? Costs, land needs & more*. Retrieved November 28, 2020, from https://www.solarreviews.com/blog/what-is-a-solar-farm-do-i-need-one

Indiana Solar. (n.d.). Retrieved September 16, 2020, from https://www.seia.org/state-solar-policy/indiana-solar

Kumar, D. (2019). *MATLAB Simulation Model of Hybrid Wind-Solar Energy System using MPPT Algorithm using a Converter Topology*. International Journal for Research in Applied Science and Engineering Technology, 7(3), 1704-1710.

Lafayette, Indiana population 2021. (n.d.). Retrieved March 31, 2021, from https://worldpopulationreview.com/us-cities/lafayette-in-population

LG Solar 72-Cell Solar Panels for Commercial Installation Available this Summer. (2016). Newstex Trade & Industry Blogs, Newstex Trade & Industry Blogs, 2016-07-14.

Liu, Zhijian, Li, Hongqiang, & Li, Guiqiang. (2019). *Special Issue for Building Energy Conservation and Renewable Energy Integration.* Journal of Thermal Science, 28(6), 1103.

Mass, Clifford F, & Ovens, David. (2019*). The Northern California Wildfires of 8–9 October 2017: The Role of a Major Downslope Wind Event. Bulletin of the American Meteorological Society*, 100(2), 235-256.

Mohlin, Kristina, Bi, Alex, Brooks, Susanne, Camuzeaux, Jonathan, & Stoerk, Thomas. (2019). Turning the corner on US power sector CO2 emissions—a 1990–2015 state level analysis. *Environmental Research Letters*, 14(8), 84049.

Moorman, Christopher E, Grodsky, Steven M, & Rupp, Susan. (2019). *Renewable Energy and Wildlife Conservation (Wildlife management and conservation).* Baltimore: Johns Hopkins University Press.

Moshammer, H., Simic, S., & Haluza, D. (2016, October 24). *UV "Indices"-What Do They Indicate?* Retrieved November 28, 2020, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5086780/

NAE Grand Challenge for Engineering. (2019). Retrieved September 12, 2020 from http://www.engineeringchallenges.org/9136.aspx

National Renewable Energy Laboratory (NREL). (n.d.). Retrieved November 01, 2020, from https://www.nrel.gov/

Purdue University. (n.d.*). Compute | Asmt 5.A – Economic Analysis*. Retrieved October 25, 2020 from Purdue University Engage: https://engage.purdue.edu/learn/mod/assign/view.php?id=157828

Raymond, Leigh; Gotham, Douglas; McClain, William; Mukhopadhyay, Sayanti; Nateghi, Roshanak; Preckel, Paul V.; Schubert, Peter; Singh, Shweta; Wachs, Liz; Widhalm, Melissa; and Dukes, Jeffrey, "Climate Change and Indiana's Energy Sector: A Report from the Indiana Climate Change Impacts Assessment" (2019). *Energy Reports.* Paper 1. http://dx.doi.org/10.5703/1288284316878

Roser, H. R. and M. (n.d.). *CO2 emissions*. Our World in Data. https://ourworldindata.org/co2-emissions.

Sendy, A. (2020, November 07). *How much do solar panels save in 2020?* Retrieved November 28, 2020, from https://www.solarreviews.com/blog/what-is-the-average-solar-savings-for-a-residential-solar-installation-in-the-us

Solar Industry Research Data. (n.d.). Retrieved November 28, 2020, from https://www.seia.org/solar-industry-research-data

Spaulding, A. (2018, December 19). *Readers React: How to make home solar panels affordable by tweaking the 30-year mortgage*. Retrieved November 28, 2020, from https://www.latimes.com/opinion/readersreact/la-ol-le-solar-power-install-homes-20181219-story.html

Statistical & Data Analysis Software Package 2021. (n.d.). Retrieved February 27, 2021, from https://www.minitab.com

Szabo, L. (2017). *The history of using solar energy*. 1-8.

Therms (US) TO KILOWATT-HOURS CONVERSION. (n.d.). Retrieved February 21, 2021, from https://www.metric-conversions.org/energy-and-power/therms-us-to-kilowatt-hours.htm

U.S. Department of Energy. (2016). *State of Indiana ENERGY SECTOR RISK PROFILE* [Brochure]. Indianapolis, IN: Author.

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis. (n.d.).

United States: Vectren proposal commits SW Indiana to fossil fuel dependence. (2018). *MENA Report*, Retrieved from https://search.proquest.com/docview/2006947046?accountid=13360

Wynder, E. (2019). *Solar panels improve home sales*. Grand Rapids Business Journal, 37(29), 5.

