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Process Development For Evaluating Utility Scale Solar At A Combined Heat and Power Facility

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PROCESS DEVELOPMENT FOR EVALUATING UTILITY SCALE SOLAR AT A COMBINED HEAT AND POWER FACILITY

A Thesis

Submitted to the Faculty

of

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by

Samuel J. Landry

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I would like to dedicate this work to my family as they have given me the strength and ambition to continue on through my education and pursue my goals. Without my families support I may not have been able to get to this point in my life and I am thankful for that gift every day.

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LIST OF ABBREVIATIONS

BTU – British Thermal Unit

CHP – Combined Heat and Power

CO_2 – Carbon Dioxide

CPP – Clean Power Plan

DOE – Department of Energy

DSIRE – Department of Energy Database of State Incentives for Renewables & Efficiency

EERE – Energy Efficiency & Renewable Energy

EIA – Energy Information Administration

EPA – Environmental Protection Agency

GHG – Green House Gas

IGA – Indiana General Assembly

NCSL- National Conference of State Legislatures

OAT – Outside Air Temperature

PPA – Power Purchase Agreement

PV – Photovoltaic

RPS – Renewable Portfolio Standard

RTP – Real Time Pricing

GLOSSARY

Combined Heat and Power – "Combined heat and power (CHP), also known as cogeneration, is the simultaneous production of electricity and heat from a single fuel source, such as: natural gas, biomass, biogas, coal, waste heat, or oil " (Environmental Protection Agency, "Combined Heat and Power Partnership")

Degree Days – "A "degree day" is determined by comparing the daily average outdoor temperature with a defined baseline temperature for indoor comfort (in this case, (65°F)." (Environmental Protection Agency, "Heating and Cooling Degree Days")
.
Photovoltaic – "Solar cells, also called photovoltaic (PV) cells by scientists, convert sunlight directly into electricity. PV gets its name from the process of converting light (photons) to electricity (voltage), which is called the PV effect." (National Renewable Energy Laboratory, "Learning About Renewable Energy")

Utility Scale – "For this paper, "utility-scale" is defined as projects 5 MW or larger. These projects were either publicly announced and hold a long-term power purchase agreement or were announced directly by a utility." (National Renewable Energy Laboratory, "Utility-Scale Concentrating Solar Power and Photovoltaics Projects: A Technology and Market Overview")

ABSTRACT

Landry, Samuel J. M.S., Purdue University, December 2015. Economic Analysis and Appraisal of Utility Scale Solar on a Combined Heat and Power Facility. Major Professor: William Hutzel.

When considering the value of utility scale solar project and its impact, there are many variables to weigh and this can become a complex task without guidance. One key to a successful project is the ability to organize ideas and break down problems by sections. An array is only as valuable as the energy that it offsets. The rates that are offered in complex generation scenarios often vary from the more stable rates seen by residential spaces. Because of this, an investment in a solar array may not have the same straight forward payback as a residence. Essentially, the array's value is restricted by the rate that the utility is charging, which is driven by predictive variables. This could either be beneficial to the payback of the investment or detrimental depending on the rates being avoided. By systematically analyzing weather data, utility pricing trends, performance, and energy escalation, a process was produced to deliver clarity as to the value of a utility scale solar array. With these topics covered, combined with a projection of value, an understanding of the opportunities ahead has become clear.

CHAPTER 1. INTRODUCTION

1.1 Introduction

This chapter provides the necessary background for the following research. The scope and breadth of the valuation of a solar photovoltaic (PV) system at a combined heat and power (CHP) facility will be discussed in order to build relevance as well as form the outline for the assumptions, limitations, and delimitations of the analysis.

1.2 Statement of Purpose

The purpose of this research was to develop a process to analyze the potential for utility scale solar investment at a combined heat and power facility and the economics of defining what a kilowatt hour means in terms its time sensitive historic value. The objective is to develop further understanding of the characteristics of such an installation so that further considerations can be made for investment. The findings will define a process to take in order for other interested combined heat and power facilities with similar characteristics to carry out their own investigations.

1.3 Research Question

What is the value of a kilowatt hour of electricity from solar photovoltaic electricity at a facility that operates its own cogeneration heat and power facility? This analysis specifically focuses on the production value as it relates to time and value prediction based on consumption and demand trends.

1.4 Scope

The following analysis was limited to the economic values and weather experienced by Purdue University, the location at which this study has taken place. The process developed thereafter has been adapted for use by other institutions that operate cogeneration power facilites by using their own utility costs and weather data. In this case, Purdue University is located in the Midwest of the United States where coal is abundant and natural gas is of low cost, resulting in some of the lowest electrical utility prices in the country.

Purdue University is unique to this because it provides some of its own energy. The remaining energy is purchased from the local utility at two separate rate structures. The first is purchased a year ahead and makes up the base supply of energy to the campus. The second is purchased if Purdue's utility cannot meet the demand, or it is economically beneficial to purchase from the local utility. These rates change every hour and Purdue's utility is notified of the prices one day in advance. These changes are affected by, but not limited to, factors such as weather, resource supply, demand, and regulations. With the solar energy market rapidly developing and the dynamic change of fossil fuel based generation, this research will attempt to characterize and understand these moving targets for the scenario given.

1.5 Significance

Environmental concerns create pressure for research in alternative energy sources. This, in conjunction with the decreasing cost of renewable energy, provides substantial justification for this research to be conducted.

1.5.1 Environmental Concerns

The risks of the continually increasing rates of energy consumption are well known. In 2011, United States' CO_2 emissions were recorded at 5,481 million metric tons. The largest contributor to this total comes from 2,299 million metric tons of petroleum, which is synonymous with supplying the energy for most types of transportation. Second is 1,874 million metric tons of coal, most commonly associated with the production of utility scale electricity. In terms of overall energy, coal only represents 17.3 quadrillion Btu or 18% of the 95 quadrillion consumed each year. To give perspective, 91% of annual coal powered electricity production, accounts for nearly 1,705 million metric tons of CO_2, 31% of 2011's total emissions (U.S. Energy Information Administration, 2011).

1.5.2 Indiana Electricity Scenario

Coal is an abundant resource used for electricity production in the Midwest. This region benefits from the comparatively low cost of electricity due to this resource and its proximity to the consumer. According to the U.S. EIA (2012), Indiana is ranked 10^{th} in total energy consumption per capita at 426 million Btu, 8^{th} in total CO_2 emissions at 207 million metric tons, and 7th in total coal production at 36,720 thousand short tons. When combined, energy consumption by source states that Indiana places 2nd in coal use.

Indiana's State Utility Forecasting Group (SUFG) estimates that the rate of electricity will increase 1.29% annually between 2013 and 2030. Although the increased price is expected to deter consumption increases, increased consumption will most likely continue due to population growth and improved quality of life.

Currently, Indiana only has a voluntary renewable portfolio standard (RPS) to encourage renewables. If enforced it would define a requirement for the state that would specify a percentage of total energy produced from renewables. According to the U.S. Department of Energy's Database of State Incentives for Renewables & Efficiency (DSIRE2015), the state has a goal to achieve 7% of its energy through renewables from 2019 to 2024, and 10% by 2025. Utilities can purchase or trade Clean Energy Credits to meet this goal, but ultimately this goal is not concrete or enforced so the overall amount of renewable energy is unlikely to change.

1.6 Assumptions

- The price of electrical energy will increase according to projections by the Indiana's State Utility Forecasting Group
- Electrical energy consumption quantities will follow past trends
- Wade Utility plant will make production decisions based on economic interest

1.7 Limitations

- Solar intensity data collected will be used to estimate past production when solar production is not available.
- Characteristics of the solar array other than production will not be analyzed
- The analysis does not monetize social, environmental, or research benefits from having solar photovoltaics

1.8 Delimitations

- This study did not attempt to analyze changes to local, state, or federal renewable energy policies
- Costs associated with new EPA mandates were not be predicted or implemented
- Storage possibilities were not analyzed
- Demand side management was not included in the valuation or analysis
- Interconnection arrangement estimates were not detailed in the economics
- Extreme weather was not analyzed or predicted

1.9 Summary

This study evaluates the value of solar production in the context of Purdue University's combined heat and power facility. This is a complex computation because there are several factors that determine the cost of electrcity generation. The scenario presented explains the significance of each kilowatt hour of potential solar electricity and opens the door for further investigation of other alternative energy sources. Combined with the pressure created by environmental, economic, and social concerns the move to renewable alternatives from fossil fuel generated power is steadily increasing.

CHAPTER 2. REVIEW OF LITERATURE

2.1 Introduction

In the energy production field, many considerations have to be made including regulations, market trends, accelerated development, and potential environmental fallout. At the completion of this section, a picture of the current state of energy production and the catalyst of this research will be established.

2.2 Energy Consumption

According to the U.S. Department of Energy's (DOE) and the office of Energy Efficiency & Renewable Energy (EERE), Indiana ranked 9th in per capita energy consumption in 2010. This data shows an annual increase in electricity consumption equal to 1.8% between 1980 and 2010. The Energy Information Administration's (EIA) projects a rate of 0.8% per year increase of consumption through 2030 which in turn means that electrical generation capacity to meet demand will be nearly 43% larger than the infrastructure in 2011. Specifically residential electricity consumption per capita in Indiana is 5,204 kWh which is higher than the U.S. average of 4,566 kWh. (EERE, 2015)

2.3 Emissions

An increasingly concerning issue around the globe is the total carbon dioxide emissions attributed to human production through normal activities. The processes in which energy is produced and the increasing quality of life seen by humans shows a strong relationship with total greenhouse gasses present in the atmosphere. Naturally, the atmosphere holds a certain amount of carbon which is part of the earth's carbon cycle, a system which the earth regulates its carbon distribution, but this is a fairly delicate operation. With this in mind, new rules proposed by the United States Environmental Protection Agency (EPA) target power plants in order to lower greenhouse gas (GHG) emissions.

The Clean Power Plan (CPP) as it is called, sets goals for each state based on their average emission rates. These goals are expected to be achieved by 2030 and to be sustained in the future, while interim goals can be seen in sections between the implementation of this ruling and the expected completion date. Again these rulings will be state specific in order to accommodate each state's specific needs and limitations. The common reaction to this movement was that the states should have the authority govern their own implementation of this regulation so that they can meet their own needs based on the scenarios that are unique to them. (NCSL, 2015)

2.4 EPA Regulation

The concern within states is understandable as they most likely understand their own limitations more accurately than an over seeing authority, however an issue of leniency occurs. Indiana in particular has urged the EPA to respect the primacy of the specific economic needs of the state and to understand that states require flexibility in order to meet the demands of the carbon dioxide performance standards by these fossil-fueled power plants. (IGA, 2014 Session)

The major problems brought into question by Indiana in a testimony given by Thomas Easterly, the Indiana Department of Environmental Management Commissioner, is that the increased cost of this regulation will be handed down to the consumers and may result in high missed payment rates, subsequently shutting off power to many home owners in vulnerable parts of society. They also fear that the imposed regulation will subsequently increase GHG emissions as a result of the international competitiveness. Indiana's reasoning is that this movement will cause job losses in the manufacturing industry which will in turn demand these same products from international industries that have less efficient production methods, thus increasing the global emissions. A great struggle between the economics of this governance can be seen between the environmental and economic concerns, and both sides are capable of making strong cases. (U.S. House Representatives Committee on Energy and Commerce. September, 2014)

2.5 Indiana's Clean Energy Portfolio Goal

Enacted in 2011, Indiana has set an incentivized voluntary Clean Energy Portfolio Standard (CEPS) stating that 10% of its energy production will come from "clean energy". This is fully detailed in the Indiana Code 8-1-37, and the term in section 4(a) of the document where "…'clean energy resources' means any of the following sources, clean sources, alternative technologies, or programs used in connection with the production of conservation of electricity:" . This list includes the typical methods of clean energy production as well as coal bed methane and natural gas if it displaces electricity produced from an existing coal fired facility. The code goes on to state that the supplier would not be required to meet the clean energy goals if the particular CEPS goal would require an unreasonable increase in rates and charges as determined by the commission. Again these decisions are voluntary so a utility may not adopt them if there they do not see it as beneficial.

2.6 Coal Generation Trends

According to the 2013 electricity projection by Indiana's SUFG, average compounded growth rates are expected to reach 1.29% between 2013 and 2030. This is an increase from 0.88% in 2011 and 0.89% in 2009. This means that the price paid per kWh is expected to steadily increase over this time period or until regulation takes place to counter this.

In Figure 2.1, there is a sharp estimated increase between 2014 and 2020. The lines shown illustrate projections from previous years, as well as variances based on the potential for EPA regulation and its effect on pricing. In the report reference, they used 2011 dollars to base their previously expected rates to keep inflation consistent. (SUFG, 2013)

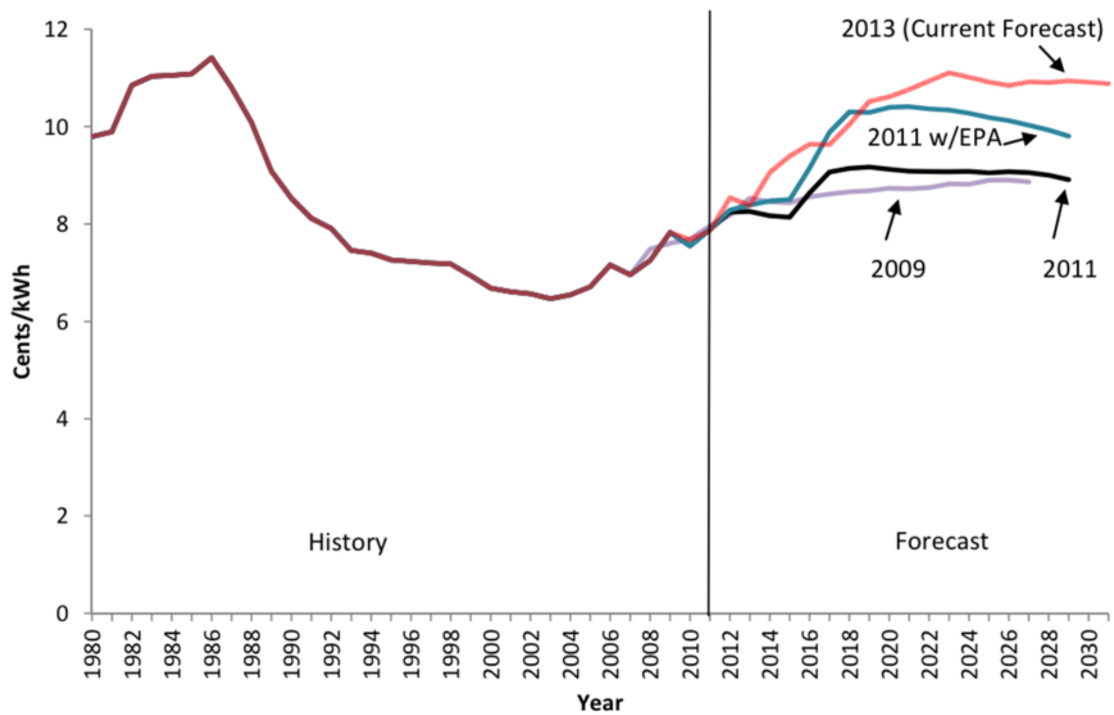

Figure 2.1 Indiana Real Price Projections in Cents/kWh (2011 Dollars)

(Figure 1-4. Indiana Real Price Projections in cents/kWh (2011 Dollars)(Historical, Current and Previous Forecasts) Chapter 1. pg. 8

2.7 Natural Gas Generation Trends

Over the past decade, production and consumption of natural gas has increased significantly over the past decade. This could potentially play a large role in the outcome of electricity generation costs. If more utilities are moving towards natural gas generation the price of the generated electricity may drop. This, however, is still subject to EPA regulations and finite supply concerns, much like coal.

Figure 2.2 illustrates the historical and projected natural gas consumption by each sector of use. Critically, the projection for electrical power is expected to steadily increase. With this in mind, the stability of its price will be under question as a result of the increased consumption. Natural gas could suffer the same fate as coal in that the emissions will draw the attention of the EPA, as mentioned earlier, and thus the price will increase.

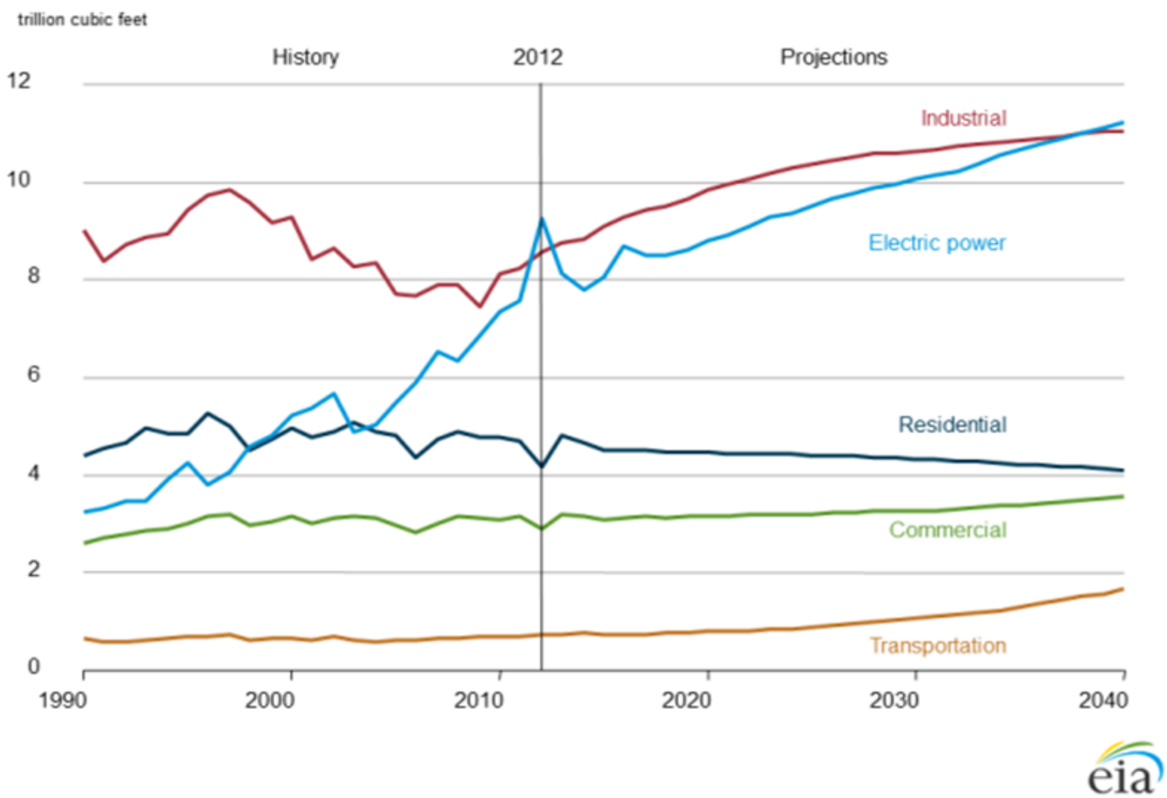

Figure 2.2 Total Natural Gas Consumption by Sector
(Figure MT-39. Natural gas Consumption by sector, 1990-2040)

Figure 2.3 is the relationship between historical and projected production as well as the consumption of natural gas in the United States. As the line for imports passes the horizontal axis, it becomes a negative number representing that natural gas has become an export. The difference between total production and consumption can also be seen as an indicator of the import/export relationship. As total production surpasses consumption, the market shifts towards being a net exporter. Since a large portion of natural gas production comes from expected increases in shale gas extraction, it is expected to see some opposition from environmental agencies. This will ultimately affect the gas price stability.

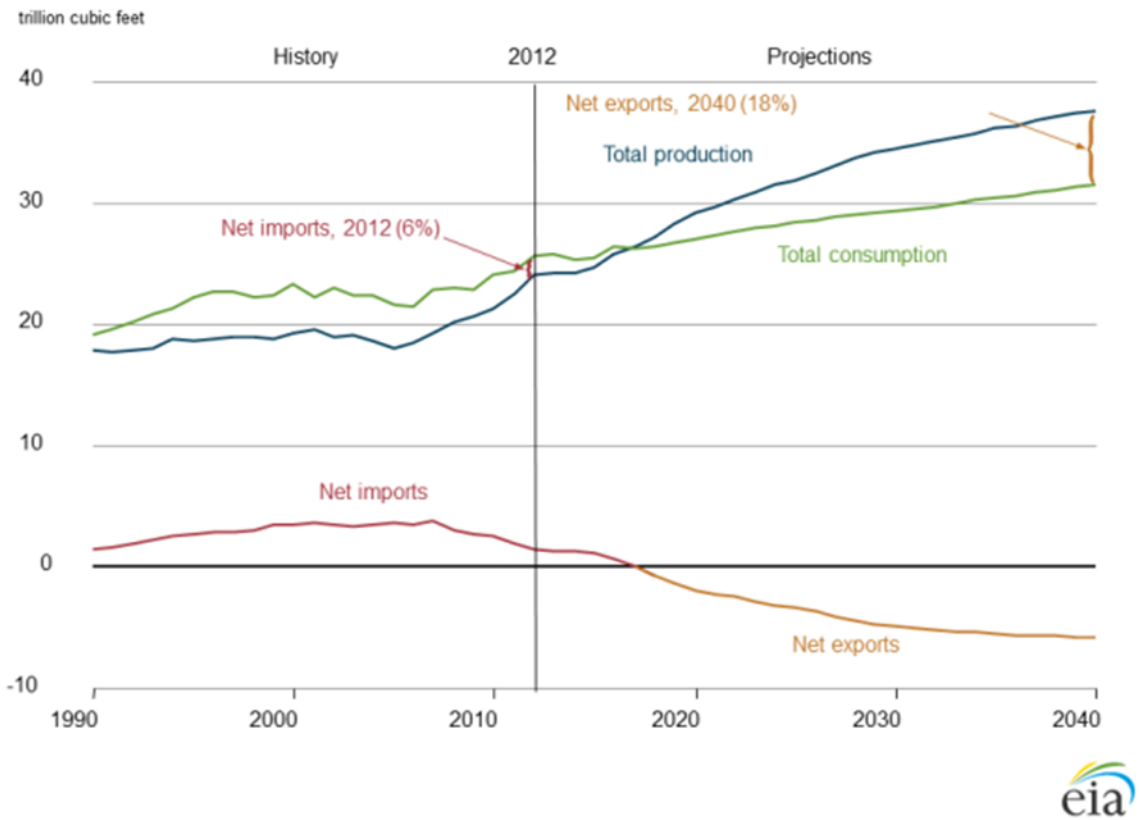

Figure 2.3 Total Natural Gas Production, Consumption and Imports

(Figure MT-42. Total natural gas production, consumption, and import, 1990-2040)

Despite the increased production rates, the EIA predicts that natural gas prices will increase regardless of multiple combinations of economic growth, be it high or low, and gas resources. The reference case used in this study states a 3.7% per year increase in the average annual price in dollar per million Btu (British thermal unit). (EIA, 2015)

Between 2012 and 2040 the Annual Energy Outlook (AEO) 2014, found a 42% increase in natural gas-fired generation. This report shows that the Reliability First

Corporation region, an organization intended to preserve service reliability which encompasses Indiana, will have the largest decrease in coal-fired capacity (21.7 Gigawatts) and the third largest increase in natural gas-fired generation at 103 million MWh. These numbers are also at risk considering the regulations of GHG emissions on the frontier, which will place strain on the reliability of intermittent dispatchable assets and the prices that the utilities are able to provide. The combination of increased energy consumption, pressure imposed by environmental regulations, and utility rate volatility creates an opportunity for alternative generation sources to relieve some of the foreseeable economic and environmental unrest. (EIA, 2014)

2.8 Smart Grid Technology

The expansion of smart grid technology opens up new opportunities for energy production diversification and management. A continual stream of information about consumption and real-time feedback allows distribution systems to become more reliable than the previous infrastructure. Not only do they allow for in-depth information, they will allow for data collection and analysis that was previously unknown at that granularity, providing a deeper understanding of load profiles, production, and distribution. It is crucial that the capabilities of smart grid integration are understood in this study. Being able to manage energy production, allocation, and the economics inside of a distribution network are necessary components to an effective alternate energy installation. As a more diverse portfolio of energy production methods become integrated into our distribution network, the ability to manage and qualify these becomes critical. It is necessary for the array to be incorporated into this type of system in order to sell the energy in agreement with the distribution network.

A study in 2012 by Malik and Bouzguenda looked at the energy savings and economics of investing in smart grid integration. From a utility standpoint, they looked at this in terms of the total cost of generation including energy not served, fuel costs, maintenance and so forth. The goal as to understand the value of the energy savings in its entirety. They found that although their estimated peak load was reduced by only 5%, the total avoided costs reached $2,311,773. As a result they concluded that the correct implementation of smart grid technology will outweigh the upgrade costs. (Malik. Bouzguenda. 2012). This implementation of progressive technology works as an indicator for this research. Not only because of the impact that intelligent data collection has on analysis, but also the philosophy behind the study, which is to improve the existing methods of utilizing energy to lower the consumption.

2.9 Solar Markets

The market for renewable energies is very much a moving target. With government incentives for both production and consumption, it is expected that this market will begin to mature. An investigation of the expected movements in this area is necessary for this study's progression.

2.9.1 Solar Cost Curve

Solar PV technology is moving quite rapidly in both efficiency and pricing. Specifically, the pricing decrease has come to a point that a standard utility scale installation in 2014 was expected to use $1.69/Wdc as a figure for total components, installation costs, subsystems, and engineering. This is a 2.2% decrease over one financial quarter. Overwhelmingly, sources point to a downward trend in the price of solar photovoltaic technology, which is great news for those looking to diversify their energy production portfolios. (SEIA, 2013)

2.9.2 Solar Investment Risks

With each investment there are associated risks. Solar PV is one of the fastest growing technologies and is doing so on a global scale. The ability to quantify this growth and expansion can be a difficult task, but an important one in understanding the risks that are involved with a potential investment. Jonatan Pinkse and Daniel van den Buuse noted that some of the early movers on this technology have been large oil corporations such as Royal Dutch/Shell, BP and Total once struggled with the technology in this dynamic state. Notably, this study took place in 2012 and a lot has changed in the market since this time. It is clear that solar PV is in a disruptive state and the extent to which investment risk is involved needs to be discussed to justify interest in the following study. (Pinkse. Buuse. 2012)

2.9.3 International Trade Tariffs

It should also be known that the price of solar panels is at risk with tariffs being enforced on Chinese and Taiwanese companies as a result of their control of the solar PV manufacturing market. In 2012, the U.S. International Trade Commission (ITC) dispensed a ruling that would impose duties on solar cells and modules produced from China. These duties range from 22.5% to 255.4% based on the manufacture’s compliance and performance in an investigation conducted by the International Trade Commission.

(United States International Trade Commission, 2012). Concerns over whether this is beneficial for the development of the solar energy production market are being risen by the Solar Energy Industries Association. Clearly the variability of solar PV pricing is a concern, but the common understanding is that it will decrease with time and further maturity of the market.

CHAPTER 3. RESEARCH METHODOLOGY

3.1 Introduction

This research has developed a process for evaluating the production of solar electricity generated at a cogeneration combined heat and power facility. This was accomplished by accurately quantifying a solar array's value as it relates to the value of the electricity that it offsets.

Figure 3.1 is the process used to evaluate the production of the solar array, starting from the left side. Since the consumption must be met by the suppliers, the supplied power is equal to consumption. This is then be broken into the three contributing entities analyzed in the example case. This works as the framework for how the array's potential production was valued.

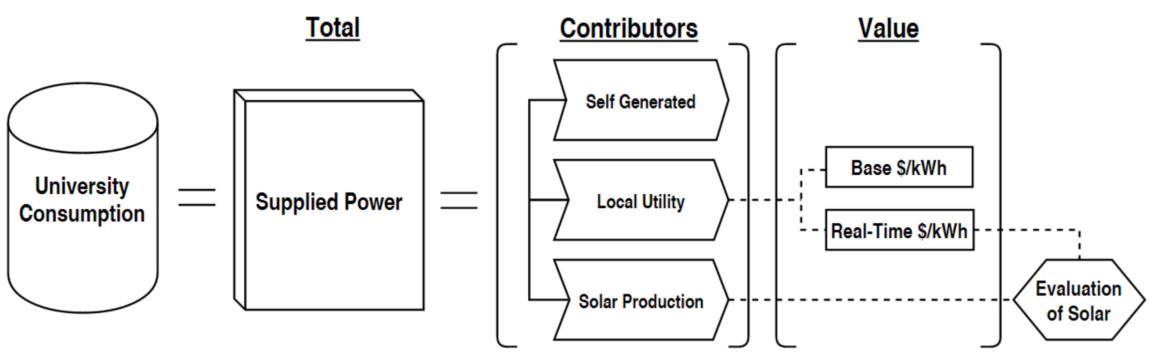

Figure 3.1 Utility Scale PV Array Valuation Process

3.2 University Consumption

Identifying the university consumption trends is the first step of this study in that it will dictate the usefulness of a solar array. A sustainable or alternative energy source is only as valuable as the demand that it offsets. In many cases this is a straight forward definition and production of sustainable power can be given a value quite easily, by recording the price and quantity of power that would have been purchased. In fiscal year 2014, Purdue's total annual electricity consumption was 318,351 MWh, which is made up of multiple parts. A record of historical consumption data was collected and analyzed based on peak demand, total demand, and seasonal rates.

3.3 Supplied Power

The next step was to break down the complexity of supplied power, seeing as the supplied power dictates the price of the demanded power. The power is supplied by the local utility and the university's self-generation at Wade Utility Plant. Other forms of energy production were not analyzed as they did not play a part within the scope of this evaluation. The two main sources have varying factors that will play important roles in determining the value of power produced by the solar array. The relationship between the two suppliers was analyzed to most accurately determine the potential value that this array will represent. This was accomplished by gathering data on the associated prices for each segment of the total demand and comparing them to the demanded power at each time.

3.3.1 Self-Generated Contribution

A characterization of the production parameters for Wade Utility Plant was created to understand the sensitivity of their economic situation. Identifying when to produce power and how much to produce based on the cost of production and the demand is not always clear. A thorough understanding of these decisions was essential in quantifying potential offsets created by the array and how to handle them.

3.3.2 Local Utility Contribution

This step looked at the local utility's contribution to the supply of power that was required to meet the university's demand. The university purchases a portion of its power from the local utility, and thus, this entity governs a portion of the dollar value a solar array offsets. Wade Power Plant makes decisions on whether it is more affordable to purchase power from the local utility or to increase their own production. In some cases the rates provided by the local utility offer better financial options, which puts Wade in a position to make economic decisions as needed. With such large quantities of power being purchased, these rates can have substantial implications. This contribution is broken into two categories; base pricing and real-time pricing.

3.3.2.1 Base Pricing

Base pricing was analyzed because its role as a predetermined purchase commitment. Using past data, the university projects what their future consumption will be and what rates they expect to see from the local utility. Knowing that they cannot meet all of their demand, but having the flexibility of purchasing and production options, Wade annually signs an agreement to purchase a concrete amount of power "year-ahead". Each hour of the year, the local utility knows the exact quantity of power to deliver at a price that is predetermined and agreed on. This study refers to this as "Base" or base load, as it will always be delivered and is a moving yet predictable variable. In the illustrations, the base is shown at the bottom of the stacking graph to demonstrate its position in the parts that make up the total demand.

3.3.2.2 Real-Time Pricing

Real-time pricing was observed in this section as it relates to the hourly price of electricity. Often times the combination of Wade's production and the base contribution are not enough to meet the total instantaneous demand. Since Wade is limited in its ability to ramp up production, as well as capacity to meet this level of consumption, the remainder must be met by electricity valued by the local utility. This is called "Real-Time Pricing" or "RTP" and is determined daily for each hour of the day. To be clear, this rate is not governed by the base pricing seen before, so in the illustration of the demand broken down by parts, this is represented above Wade as it fills the remaining need. The price that is issued for each hour can range from $0.03 and up to $0.30 depending on different economic factors of producing energy at that instance in time. This study defines a trend for this change in pricing.

Using historical data, an investigation was made to analyze RTP over the last two years to better understand where the variability of the pricing originates. This is crucial to the evaluation of the array's production because this will essentially determine the value of the energy it is producing. Not all energy is created equally, so finding the variables that most highly affects its worth can lead to a better evaluation of alternative production methods.

3.4 Solar Production

A solar irradiance analysis was performed to understand the metrics that drive the production of energy from the solar array. Simply, how much solar intensity is there in a given area over time? The values for this have been recorded and are available for Purdue University's campus but were revisited and analyzed in this work because they play such an important role. Depending on how strongly RTP affects the overall value of energy production, a slight error in the solar irradiance calculation has considerable repercussions. In this study, solar irradiance was looked at over the length of time that reliable data exists to gain a strong understanding of its variance as well as the potential for yearly trends. Once accomplished, an estimated solar production graph was overlaid in the demand by parts graph.

3.5 Economic Evaluation

Using RTP as the valuation method, a high level economic analysis was created that allows for the manipulation of multiple array parameters. Each hourly increment of RTP data is compared against the production potential of the proposed array at that same hour. The equation for evaluating these hourly increments is as follows and the associated parameters are described in Table 3.1:

Table 3.1 Solar Production Valuation Parameters

Symbol	**Unit**	**Description**
RTP_t	kWh	Real Time Pricing Supplied By The Local Utility
B_t	kWh	Base Pricing Supplied By Local Utility
W_t	kWh	Wade Supplied Contribution
SPV_t	kWh	Estimated Solar PV Production
SI_t	Wh/m^2	Solar Intensity Integral Sum Over One Hour
C_t	kWh	Consumption
RTP_p	\$/kWh	Real Time Pricing Cost
SPV_p	\$	Estimated Solar PV Production Value
AC	W	Array Capacity
PR_t	%	Performance Ratio
T	hours	Length Of the Observed Study Period
t	hours	The Specific Time Being Studied

$$SPV_t = PR_t \times SI_t \times AC \quad (1)$$

The production of the array was valued at RTP and given this value by the following equation:

$$SPV_p = RTP_p \times SPV_t \quad (2)$$

Thus a yearly production value of an array will be calculated by the following equation:

$$SPV_p(t,T) = \sum_{t=0}^{T} (RTP_{p(t)} \times SPV_{(t)}) \quad (3)$$

For clarity, the production of the array at each individual hour was multiplied by the RTP at that same hour. This was performed for each hour of the year, where T is 8760, and then summed to gain the annual production value. The total composition of the hourly consumption with solar production introduced is represented in this equation:

$$C_t = B_t + (W_t + (RTP_t - SPV_t)) = 100\% \tag{4}$$

3.6 Array Variability

Finally, using this method, the array was altered to create comparative variations of the installment to analyze their final values. This section did not go into detailed about the design of the array but rather looked at finding the variables that predict the value of the array. This utilized the data found by investigating recent utility scale solar projects in Indiana and basing the array parameters around these. As seen in the previous equations, SPV is not actually given a value. For testing purposes it was set at 5MW. This capacity was chosen as a result of the definition of a utility scale solar PV installation. It should be noted that this term is still debated. The total price of the array was determined by using market research by the Lawrence Berkeley National Laboratory which established utility scale solar PV projects to be \$1.77/W. The inflation rate settled at 1.29% compounded annually as this was the factor found in the most recent SUFG report. Lastly, the valuation of the array was altered to a power purchase agreement (PPA) to compare against RTP. This not only allowed for a different economic perspective, it also helped in the analysis of what affects the array's production value other than just the direct value of the electricity it offsets.

CHAPTER 4. RESULTS

4.1 University Demand

The first step in the analysis process was clearly defining what the consumption profile of the campus was. To do this, billing statements from the local utility were collated and combined with the production data from Wade. As a direct result of this, the total consumption for 2014 was 318,351MWh. To better understand how this consumption was quantified, this section will go into detail as the investigation proceeded.

4.1.1 Consumption Profile

Figure 4.1 shows the total generation of energy by the university where the generation comes from. The left vertical axis is the consumption data in kWh and is linked to the data in orange, green and blue. Orange is the energy from purchased at RTP. Green is the energy generated by Wade. Blue is the base energy purchased in advance from the local utility. The right vertical axis is the RTP in $/kWh where the black points are individual values and the yellow lines are averages seen over a month.

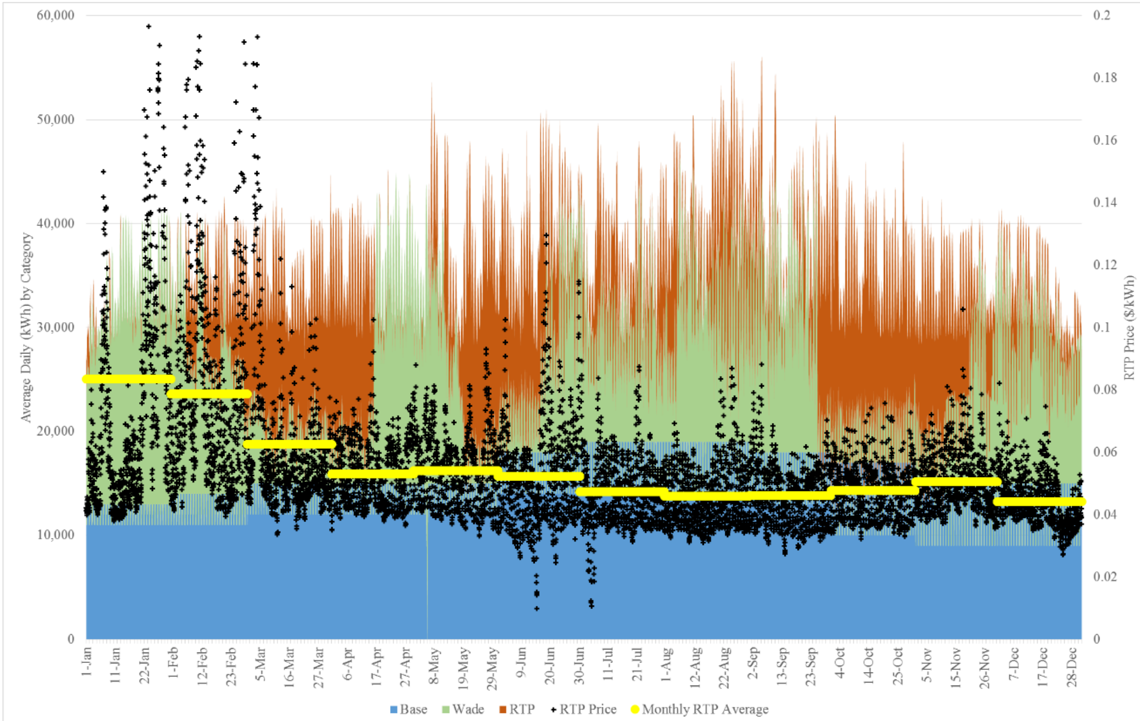

Figure 4.1 Purdue University 2014 Generation Profile

Figure 4.1 provides insight into daily and seasonal energy generation decisions. For example, in March of 2014, the base energy (blue) is stable, however the Wade energy (green) drops out. Instead the energy was met by RTP (orange). The RTP price (black dots) help explain this interaction. For the March time period, RTP was fairly low, which allowed the university to favorably purchase electricity.

Once the overview was established, the next step was to make sense of the data as it relates to electricity production from PV and its value based on the RTP given at each hour respectively. Figure 4.2 is the consumption average, maximum, and minimum value at each hour. The vertical axis is the campus demand in kW at each hour. The horizontal axis represents the hour of the day.