Xiong, D., Shi, P., Zhang, X., & Zou, C. (2016, July 26). Effects of GRAZING exclusion on carbon sequestration and plant diversity in grasslands Of CHINA-A META-ANALYSIS. Retrieved March 30, 2021, from https://www.sciencedirect.com/science/article/pii/S0925857416304499

Zhang, Huanxin, Wang, Jun, Castro García, Lorena, Zeng, Jing, Dennhardt, Connor, Liu, Yang, & Krotkov, Nickolay A. (2019). *Surface erythemal UV irradiance in the continental United States derived from ground-based and OMI observations: Quality assessment, trend analysis and sampling issues*. Atmospheric Chemistry and Physics, 19(4), 2165-2181.

APPENDIX A: 8KW SYSTEM DATAT IN INDIANA

RESULTS

Print Results

12,237 kWh/Year*

System output may range from 11,712 to 12,552 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.88	692	102
February	3.56	760	112
March	4.58	1,063	157
April	5.66	1,207	179
May	6.16	1,341	198
June	6.51	1,315	195
July	6.43	1,317	195
August	6.16	1,271	188
September	5.52	1,113	165
October	4.06	897	133
November	3.21	724	107
December	2.28	538	80
Annual	**4.75**	**12,238**	**$ 1,811**

APPENDIX B: ECONOMIC PAYBACK OF 25% SUPPLEMENTATION

year	install cost $	energy savings $	repair & maintenance $	change in worker Productivity $	total annual cash flow $	present value total annual $	cumulative value $
0	-10,235	0	0	0	-10,235	-10,235	-10,235
1	0	1,575	101	0	1,676	1,610	-8,625
2	0	1,654	102	0	1,756	1,621	-7,004
3	0	1,736	103	0	1,839	1,632	-5,372
4	0	1,823	104	0	1,927	1,643	-3,729
5	0	1,914	105	0	2,020	1,654	-2,075
6	0	2,010	106	0	2,116	1,665	-410
7	0	2,111	107	0	2,218	1,677	1,267
8	0	2,216	108	0	2,324	1,689	2,956
9	0	2,327	109	0	2,436	1,701	4,657
10	0	2,443	110	0	2,554	1,713	6,370
11	0	2,566	112	0	2,677	1,725	8,095
12	0	2,694	113	0	2,806	1,738	9,833
13	0	2,828	114	0	2,942	1,751	11,584
14	0	2,970	115	0	3,085	1,764	13,348
15	1	3,118	116	0	3,234	1,777	15,125
16	2	3,274	117	0	3,392	1,790	16,915
17	3	3,438	118	0	3,556	1,804	18,719
18	4	3,610	120	0	3,730	1,818	20,536
19	5	3,790	121	0	3,911	1,831	22,368
20	6	3,980	122	0	4,102	1,846	24,213
			net present value of life-cycle cash flows			24,213	24,213

APPENDIX C: 15 kW SYSTEM DATA IN INDIANA

RESULTS

Print Results

20,395 kWh/Year*

System output may range from 19,521 to 20,920 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.88	1,153	159
February	3.56	1,266	175
March	4.58	1,772	245
April	5.66	2,012	278
May	6.16	2,235	308
June	6.51	2,191	302
July	6.43	2,196	303
August	6.16	2,119	292
September	5.52	1,854	256
October	4.06	1,495	206
November	3.21	1,206	166
December	2.28	896	124
Annual	4.75	20,395	$ 2,814

APPENDIX D: ECONOMIC PAYBACK OF 50% SUPPLEMENTATION

year	install cost	energy savings	repair & maintenance	change in worker Productivity	total annual cash flow	present value total annual	cumulative value
	$	$	$	$	$	$	$
0	-17,805	0	0	0	-17,805	-17,805	-17,805
1	0	2,955	101	0	3,056	2,936	-14,869
2	0	3,102	102	0	3,204	2,958	-11,910
3	0	3,258	103	0	3,361	2,981	-8,929
4	0	3,420	104	0	3,524	3,004	-5,925
5	0	3,591	105	0	3,697	3,027	-2,898
6	0	3,771	106	0	3,877	3,051	154
7	0	3,960	107	0	4,067	3,075	3,229
8	0	4,158	108	0	4,266	3,099	6,328
9	0	4,365	109	0	4,475	3,124	9,452
10	0	4,584	110	0	4,694	3,149	12,600
11	0	4,813	112	0	4,924	3,174	15,774
12	0	5,054	113	0	5,166	3,199	18,974
13	0	5,306	114	0	5,420	3,225	22,199
14	0	5,572	115	0	5,686	3,251	25,450
15	1	5,850	116	0	5,966	3,278	28,727
16	2	6,143	117	0	6,260	3,304	32,032
17	3	6,450	118	0	6,568	3,331	35,363
18	4	6,772	120	0	6,892	3,359	38,722
19	5	7,111	121	0	7,232	3,386	42,108
20	6	7,466	122	0	7,588	3,414	45,522
			net present value of life-cycle cash flows			45,522	45,522