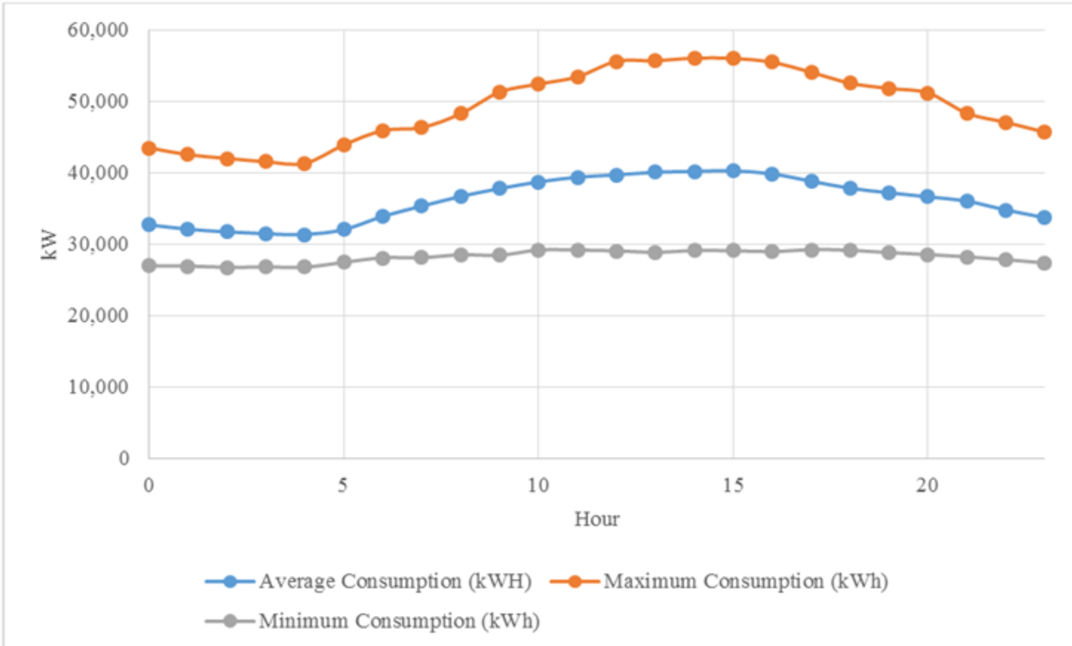

Figure 4.2 Purdue University 2014 Averaged 24hr consumption profile

The peak demand occurs during the middle of the day and tends to be at its maximum value around 3PM. The original thought was that this was related to the student occupancy of university buildings during these times. To see this assumed relationship closer, the next step breaks these periods down into “in-session” and “out of session” days.

4.1.2 Seasonal Examination

Figure 4.3 is an analysis of the university consumption broken down by the academic calendar. The vertical axis is the consumption, while the horizontal axis is the hour of the day. The orange, green, and blue colors are the fall, spring, and winter seasons, when, when 40,000 students are active on campus. The yellow color is for the summer, when there are far fewer students on campus. In addition to colors, Figure 4.3

shows both peak and average consumption. The bar graph is average consumption, while the line graph is peak consumption.

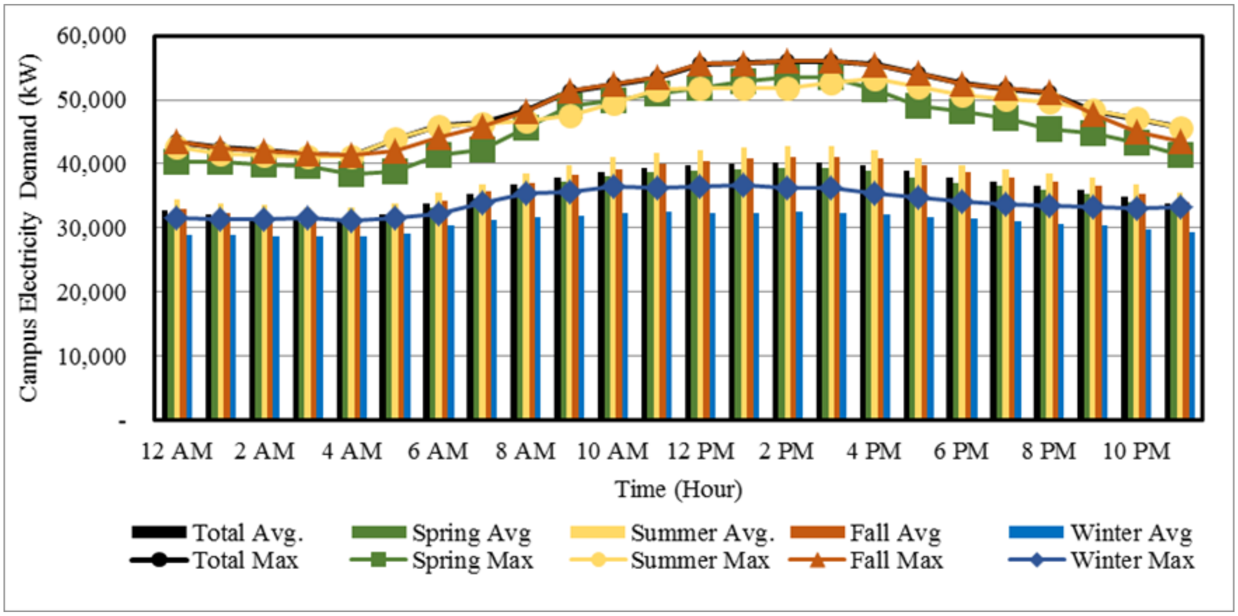

Figure 4.3 Purdue University 2014 Seasonal 24hr Consumption Profile

The curve shown for each season is similar to the averaged chart shown before in Figure 4.2. The consumption trend throughout the day does not change much from season to season, but during seasons with higher temperature, the trend is more exaggerated. Figure 4.3 also shows that electricity use is substantially less in the winter. This occurs because campus buildings use steam, not electricity, for achieving thermal comfort during the winter months.

The conclusion to this analysis is that the attendance of students is not the primary factor that affects the consumption of energy on campus. During the summer months the energy consumption, on average, is greater than the other seasons. This is caused by the way that electricity is produced on campus, and not how all energy is consumed. The cooling on campus is provided primarily by electricity and some through steam chillers, while heating is done exclusively by the steam from the CHP. With this in mind the remainder of the consumption investigation revolved around outside air temperature (OAT) as an indicator for electricity consumption.

Under this lens, it becomes clear that the OAT has a strong impact. A quick proof of this is that the consumption of electricity during the summer, when most students were on break, was the highest on average, while fall held the highest peak consumption. This peak can be attributed to the student attendance, but again, most of the consumption is due to the need to condition buildings.

4.1.2.1 Outside Air Temperature Considerations

The next step was to investigate the temperature at which the energy shift occurs. This is important to understand the trends associated with an increase in temperature and volume of consumption can be used to further understand the value of the solar production. Figure 4.4 shows the OAT on the horizontal axis as it relates to the total consumption of energy on the vertical axis.

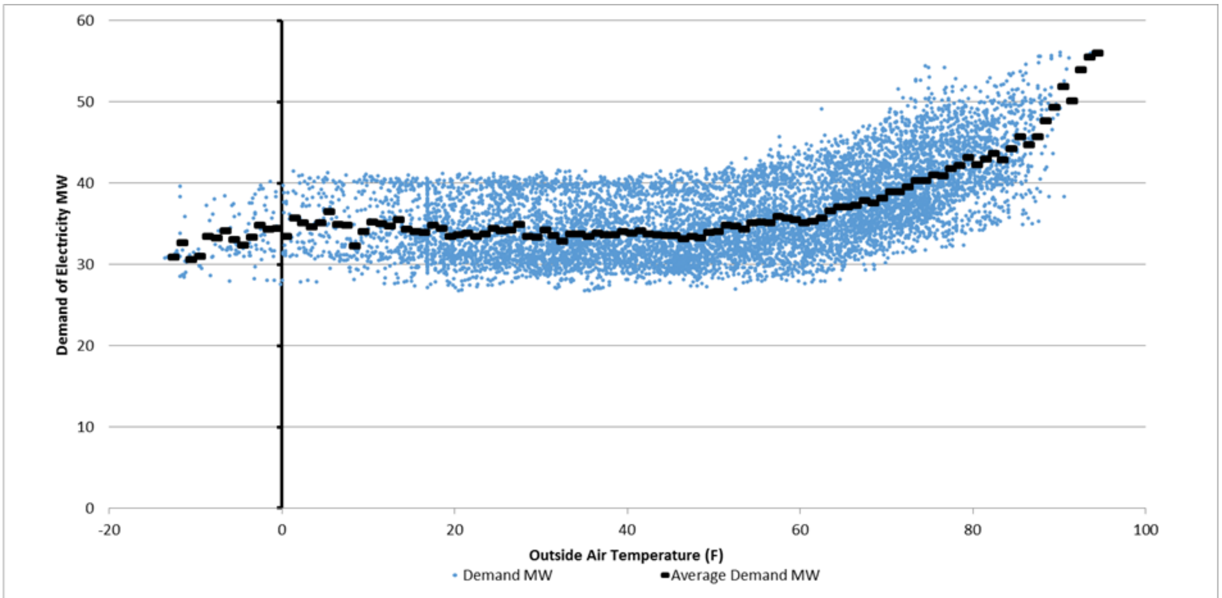

Figure 4.4 Demand of Electricity as a Factor of Outside Air Temperature

Figure 4.4 shows a clear trend in how electricity is consumed. As the OAT increases past 60 degrees, the consumption of electricity increases. Note that consumption below 60 degrees stays relatively consistent. There is a distinctive characteristic in the data that has a range of 10 megawatts. This is easily explained by the general needs of the campus such as the need to condition buildings during campus operation hours as seen by the previous graph. The base load, at 30 megawatts is consistently carried out until 60-65 degrees Fahrenheit. When the building passes the point where cooling is needed, electricity use trends upward because of the increasing need for electrically driven cooling.

4.2 Supplied Power

The university demand is being met by two to three different rate structures. These are Wade's contribution, RTP, and base. RTP and base are contributions by the local utility and according to 2014 data they contributed 65% of the annual electricity. This idea is shown by Figure 4.5. The vertical axis represents the percentage of the total demand for each of the contributors; base contribution is shown in blue, Wade in green, and RTP in orange.

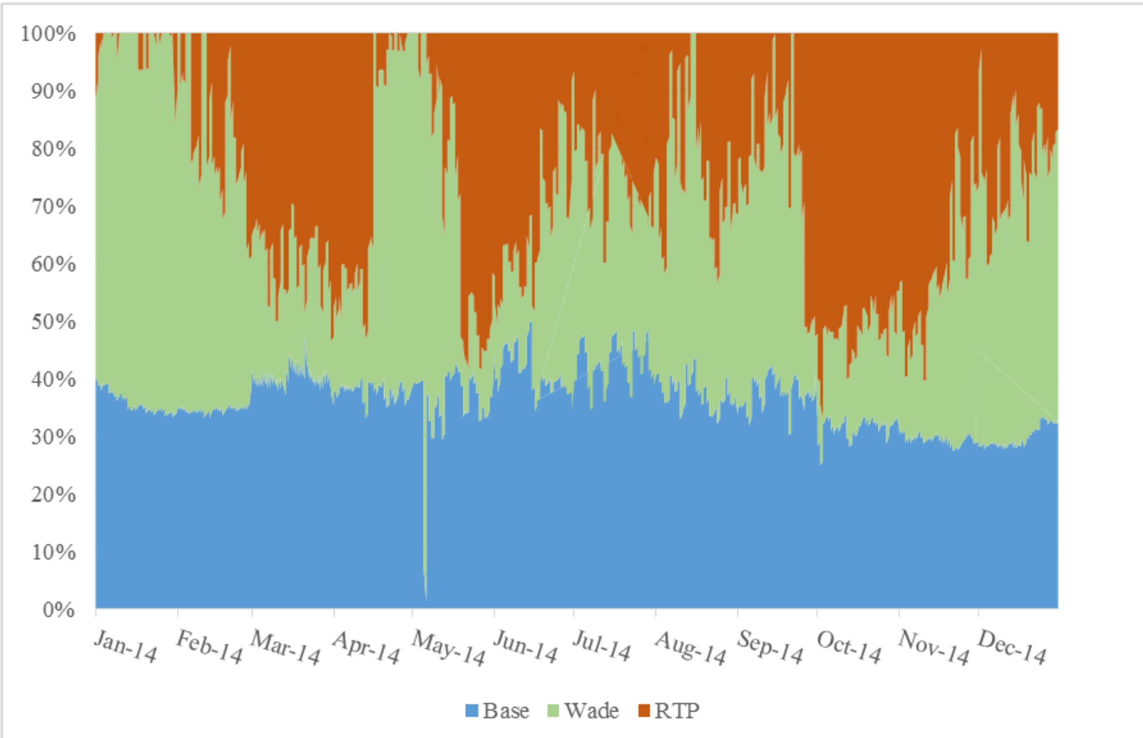

Figure 4.5 Percentage Comparison of Demand Contributors

4.2.1 Base

The base supplied power is the quantity of electrical energy that is purchased a year ahead based on the power plants opportunity cost projections. The price and volume of these purchases are set, so Wade will attempt to use all of the electricity that it has already purchased. In terms of solar production offset, base purchases will stay relatively the same. This is because of the inconsistent nature of solar production at this location. A more economically conservative approach would be to allow the production of the solar array to offset some of the production from either Wade or purchases at RTP.

Figure 4.6 illustrates this contributor by isolating the base from the other contributors and displaying the consumption according to the power plants records, on the vertical axis, as it relates to the time of the year, on the horizontal axis.

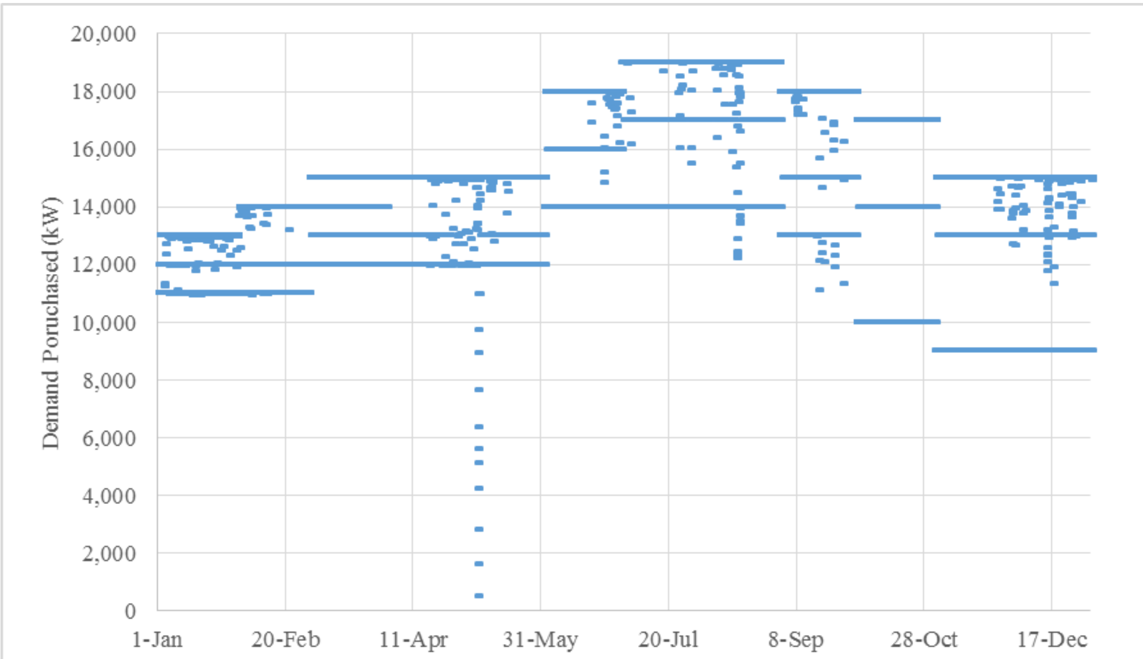

Figure 4.6 Total Base Demand Purchased for 2014

The data points that drop down in this illustration can be attributed to recording errors, since the base electricity purchases are used first. Early in the year, the base price wavers between three distinct quantities, which are common in the structure of how demand is met throughout the day. As the year moves into the hotter months, however, the blocks of the demanded base purchases spread further apart and the baseline increases frequently by 4,000kWh. This is a predictable occurrence since the base cooling loads are known and can be anticipated and therefore should be matched with an equally predictable supply of energy at a known rate. The colder months following the summer, from October on, tend to have a lower baseline, but a much greater range of consumption quantities. These differences are explained by the change in predicted demand.

4.2.2 RTP

The data analyzed for RTP ranges from January of 2013 to July of 2015 (for all data see the Appendix). In order to find a trend with the way that RTP changes, each month was separated and then investigated individually in the same manner that many of the previous charts were designed, by creating an average day of each month and then compared for distinct trends. The cycle of pricing follows a residential trend for the majority of the months. The local utility supplies power to much more than the university and the rates that are offered reflect this. During the colder months, the peaks follow a typical household use profile. Early in the morning, when appliances and temperature conditioning begins and again when the residence return home and begin using larger amounts of electricity. During the summer, the RTP will peak from noon to 3PM when conditioned spaces are using larger amounts of electricity to cool, but will fall back into the average trend once the outside temperatures decrease.

Figure 4.7 illustrates the university's average consumption of RTP as it relates to the average price being offered. The left vertical axis is 2014's average RTP consumption and is shown in blue, while the right vertical axis, in orange, is the average prices respectively. The horizontal axis represents the time of day in order to understand the years averaged pattern.

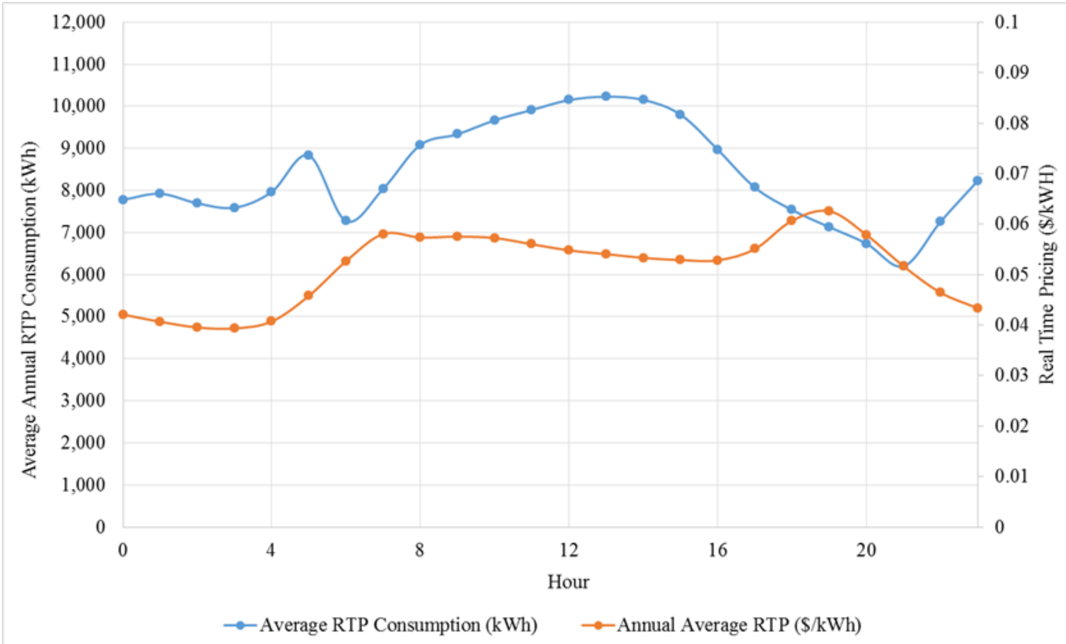

Figure 4.7 Annual Average RTP Consumption Vs Annual Average RTP Rate

The trend shows that the university's average purchases increase in the middle of the day. At 5AM, the consumption of RTP spikes and then dips back down at 6AM which is the period when the campus begins its conditioning activity. The load must be met and if the combination of base and Wade production does not meet this need, RTP fills the remaining void. After this, the demand evens out and a more natural increase of RTP consumption begins.

Many times, Wade does not have the ability to meet all of the electrical demands on campus and needs to purchase supplemental power from the local utility. Economics are another reason for deciding to purchase power over producing it. This can be shown by an examination of the cumulative consumption of RTP and the prices that are associated.

Figure 4.8 demonstrates this interaction. The left vertical axis is the value of the individual points, in one hour intervals, where Wade purchased from the local utility at

RTP, shown in blue. The right vertical axis is the cumulative total of these points, in orange, so that the total consumption at each rate can be understood more clearly. The horizontal axis shows the RTP rate that each point was purchased at. For clarity, the graph only shows prices fewer than 10 cents as there are very few times when prices reach above this.

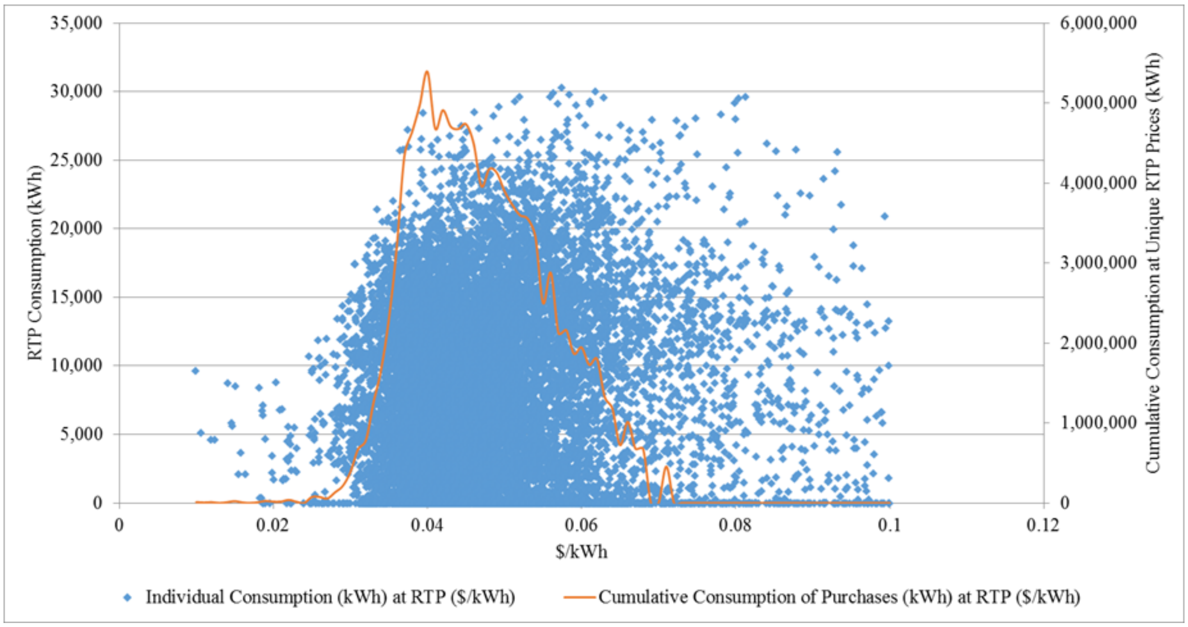

Figure 4.8 RTP price Vs Consumption Relationship, Prices Below $0.10

Most purchases are located under $0.06/kWh with a significant portion of them appearing at between $0.04/kWh and $0.05/kWh. This analysis gives insight to the trend of Wade's economic decisions to purchase electricity. Prices offered at a lower rate will be purchased if the demand requires it or if the economics work in favor of Wade. Additionally, Wade will always keep a generator running at a minimum.

As a result of developing a better understanding of the economics and configuration of Wade's purchasing mechanism with the local utility, the energy produced from a solar array would be used to offset purchases at RTP or self-generation.

This is because the production from the array is too intermittent to be reliable, and using real time prices will be the most accurate method of valuing the solar productions. The consumption priority by contributor will operate as follows assuming that the most economic decisions dictate consumption:

1. Base
2. Solar PV
3. Wade
4. RTP

4.3 Solar Production

Once the consumption profile and supplied electricity had been characterized, the next step was to relate this to the potential production of an array and to value its production based on the previous information. To do this, predictive trends were created based on the available data. Missing data was filled by defining the regression line between predictive factors and apply the resulting equations to the independent variables. The solar intensity over time (Wh/m^2) at the tilt angle of the research panels was the first variable analyzed as it was assumed as the best predictive factor for production.

Figure 4.9 shows the missing solar intensity gaps that were filled. The vertical axis is the integral sum of solar intensity over each hour in Wh/m^2, while the horizontal axis is the time of the year.

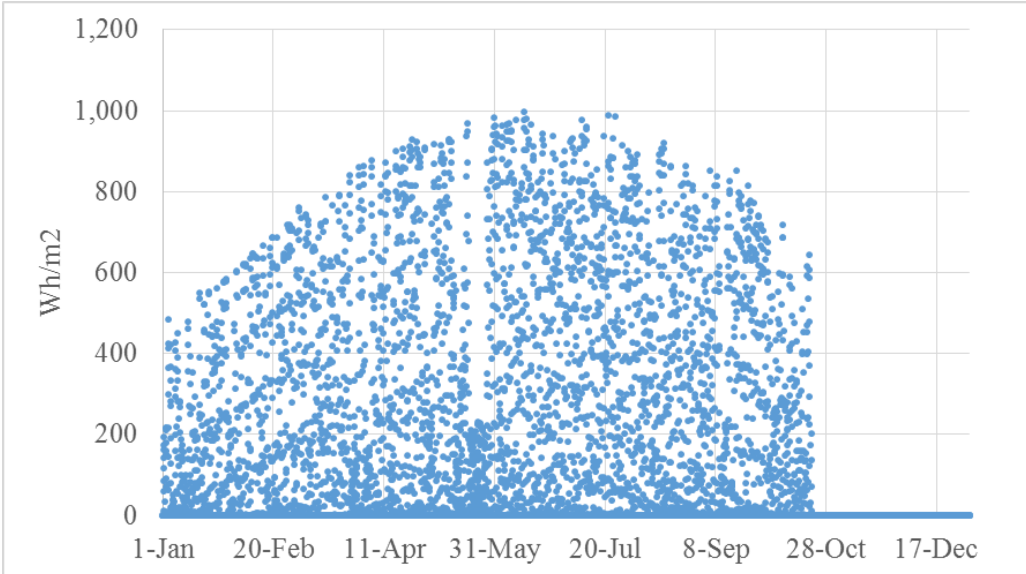

Figure 4.9 Research Solar Array's Recorded Solar Intensity for 2014

Figure 4.10 shows the missing production gaps that were eventually filled by a predictive factor. The vertical axis is the integral sum of production over each hour in Wh, while the horizontal axis is the time of the year.

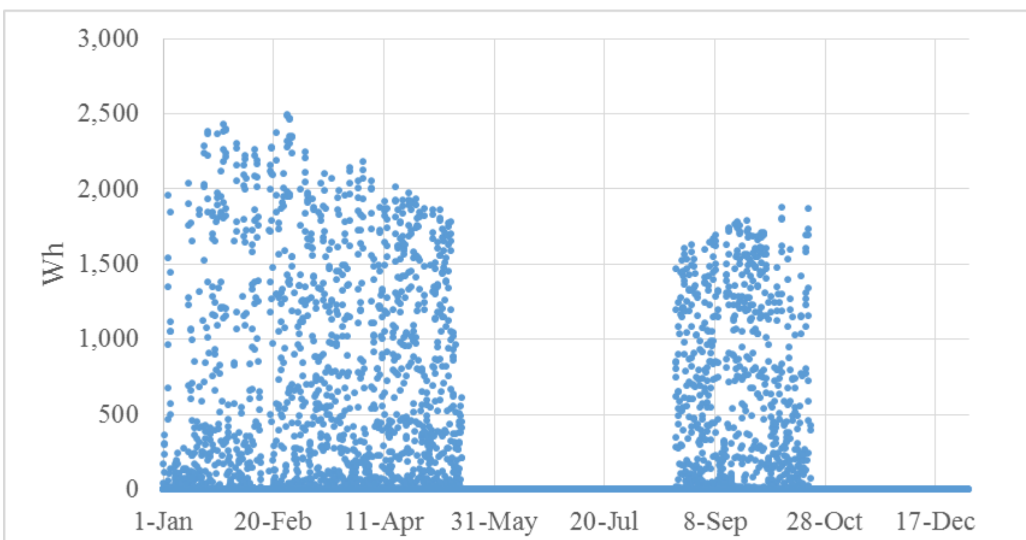

Figure 4.10 Research Solar Array's Recorded Production for 2014

4.3.1 Predictive Factor

To accurately estimate the missing data points, a strong relationship needed to be proven between production and some predictive variable. This relationship was ultimately proven to be most strong between solar intensity over time in Wh/m^2 and kWh output. Although this is an obvious connection, for the validity of production estimation the relationship needs to be proven.

Figure 4.11 is a scatter plot comparing the output in Wh on the vertical axis, to each respective solar intensity point in Wh/m^2 on the horizontal axis.

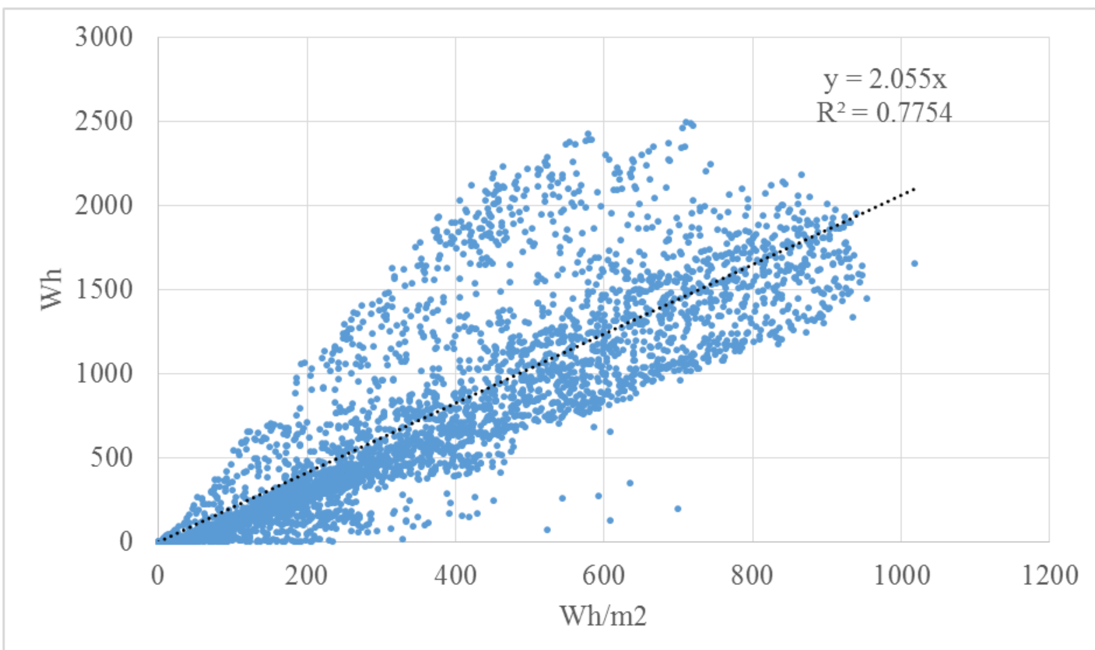

Figure 4.11 Research Solar Array Production vs. Solar Intensity Relationship

Data points at zero solar production value points were filtered as these can either be attributed to nighttime recordings, which would disproportionately strengthen the relationship, or errors in the pyranometer and have been filtered out.

The solar production has a wide range when the entire year is analyzed this way. Dividing this into monthly segments increases the predictive capabilities, thus a moving predictive factor was calculated in order to better represent the array's production as it reacts to seasonal variations. The most notable of the parameters of the array studied are the age and efficiency of the panels. This is reflected in the performance of the panels as the temperature varies. In the context of the consumption of energy on the campus, the higher the temperature, the greater the consumption of energy, however the production efficiency is lower during this time in this analysis.

Figure 4.12 shows the effects of the OAT on the production as a percentage of the maximum value seen, normalized production. The left axis is the consumption of electricity in MW and is represented by the blue data points while the right vertical axis shows the normalized production in percentage, represented by orange. The horizontal axis displays the temperature in degrees Fahrenheit.

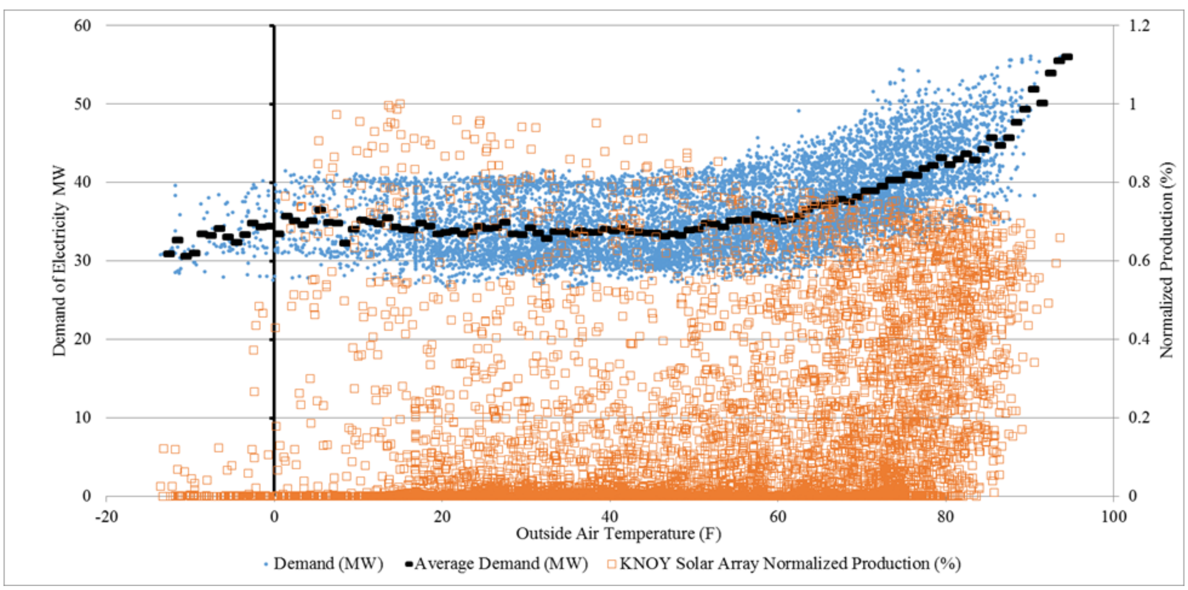

Figure 4.12 Researched PV Normalized Production Recordings and Total Demand vs Outside Air Temperature

Although the largest production percentages occur at less than 20 degrees Fahrenheit, most of the production density is concentrated above 60 degrees. There is an expectation that the performance ratio will decrease during increased temperatures, however it is concerning that the performance would drop down to 70% even below 90 degrees.

Once the performance relationship between temperature and production had been established, the remaining gaps in the data were filled with a unique temperature performance factor for this specific system. This was created by plotting the regression of production and solar intensity, against temperature. Figure 4.13 is the predictive factor for the research solar array and the effects of temperature on its performance. The vertical axis is the slope of the regressions from production and solar intensity. The horizontal axis is the temperature in Fahrenheit.

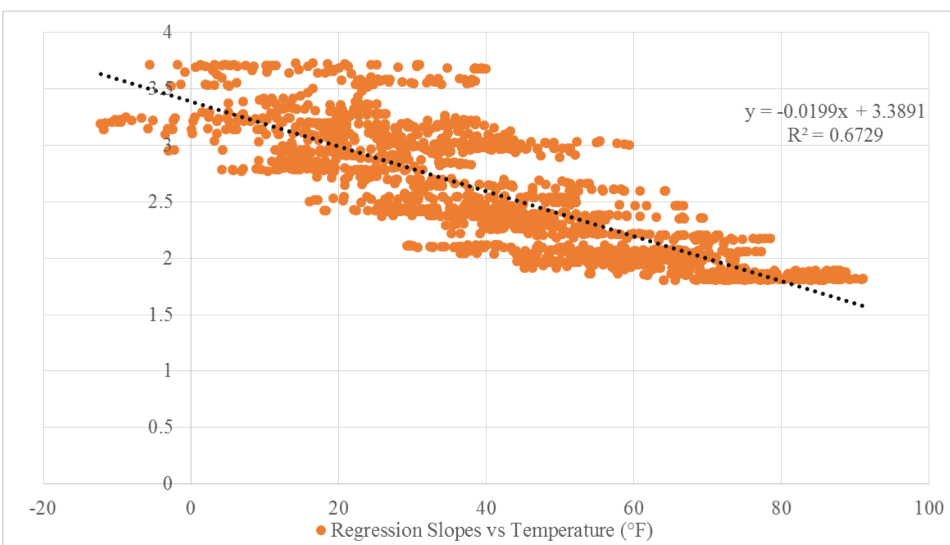

Figure 4.13 Research Solar Array's Predictive Factor Using Temperature

The total regression for this relationship is then used to estimate the production of the array at varying temperatures. Figure 4.14 is the comparison of the prediction production versus the recorded production. This was studied to check the predictive capabilities of this method before filling the gaps with this information. The vertical axis is the recorded production in Wh, while the horizontal axis is the predicted production using the temperature derating method, also in Wh.

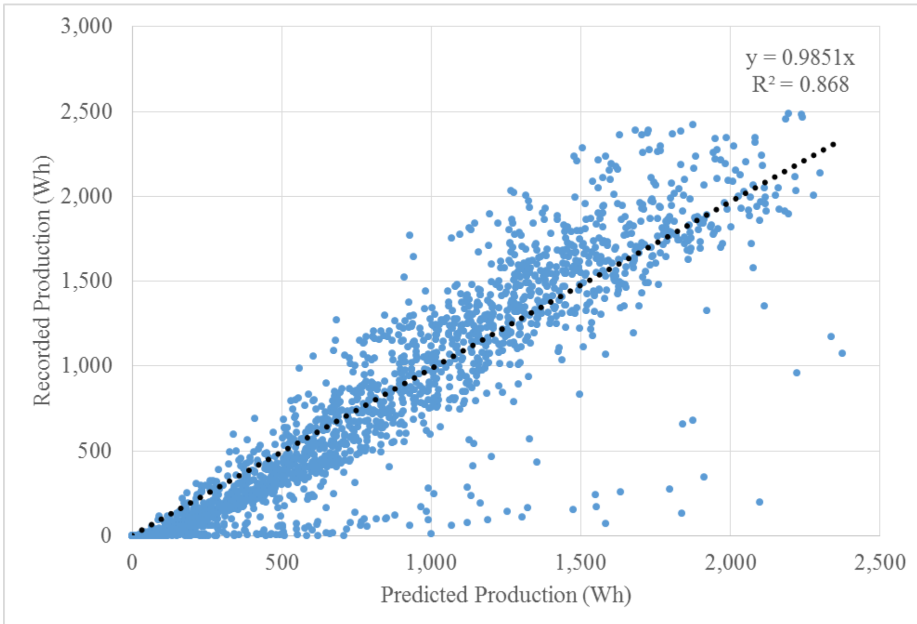

Figure 4.14 Research Solar Array's Predicted Production Vs Recorded Production

86% of the data can be explained by this relationship. Although the compiled regression analysis in Figure 4.13 had a loose relationship, this method, proved capable of estimating points where the production was actually recorded. Still, the production of the array during high temperatures was concerning. With this in mind, the NREL data was collected from the local weather station at the Purdue Airport to begin comparing results.

4.3.2 Scaling Methods

Because of the limitations of the available data set and its predictability, two separate scaling methods were used. The first uses the original data set and is scaled as if the larger array had the same characteristics as the research array. This was accomplished by combining the predicted production data with the actual data to complete a full year's data set for 2014. Figure 4.15 is the illustration of the gaps in the data set and how they were filled. The vertical axis is the production of the array in Wh, while the horizontal axis is the time of the year.