APPENDIX E: 20 kW SYSTEM DATA IN INDIANA

RESULTS

Print Results

27,194 kWh/Year*

System output may range from 26,027 to 27,893 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.88	1,537	212
February	3.56	1,688	233
March	4.58	2,363	326
April	5.66	2,682	370
May	6.16	2,980	411
June	6.51	2,922	403
July	6.43	2,927	404
August	6.16	2,826	390
September	5.52	2,472	341
October	4.06	1,994	275
November	3.21	1,608	222
December	2.28	1,195	165
Annual	4.75	27,194	$ 3,752

APPENDIX F: ECONOMIC PAYBACK OF 75% SUPPLEMENTATION

year	install cost	energy savings	repair & maintenance	change in worker Productivity	total annual cash flow	present value total annual	cumulative value
	$	$	$	$	$	$	$
0	-22,864	0	0	0	-22,864	-22,864	-22,864
1	0	3,940	101	0	4,041	3,882	-18,981
2	0	4,137	102	0	4,239	3,913	-15,068
3	0	4,343	103	0	4,446	3,944	-11,124
4	0	4,561	104	0	4,665	3,976	-7,148
5	0	4,789	105	0	4,894	4,008	-3,140
6	0	5,028	106	0	5,134	4,040	901
7	0	5,279	107	0	5,387	4,073	4,974
8	0	5,543	108	0	5,652	4,106	9,080
9	0	5,821	109	0	5,930	4,140	13,219
10	0	6,112	110	0	6,222	4,174	17,393
11	0	6,417	112	0	6,529	4,208	21,601
12	0	6,738	113	0	6,851	4,243	25,843
13	0	7,075	114	0	7,189	4,278	30,121
14	0	7,429	115	0	7,544	4,313	34,434
15	1	7,800	116	0	7,916	4,349	38,783
16	2	8,190	117	0	8,307	4,385	43,168
17	3	8,600	118	0	8,718	4,422	47,590
18	4	9,030	120	0	9,149	4,459	52,048
19	5	9,481	121	0	9,602	4,496	56,544
20	6	9,955	122	0	10,077	4,534	61,078
			net present value of life-cycle cash flows			61,078	61,078

APPENDIX G: 30 kW SYSTEM DATA IN INDIANA

RESULTS

Print Results

40,791 kWh/Year*

System output may range from 39,041 to 41,839 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)	Value ($)
January	2.88	2,306	318
February	3.56	2,532	349
March	4.58	3,545	489
April	5.66	4,023	555
May	6.16	4,470	617
June	6.51	4,382	605
July	6.43	4,391	606
August	6.16	4,238	585
September	5.52	3,708	512
October	4.06	2,991	413
November	3.21	2,412	333
December	2.28	1,792	247
Annual	4.75	40,790	$ 5,629

APPENDIX H: ECONOMIC PAYBACK OF 100% SUPPLEMENTATION

year	install cost $	energy savings $	repair & maintenance $	change in worker Productivity $	total annual cash flow $	present value total annual $	cumulative value $
0	-43,349	0	0	0	-43,349	-43,349	-43,349
1	0	5,910	101	0	6,011	5,776	-37,572
2	0	6,206	102	0	6,308	5,824	-31,749
3	0	6,516	103	0	6,619	5,872	-25,877
4	0	6,842	104	0	6,946	5,921	-19,956
5	0	7,184	105	0	7,289	5,970	-13,986
6	0	7,543	106	0	7,650	6,020	-7,966
7	0	7,921	107	0	8,028	6,070	-1,896
8	0	8,317	108	0	8,425	6,121	4,225
9	0	8,732	109	0	8,842	6,172	10,397
10	0	9,169	110	0	9,280	6,224	16,621
11	0	9,628	112	0	9,739	6,277	22,898
12	0	10,109	113	0	10,222	6,330	29,228
13	0	10,614	114	0	10,728	6,384	35,612
14	0	11,145	115	0	11,260	6,438	42,050
15	1	11,702	116	0	11,818	6,493	48,542
16	2	12,287	117	0	12,405	6,548	55,090
17	3	12,902	118	0	13,020	6,604	61,694
18	4	13,547	120	0	13,666	6,660	68,354
19	5	14,224	121	0	14,345	6,717	75,071
20	6	14,935	122	0	15,057	6,775	81,846
					net present value of life-cycle cash flows	81,846	81,846