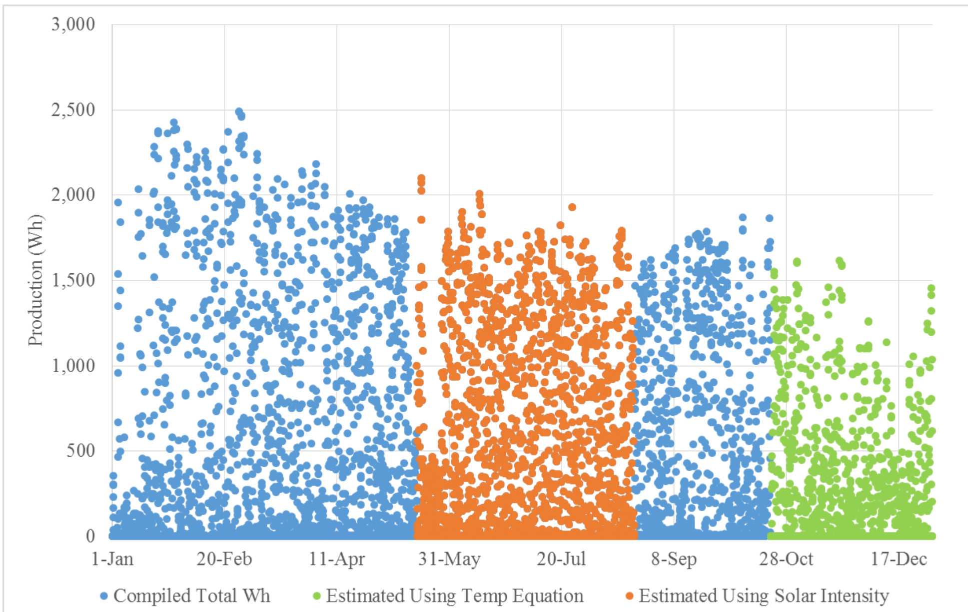

Figure 4.15 Research Solar Array Total Compiled Production Data for 2014

Again, the predictive factor was proven to have usefulness, however the data shows a downward trend as the year moves on. This could be a result of inaccurate pyranometer readings. Without additional information on this section, the predicted production still needed to be used. The array was then scaled up to 5MW, and since the parameters of the array did not change, the scaled production of the array will be a linear relationship. Figure 4.16 is the scaling of the research array, 2.88kW system capacity, scaled up to a 5MW system capacity.

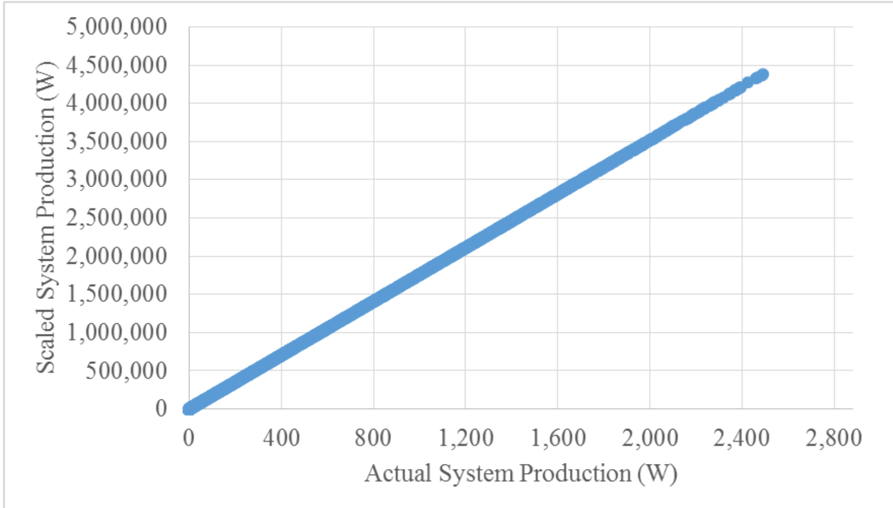

Figure 4.16 Research Solar Array System Production Scaling

For clarity, each production of the research solar array, recorded or predicted, in 2014 was multiplied by the ratio of 5MW compared to 2.88kW. Since the characteristics of the panels do not change from one size to the next in this study, the change in production has a linear relationship.

The second method used traditional means to anticipate the production of a utility scale array by collecting NREL data for the location. This method proved to be more reliable as the data was recorded at an elevation that is more similar to the environment and elevation that a larger array would be in. Because of this, the temperature data was taken, as well as the solar intensity. Much like the previous method however, a derating factor was included that allows for the alteration of expected loses. In this case, the performance of the panels decline as the temperature increases. The production derating factor was calculated for both systems with the following equation:

Table 4.1 Derating Factor Variables

Variable Name	Abbreviation	Unit
Derated Production of Max	DP Max	%
Performance Ratio	P_R	%
Solar Intensity	SI	Wh/m^2
Temperature Performance	T_P	%
Temperature	T	°F
Panel Temperature Coefficient Base	T_{CB}	°F
Temperature Coefficient	T_C	% Max Power / °F

$$DP\ Max = PR * \frac{SI}{\frac{1000Wh}{m^2}} * T_p \tag{1}$$

$$T_p = (T - T_{CB}) * T_C \tag{2}$$

*Temperature Performance cannot exceed 100%

Once this equation had been established, the production of an array using NREL data was estimated. This was then normalized based on its maximum production point throughout the year and then analyzed for performance as it relates to temperature.

In Figure 4.17, the left vertical axis is the demand of electricity in MW and corresponds to the blue data points. The right vertical axis represents the normalized production percentage using NREL solar intensity data to predict production and corresponds to the orange data points. The horizontal axis remains as the temperature in Fahrenheit.

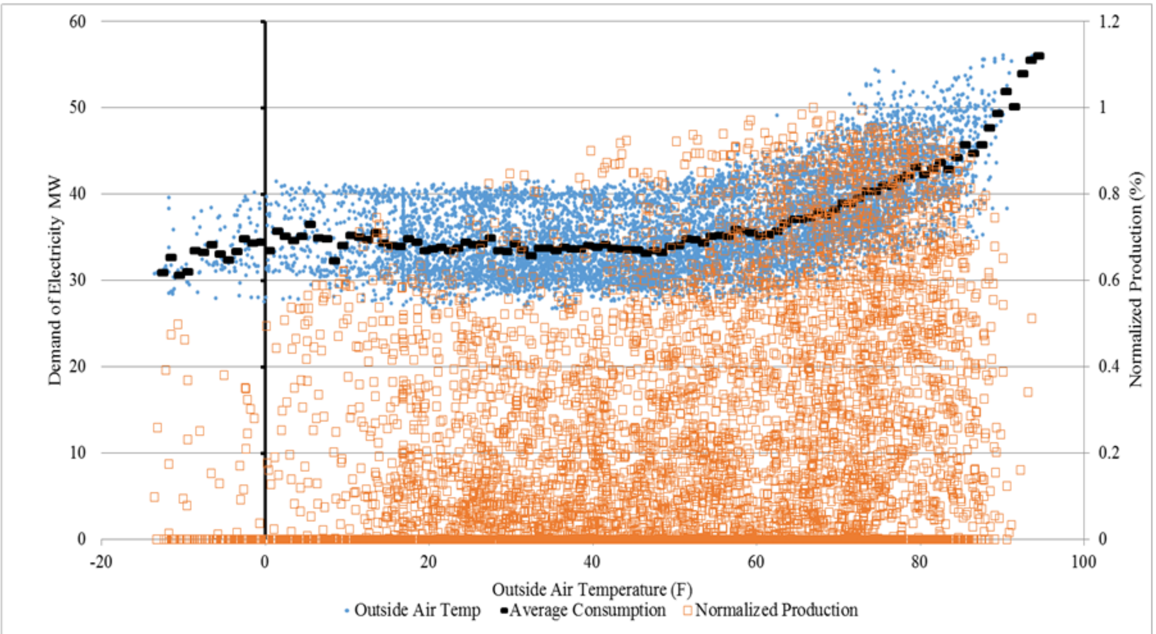

Figure 4.17 NREL Normalized Production Recordings and Total Demand vs Outside Air Temperature

As compared to the previous analysis, as the OAT increases, the normalized production increases, but reaches its maximum around 65 degrees. It should be noted that the KNOY array was built more than 10 years ago and likely is dramatically affected by increased temperatures. Referencing the base temperature for derating at 77 degrees, the estimated production using NREL data is closer to the expected result. This can be seen since after this point, the normalized production declines. These analyses have contradictory outcomes, however the NREL estimation works closer to the expectation of a solar array. Because of this, the remainder of valuation will be done using these values.

4.4 Production Value

Table 4.2 shows the parameters used for the valuation of the utility scaled array. These values were selected because of their similarities to other utility scale solar arrays in Indiana. The panel characteristics were gained by the Open PV project database, while the pricing trends come from records by the Lawrence Berkeley National Laboratory.

Table 4.2 Input Parameters For Utility Scale Array Value Prediction

Attribute	**Value**	**Unit**
Wattage Per Panel	240	W
Efficiency	14.74	%
System Size	5,070,326.69	W
Discount Rate	3	%
Cost Per Watt Installed	1.77	$/W
Operation & Maintenance	0.005	$/kWh
Performance Ratio	80	%
Annual Energy Inflation	1.29	% Compounded Annually
Annual Degradation	0.4 Per Year after 5 Years	% of Max Performance
Starting Performance	95	% of Max Performance
Panel Temperature Coefficient Base	77	°F
Temperature Coefficient	-0.2694	% Max Power / °F

The production of the array at each hour is first calculated by creating derating factor (DP Max) at each hour using the formula described by Table 4.1. After each hour of the year has a derating factor, the system size is then multiplied at each hour to gain the individual production quantities. These can then be combined with the $/kWh rates given at each hour, to find the dollar value generated. Projecting out further, the annual degradation of the system should be applied to the annual production at a linear rate. Inflation would then be added after this degradation as it is compounded annually.

4.4.1 RTP Value

Figure 4.18 shows estimated value of the array over the course of 2014. The left vertical axis is the production value in dollars, shown in blue, while the right vertical axis is the monthly totals in dollars, shown in orange. The horizontal axis is time, in this case the year 2014. Valued at RTP, the system would have generated $354,967.60 in 2014. At that same rate of production, and adjusting for inflation and panel degradation, the array has a 25 year breakeven point disregarding inverter replacement.

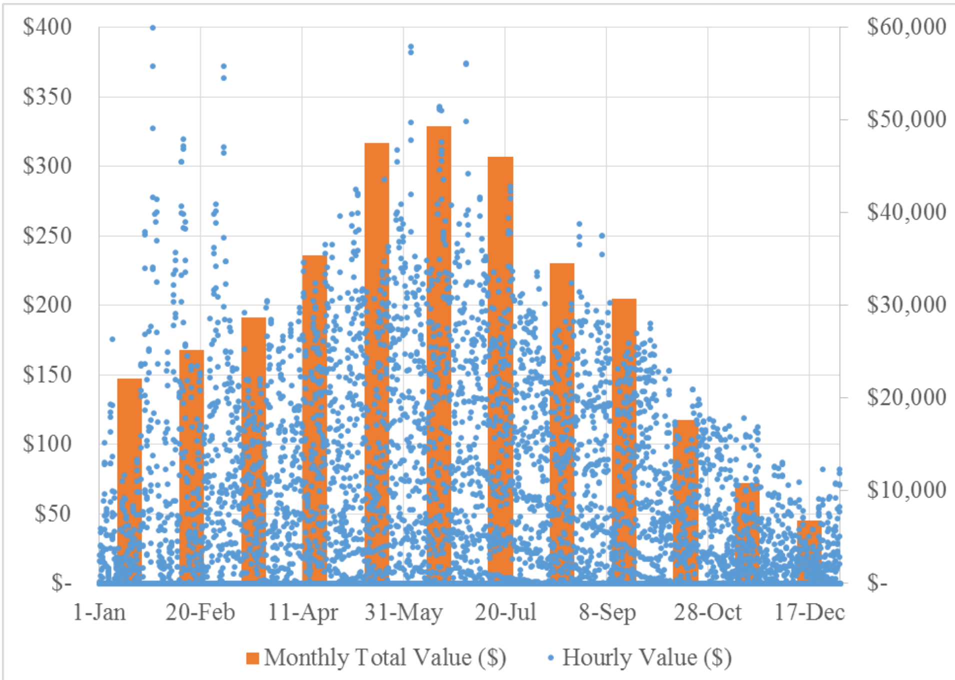

Figure 4.18 Estimated Production Value of a 5MW Array in 2014 Using RTP

Although the performance ratio is lower during extreme temperatures, production and subsequently, accumulated production value is greater during this time because of the increase sunlight hours. Also, during the summer, RTP cost peaks between noon and 4PM, lending to the increase value of the array's production. To summarize this, the array has the overall greatest value during the middle of the day, during peak production times in any season because of the considerable increase in solar intensity at these times. This positive relationship with production, consumption, and the annual RTP cycle accounts for nearly 50% of the total annual value.

Figure 4.19 illustrates the average production throughout the year, represented in one day's time. The left vertical axis shows the normalized production as a percentage of the total system capacity. The right vertical axis is the average RTP values at each hour over 24 hours. The horizontal axis is time.

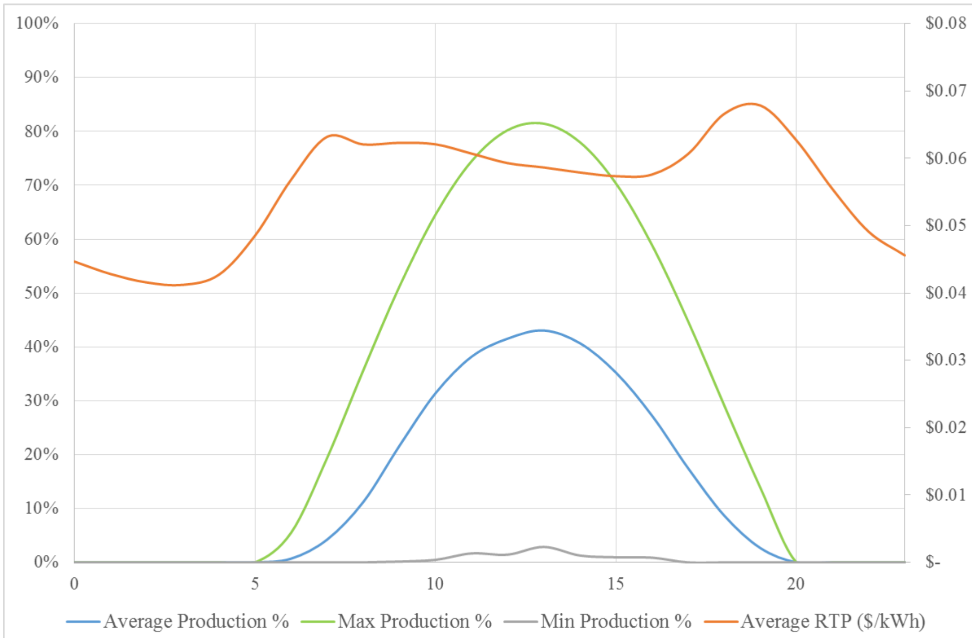

Figure 4.19 Daily Average Utility Scale Solar Array Production and RTP in 2014

This high-level snapshot of the array's production, averaged over the course of the year and compared against the RTP analyzed in the same way, gives a brief explanation of the value of the array in 2014. A similar tool can be created for any system to quickly investigate the potential for solar production at a location with relatable pricing structures.

The time value of money plays a large role in analyzing based on RTP, while placing the value with a PPA limits investment risk because of the steady. Stabilizing a key variable has its advantages and disadvantages. The next step is to price the production against a flat rate PPA.

4.4.2 PPA Value

The following section brings the impact of the RTP valuation to light. When placed into a steady purchase rate, assuming that all of the energy produced is being purchased, the net cash flow of the investment is greatly increased. A substantial portion of this is due to the 30% tax credit that can be applied. If a taxable entity owns takes ownership, they will likely enter into a PPA. Overall this lowers the breakeven point to 18 years at $0.06/kWh. Without the tax credit it will take 24 years.

Figure 4.20 is a repetition of the previous 2014 predicted value, however the rate has been set to the PPA. The vertical axes and horizontal axis follow the format of the previous RTP valuation analysis.

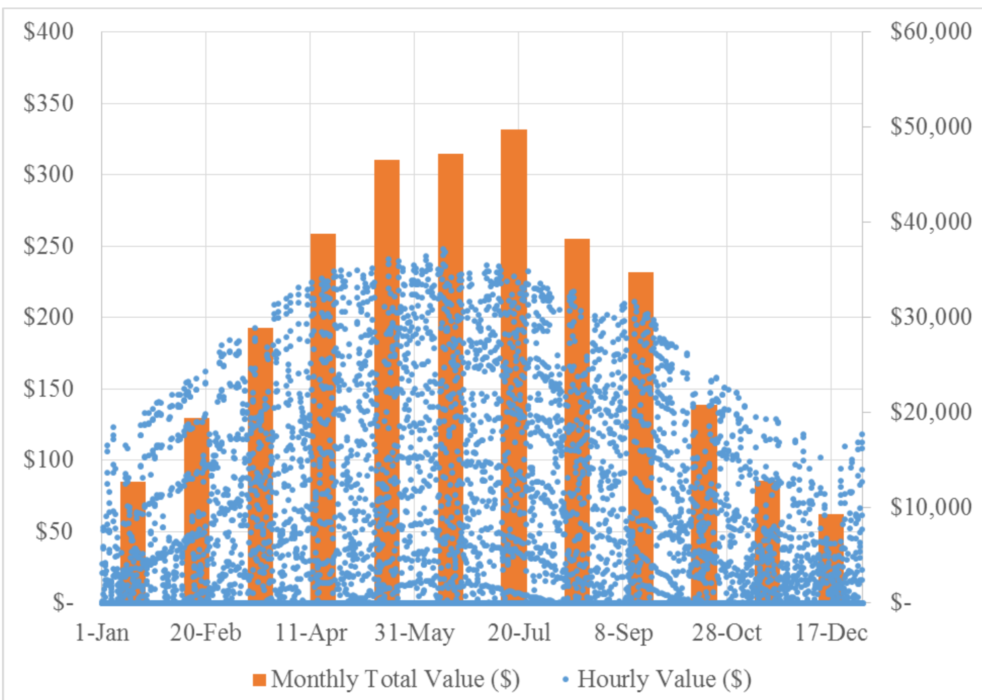

Figure 4.20 Estimated Production Value of a 5MW Array in 2014 Using a PPA

Despite this change, over 50% of the generated value still occurs between May and August. The combination of large electricity consumption, matched with prolonged production periods is apparent in both valuation methods. Another benefit of increased production periods in the summer is the ability to more reliably offset RTP costs during the middle of the day, allowing the CHP more flexibility with its purchases.

As a reference to the previous distribution of energy as it relates to contributors, Figure 4.21 displays these contributions with the added solar production. Because the value of the production does not affect the quantity that it is producing, the following graph represent both valuation methods. The vertical axis is the percentage contribution of each electricity supplier which are identified by colors shown in the legend. The horizontal axis shows these values as they relate to the time of the year.

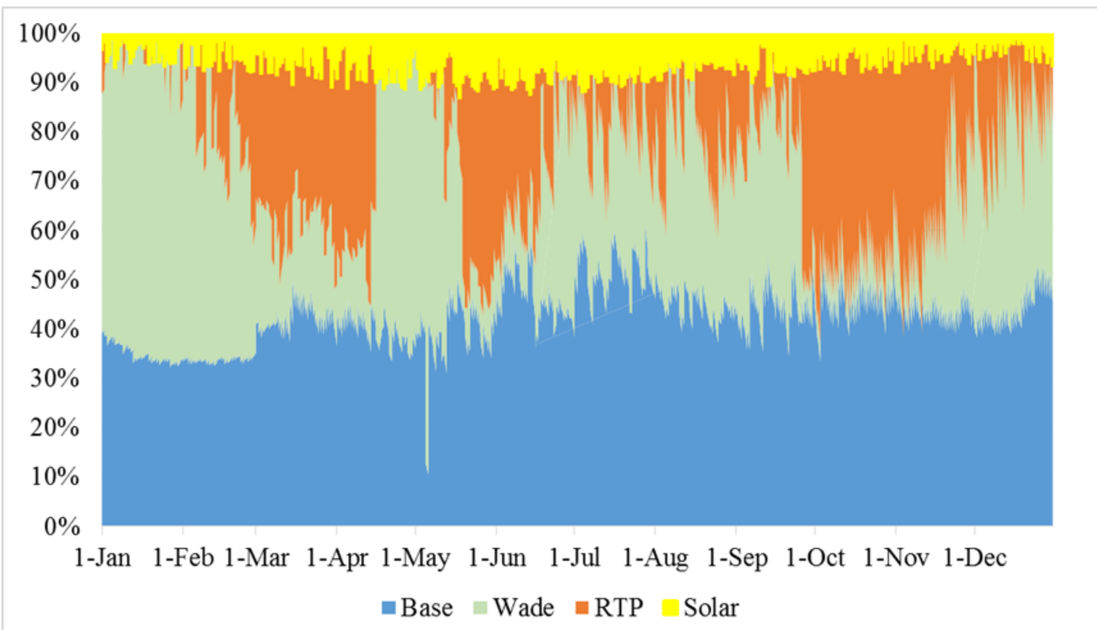

Figure 4.21 Percentage Comparison of Demand Contributors Including A 5MW Solar Array in 2014

The contribution to the demand follows the production cycle throughout the year. In the summer, the array consistently generates larger quantities of electricity, but considering that the demand is also larger, the difference in contribution percentage does not increase at the same rate that its value increases. However, the array will offset more RTP during this time as a result of larger demand and at a normally higher unit cost, greatly increasing the array's value.

CHAPTER 5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

As a result of this research, a process for creating a look back analysis for evaluating a utility scale solar installation at a combined heat and power facility has been formed. First, a clear understanding of the electricity that is being consumed was generated. This is crucial because it helped to form the value of the array. The demand is the driving factor for the value of the electricity being produced. In this analysis, it was found that most of the electricity consumption is done during the summer and fall, which was then linked to the OAT. Following this relationship further, the components of how the demand is met were analyzed individual as they relate to this relationship.

In this study, the consumption of electricity was defined as the kWh consumption at Purdue University. Since all of the electricity produced at the CHP is a provider only to the campus, the analysis of consumption focused solely within these limits and did not attempt to look at other consumers. The result of this investigation was that the university consumes more energy during occupied times, from 8AM to 4PM. However, occupancy is only an indicator of the total energy consumed in this situation. The conditioning of buildings, as a result of the expected occupancy, proved to have better predictive capability.

Next, the value that the potential solar production would have been given was characterized. Since the CHP purchases a base amount of energy from the local utility at a flat rate a year ahead to minimize risk, the value of the solar production was be based on the price of the supplemental power provided by the RTP from the local utility. Since the RTP rate changes each hour with only a day's notice, the trend was compared against a 24 hour timeline as it relates to the consumption on campus. This resulted in the realization that the RTP rate is not governed by campus demand. Throughout most of the year, the rates peak in the early morning and again near the end of the day. This trend follows the cycle of a residence, which is understood since the local utility provides energy primarily to the surrounding consumers which are mostly considered residential spaces. This cycle does however shift in the summer when the loads from all consumers increase their demand because of mid-day heat.

Once the value of each hour in 2014 had been established, the prediction solar production and its accumulated value was analyzed. Because of the investigation limitations with the available data and the definition of "utility scale", it was concluded that a local NREL database would be used to scale the production of the array. The data used was understood to be better suited for this type of projection as the collection location has a similar setting to where an array of this size would be constructed. The value was then calculated using parameters based on other utility scale solar projects in close proximity to the studied location using the Open PV database. Table 4.2 lists these parameters and applying the RTP values at each hour respectively, the value of the array in 2014 would have been $354,967.

5.1.1 Strengths and Weaknesses

With over a year's worth of supplied power data, a definite trend from month to month was determined and proves to be a definite strength of this research. The accuracy and consistency with how the database is managed allowed for an in-depth analysis.

The major weakness with this study was that the solar intensity and production data was predicted. The true 2014 data from the array only accounted for a portion of the year and the gaps were filled by calculating predictive factors based on OAT. The decision was made to utilize a separate set of data because of the research array's inconsistencies and age.

Another weakness of the study was the definition of the term "utility-scale". The study used references that keep the term within capacity estimated, but other sources have different definitions of what size qualifies as "utility-scale". Since this term is currently ambiguous in the solar PV industry, this could pose problems if the reference materials used for a different project have contrasting definitions.

Lastly, the delimiting the analysis of interconnection costs and possible credits could have an impact on the value of the array. These fell outside of the scope of the research question, but through further understanding of the problem, these have valid arguments when discussing the overall economics.

5.2 Conclusion

Using the estimated value of installation cost, and including electricity inflation rates and system degradation, the investment breaks even in 25 years, at RTP and without a tax credit, and would contribute 3.7% of the annual consumption when the sun is shining. The net present value of this investment, using RTP, totals $-1,853,973 at a 3% discount rate. While high OAT lowers the performance ratio of the solar array at extreme temperatures, it is also linked to greater demand when the sun is shining, thus increasing the value of any electricity produced at this time. This favorable relationship generates half of the array's annual value in a 4 month period.

An alternative method of valuing the array was also used. This took the form of a PPA that solidifies the rate that the electricity would be purchased at. In this investigation, it was assumed that a taxable entity would own the array and that the purchase would take advantage of a 30% tax credit. This lowers the initial net cost to $6,282,135. Using $0.06/kWh as the PPA rate for comparison against RTP, the net present value of this investment is $942,372 at a 3% discount rate. This discount rate was chosen for both evaluations because of the lower risk associated with the production of a utility scale array.

On the surface, valuing the array at RTP would be a more lucrative investment, however there are factors to be considered that add value to the array if it were owned by Wade which is outside of the scope of this research. Regardless, using the process in Figure 3.1, a simple economic analysis of the array's production value was estimated. Clarifying the approach accelerates the ability to analyze similar projects as it separates and defines the catalysts that affect the value of the array's production. Although there is still plenty of work to do after these have been identified, they are better understood in the scope of the overall project and have less ambiguity in context. Overcoming the complexity can be a major hurdle in solar development projects, especially ones that have so many predictive factors. The study was successful in looking back to create a streamline process that evaluates the production of utility scale solar project.

5.3 Recommendations

This section provides further identification of areas that could be analyzed as a result of this research. These are questions that are either unanswered, or did not fit into the scope of this research.

5.3.1 Solar Resource Data

Much of this discussion revolves around quantifying the value of a utility scale solar array in conjunction with a combined heat and power facility. To alleviate this, better records of solar intensity would greatly improve the validity of any statement made about the solar production at Purdue University. Although the solar resource data at the university airport is available, the predictive characteristics change at the different locations on campus. For instance the original collection of research solar array data gave some faulty numbers and did not have as strong of a correlation to the local airport data as expected. This could be a result of elevation or solar intensity reading accuracy. It is recommended that wherever an actual array is built, that data is gathered at that exact location and to use archived data to verify.

5.3.2 Self-Generation characteristics

Although total self-generation data was collected, further understanding of the solar array's utilization could come as a result of a thorough investigation of the elements the dictate the value of self-generated production. In the context of this study, the solar array's production was valued at RTP as this was the value that it would offset. However, as a result of this research, there is an argument to be made about the array's value as it relates to the steam that Wade during these solar production periods. Since Wade is a combined heat and power facility, some of the cooling of buildings is provided with steam driven chillers, and all of the heating is supplied by steam. As an example, in the winter, buildings are being heated by steam and so there is less steam to create electricity, which increases the value of solar production during this time because it puts less strain on the steam driven electric generators. This then gives Wade more production flexibility which allows them to make better economic decisions.

5.3.3 Storage

The addition of storage capabilities would greatly improve what the solar production is valued at. Since both RTP and solar intensity have time components that the current system has no control over, the ability to store some of the energy would improve this interaction. An investigation of the right storage size as it relates to the production capacity of the solar array and its optimal sizing to maximize value against RTP could be very insightful. The ability to control the release of energy to cover higher RTP costs may prove to justify the expense of adding this storage capability. One argument against this however, as proven by this research, is the relationship between the solar production and RTP during the summer. Since the RTP, solar production, and demand line up during this time, it accounts for 50% of the value throughout the year.

Likely most of the storage value would come from its performance in the remaining 8 month of the year where RTP and solar production are out of sync.

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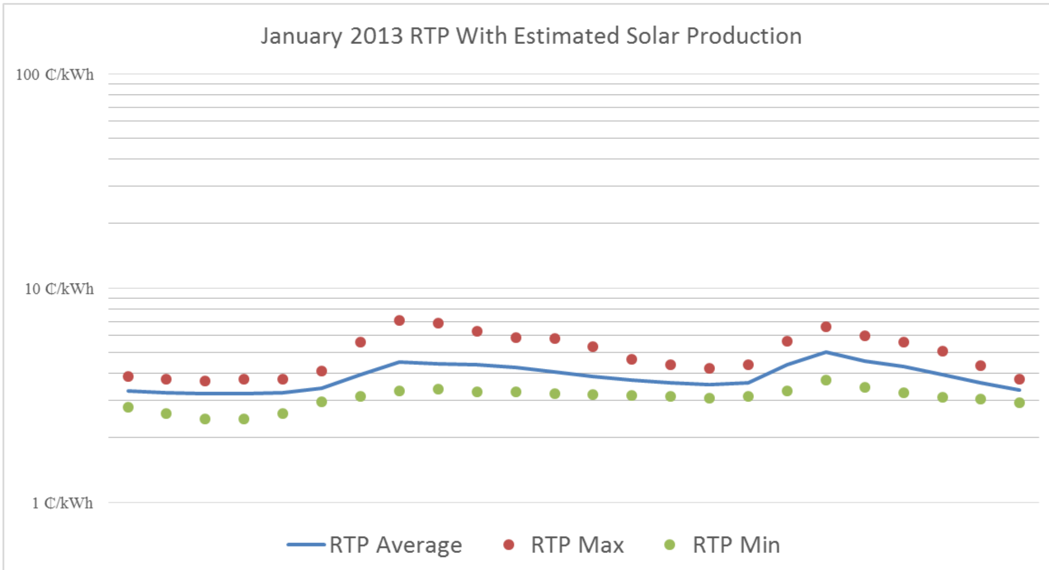
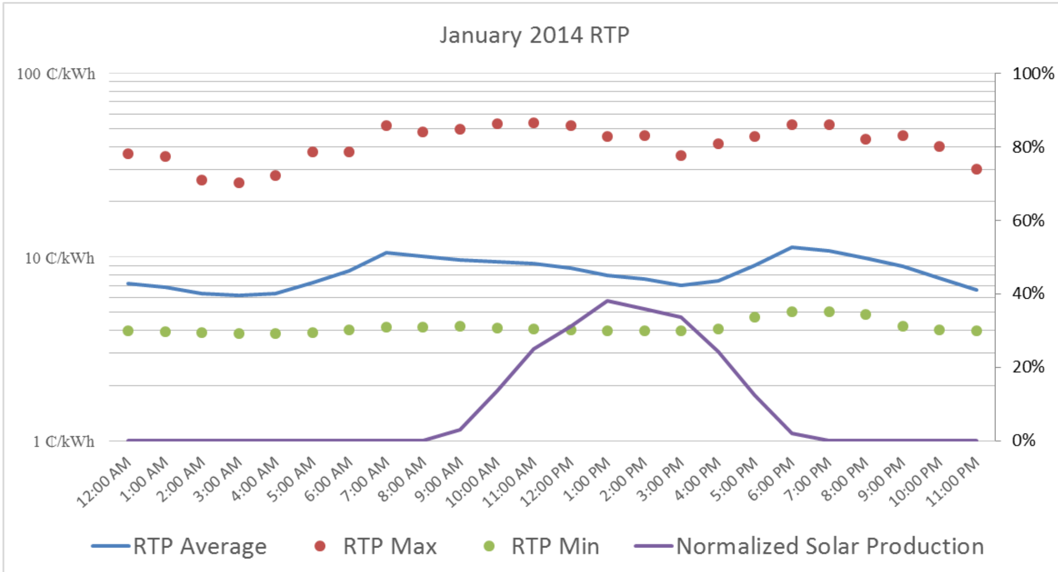
APPENDIX

APPENDIX

Historical RTP Data Vs Recorded KNOY Solar Production

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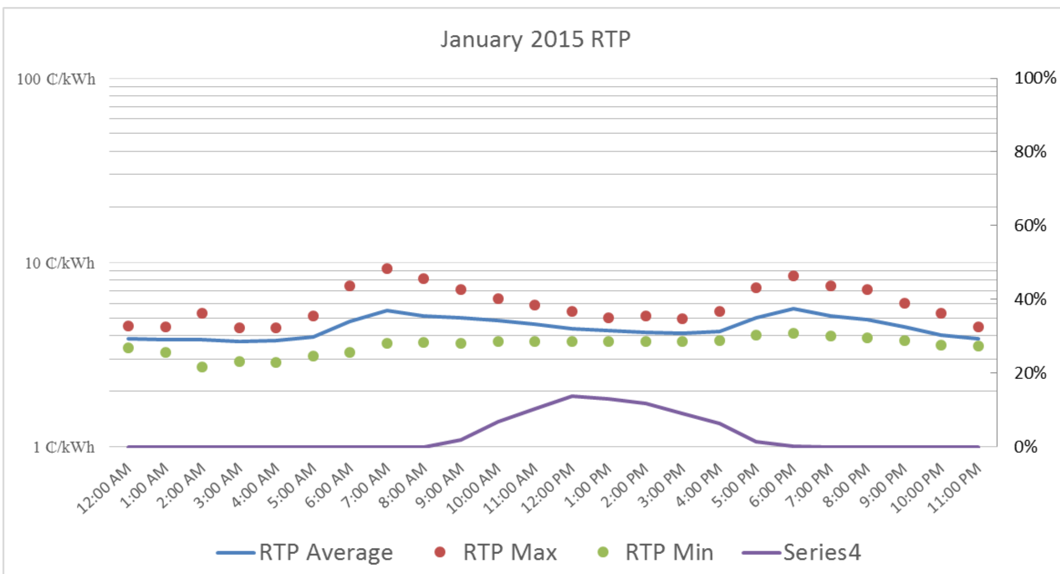
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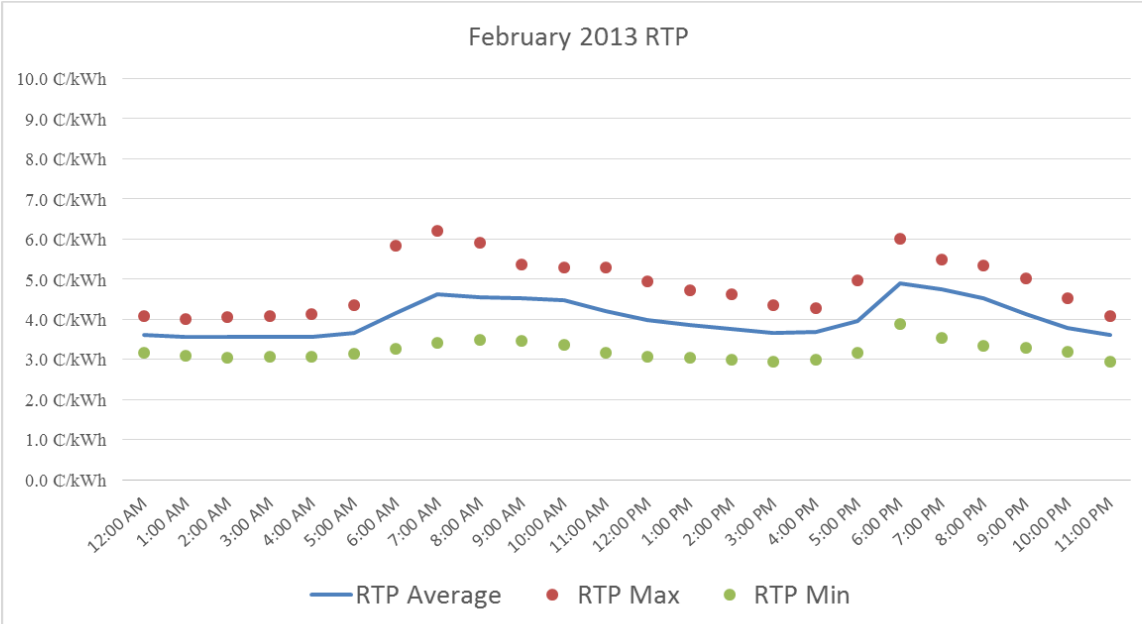
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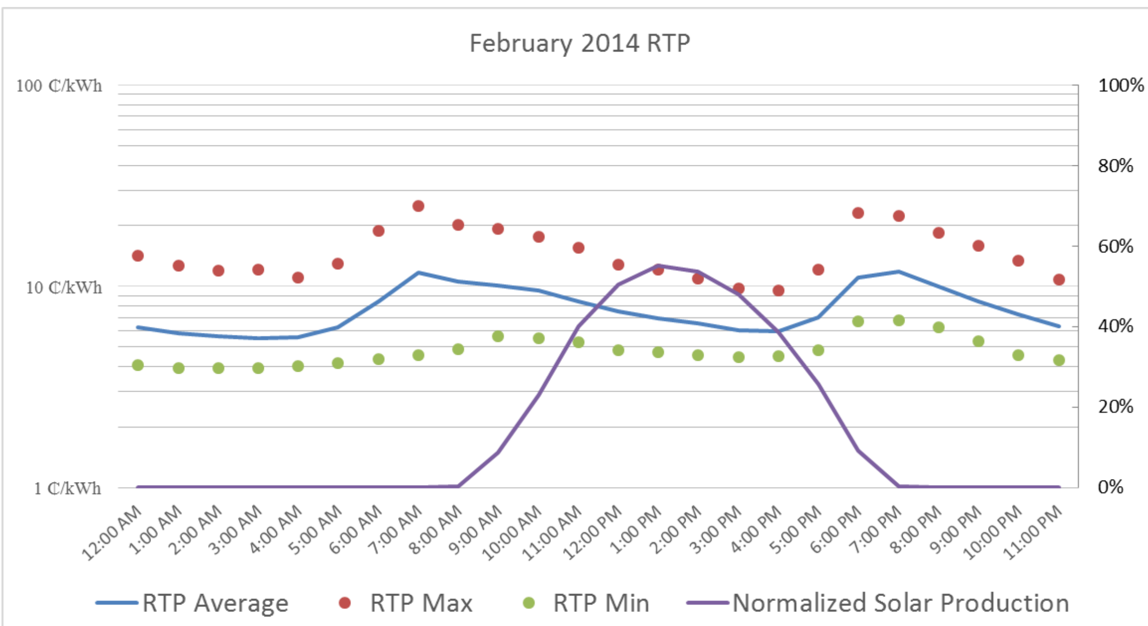
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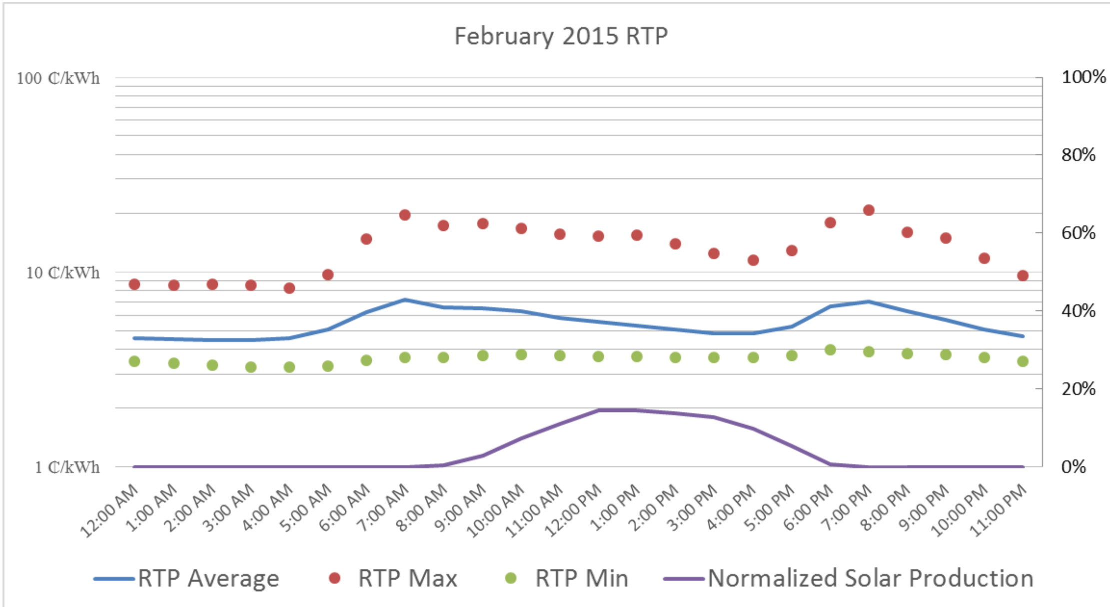
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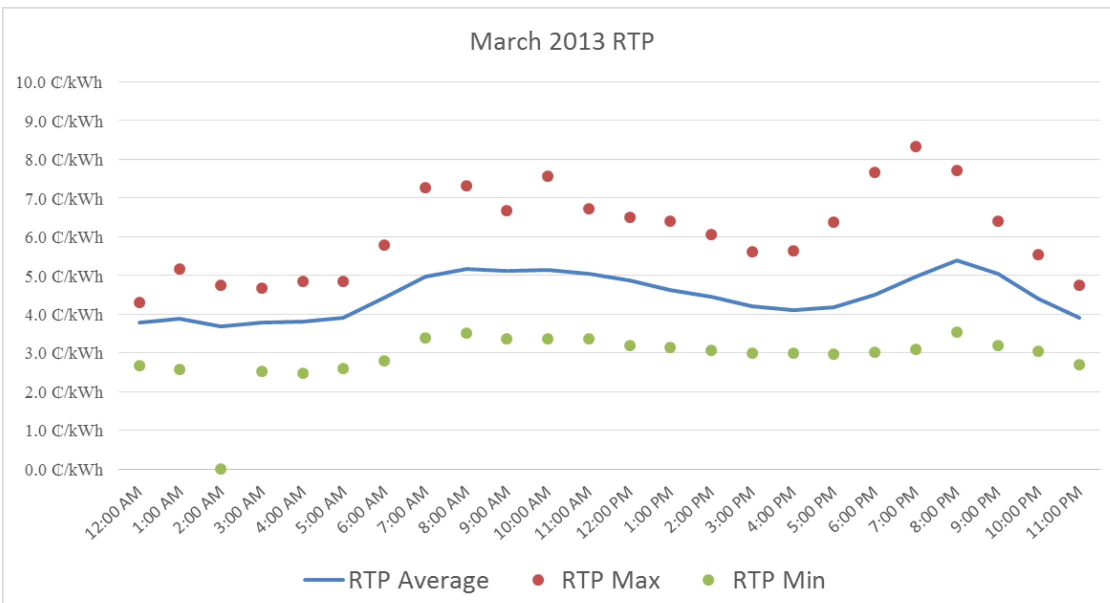
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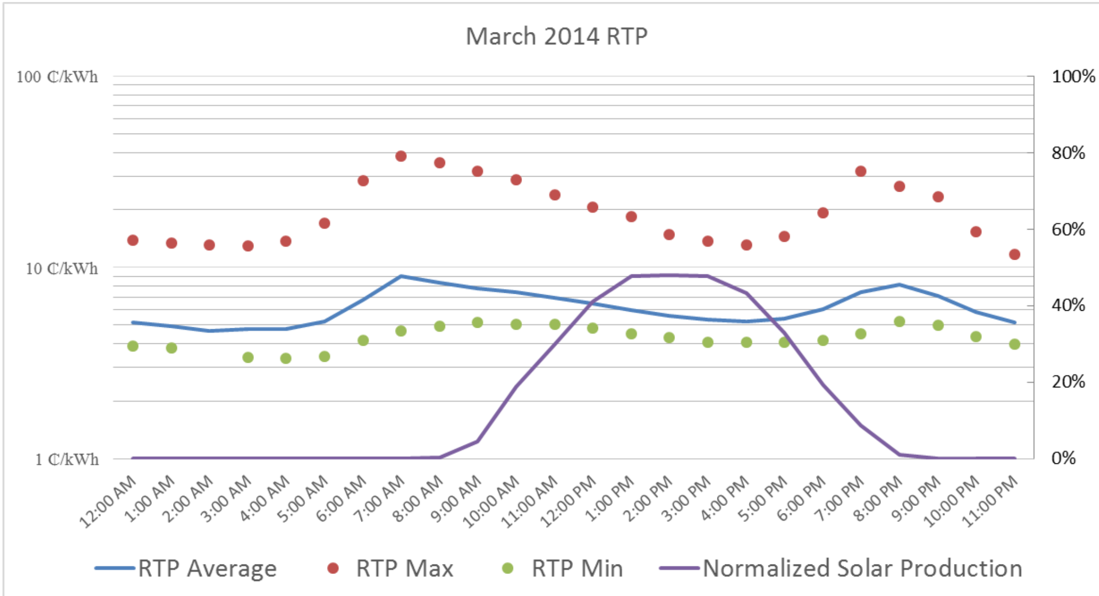
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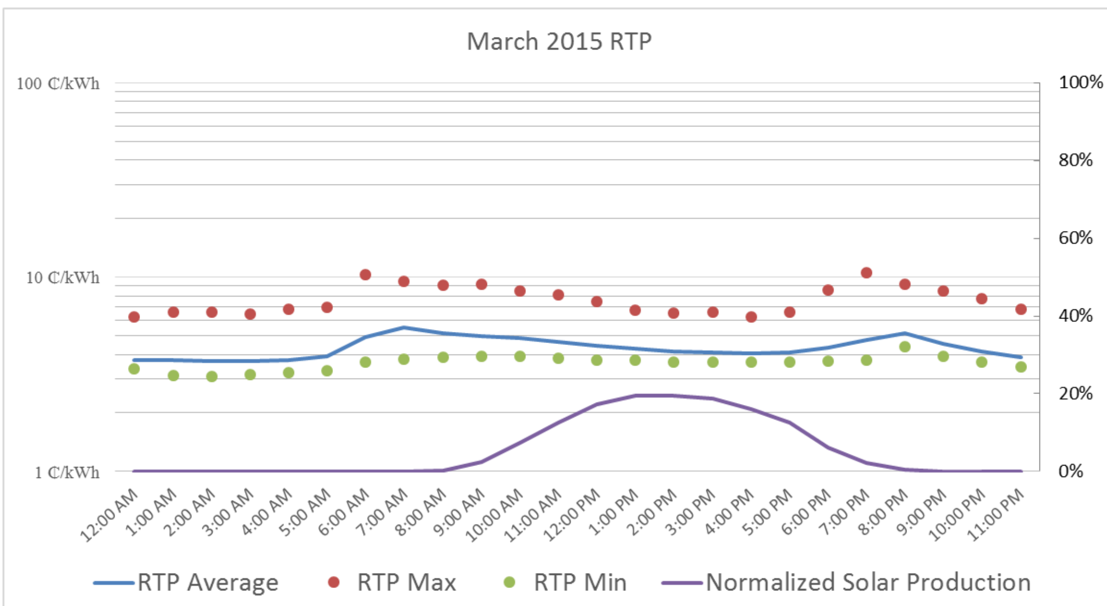
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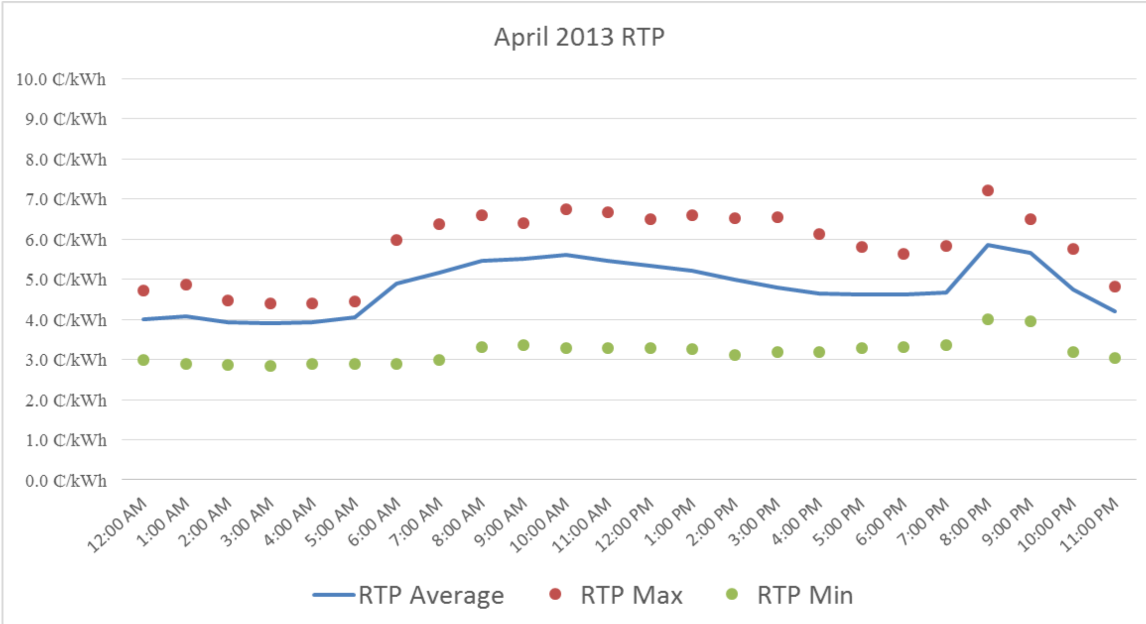
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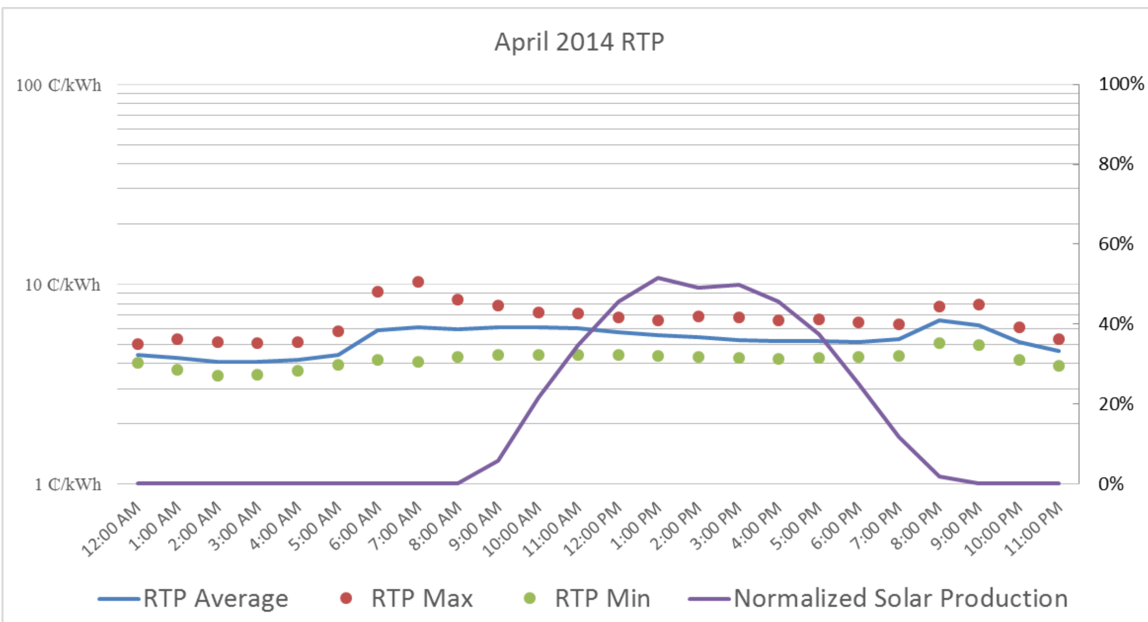
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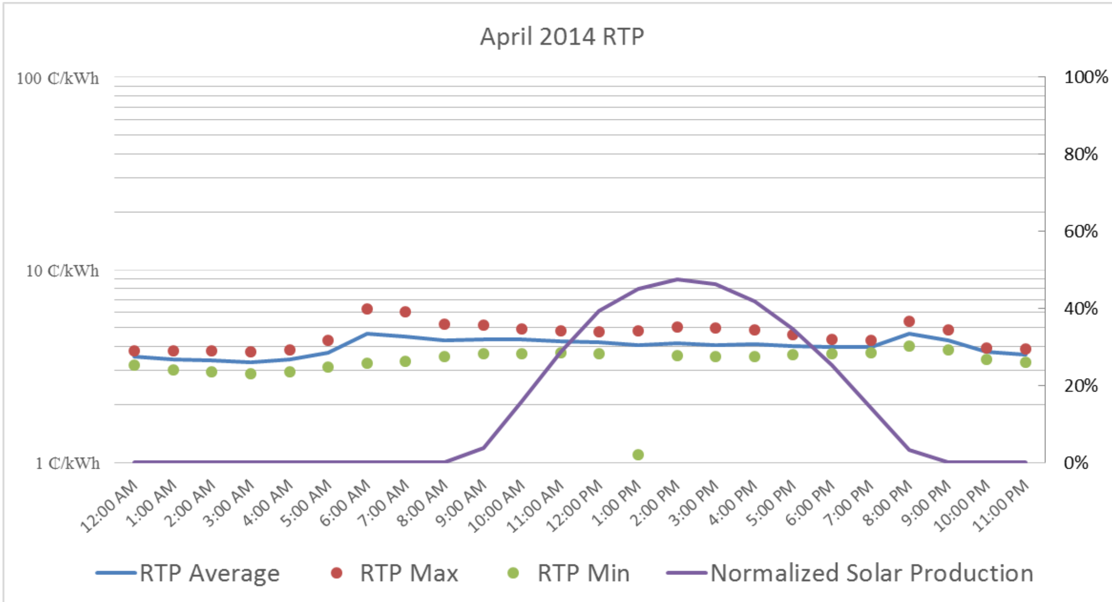
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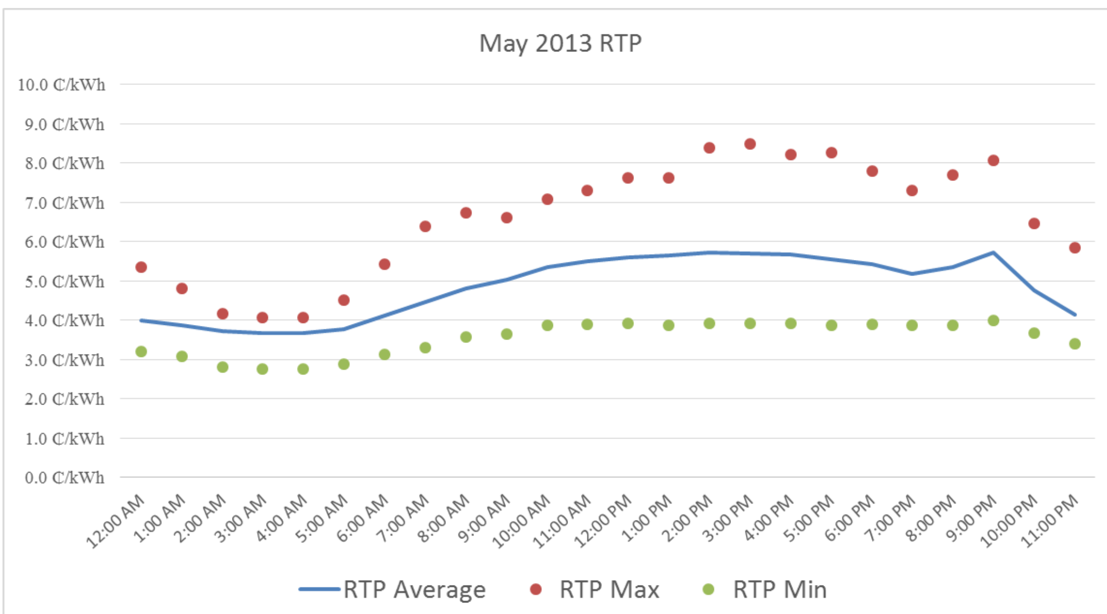
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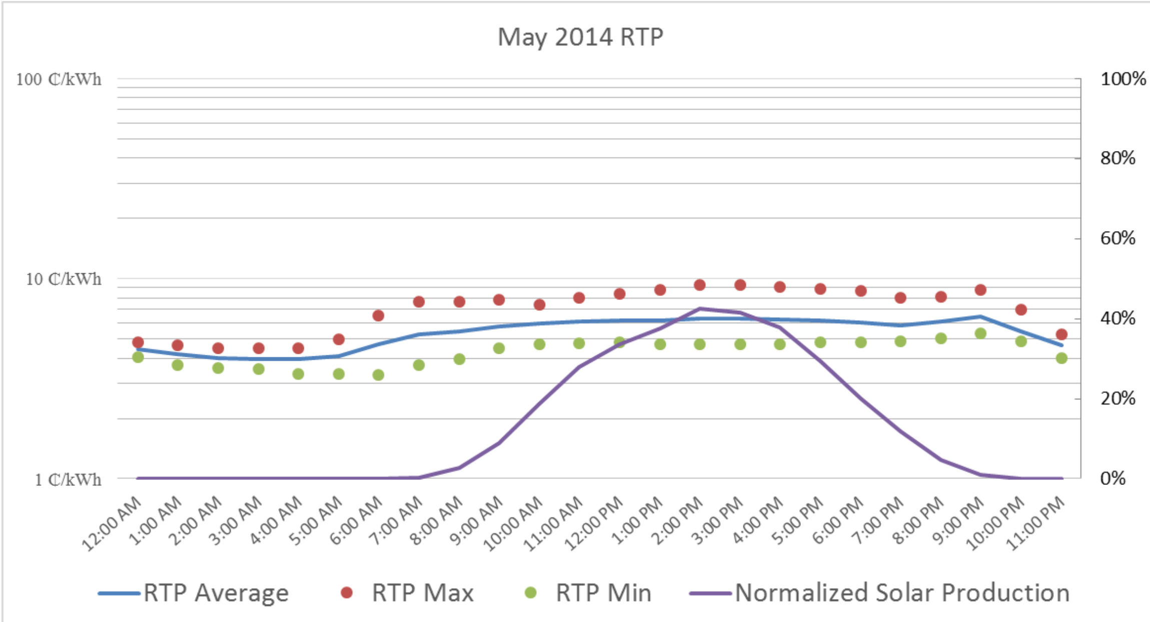
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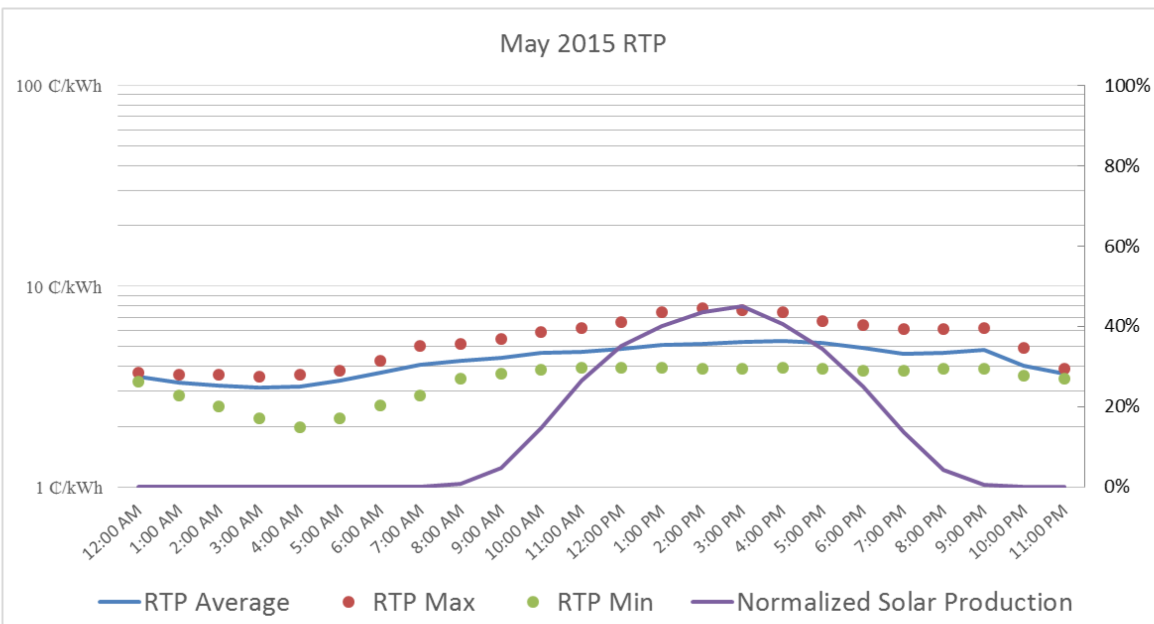
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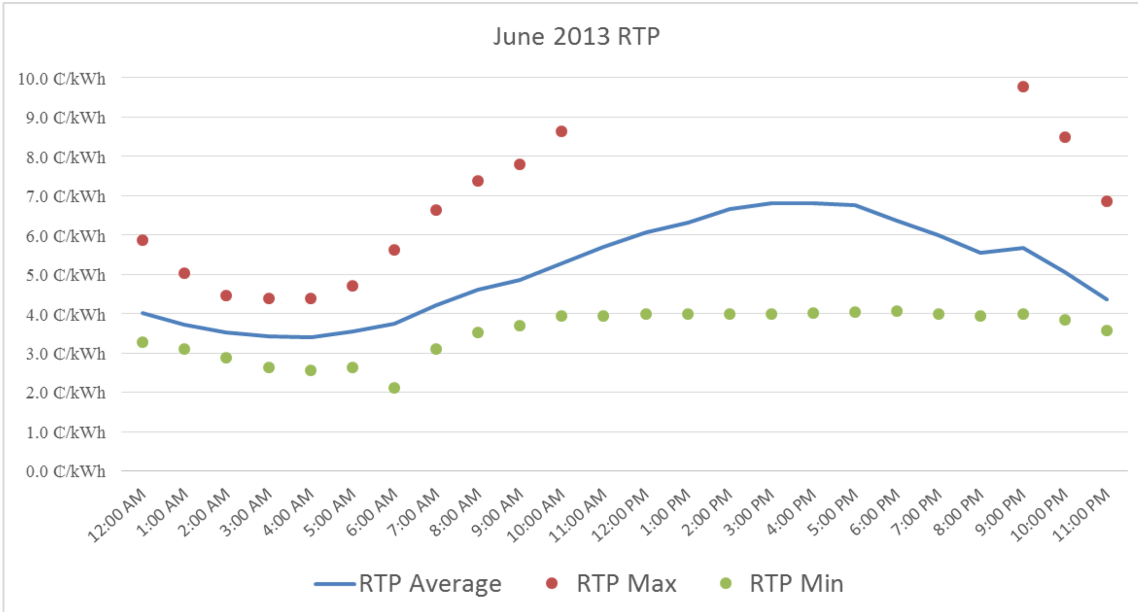
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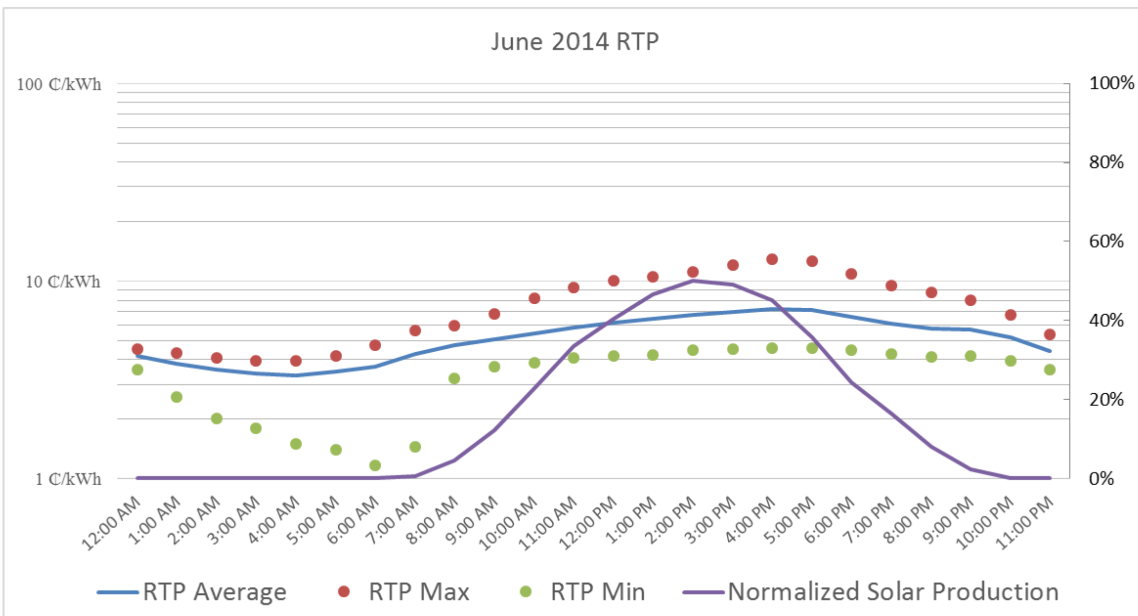
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RTP Average
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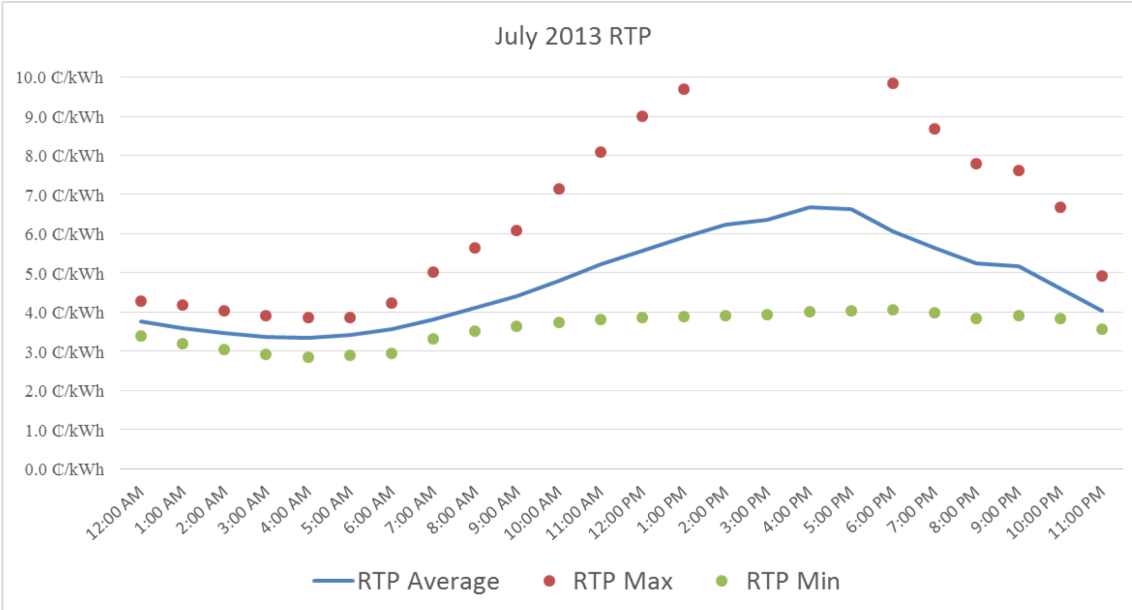
Normalized Solar Production


July 2013 RTP
10.0 ₵/kWh
9.0 ₵/kWh
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RTP Average
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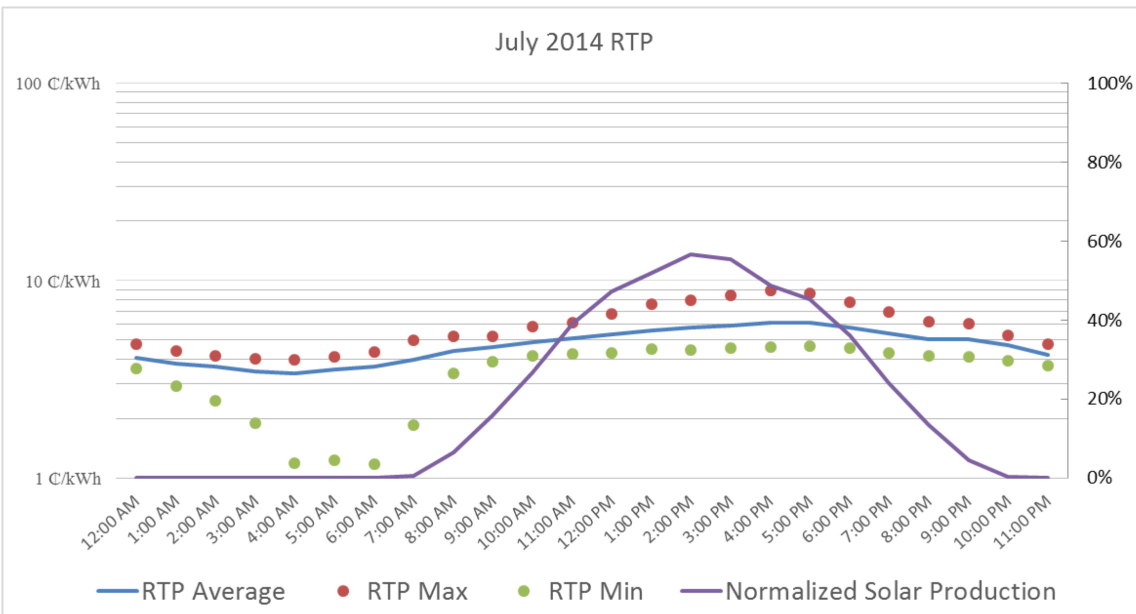
July 2014 RTP
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RTP Average
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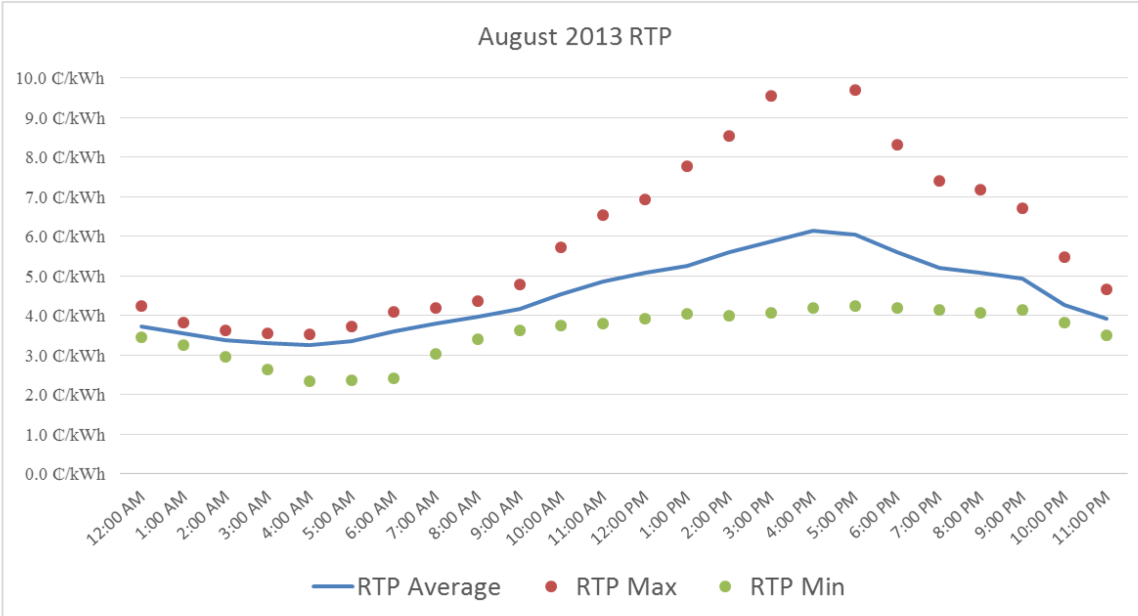
Normalized Solar Production


August 2013 RTP
10.0 ₵/kWh
9.0 ₵/kWh
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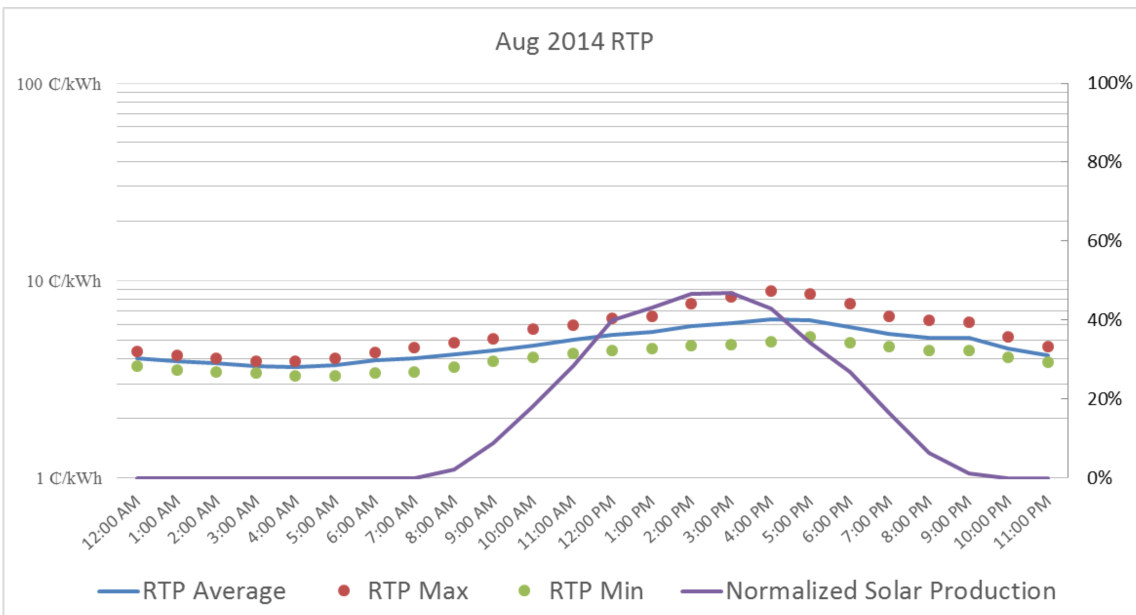
Aug 2014 RTP
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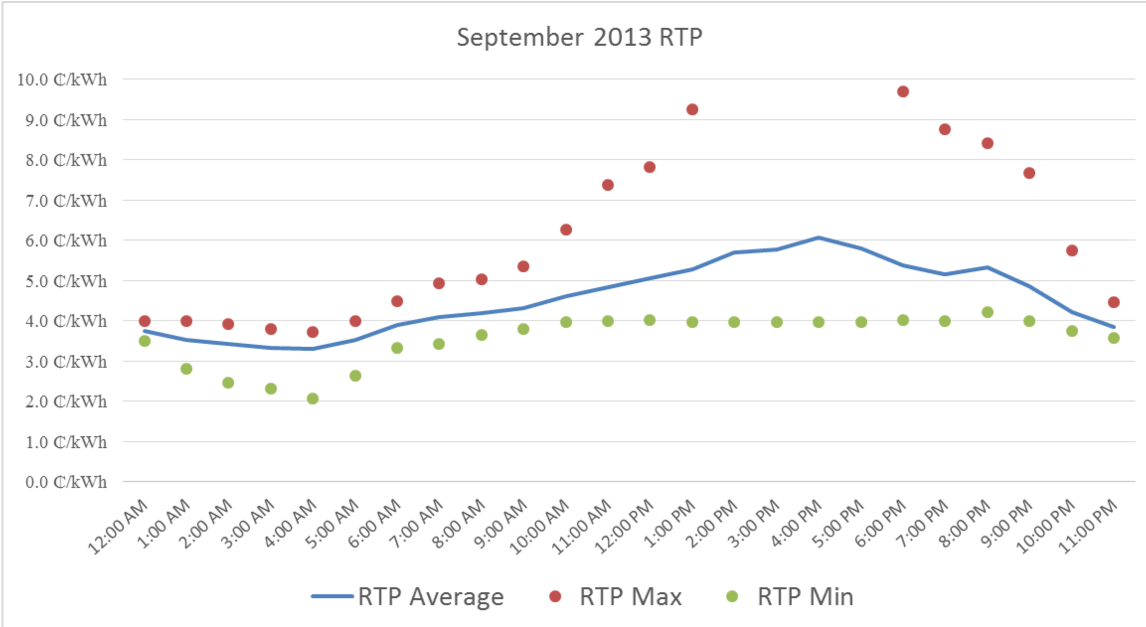
Normalized Solar Production


September 2013 RTP
10.0 ₡/kWh
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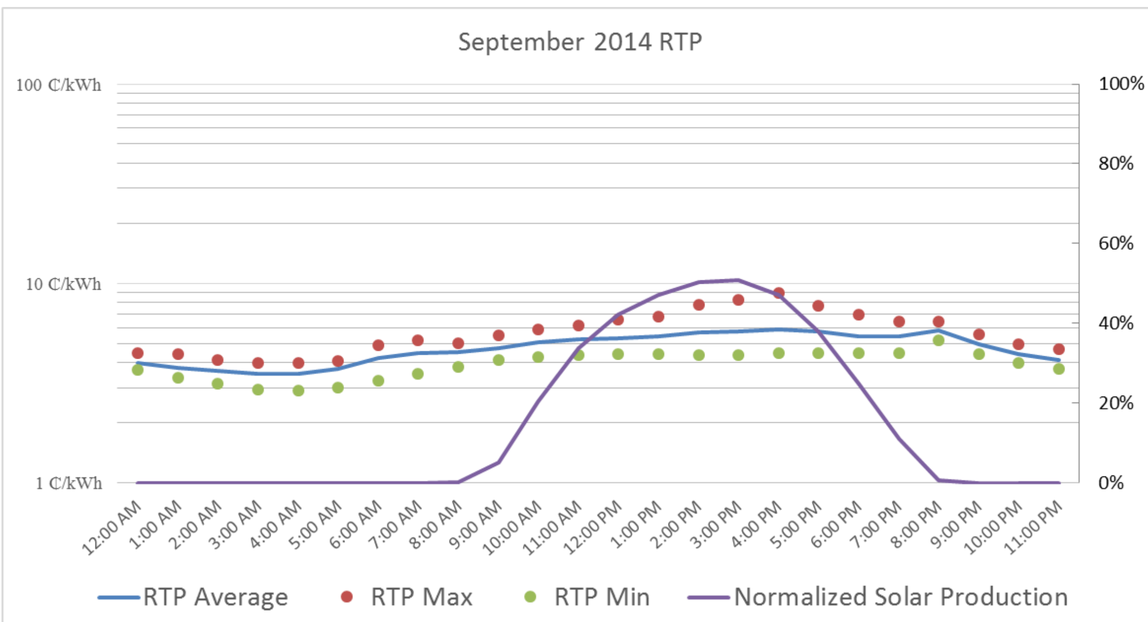
September 2014 RTP
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RTP Average
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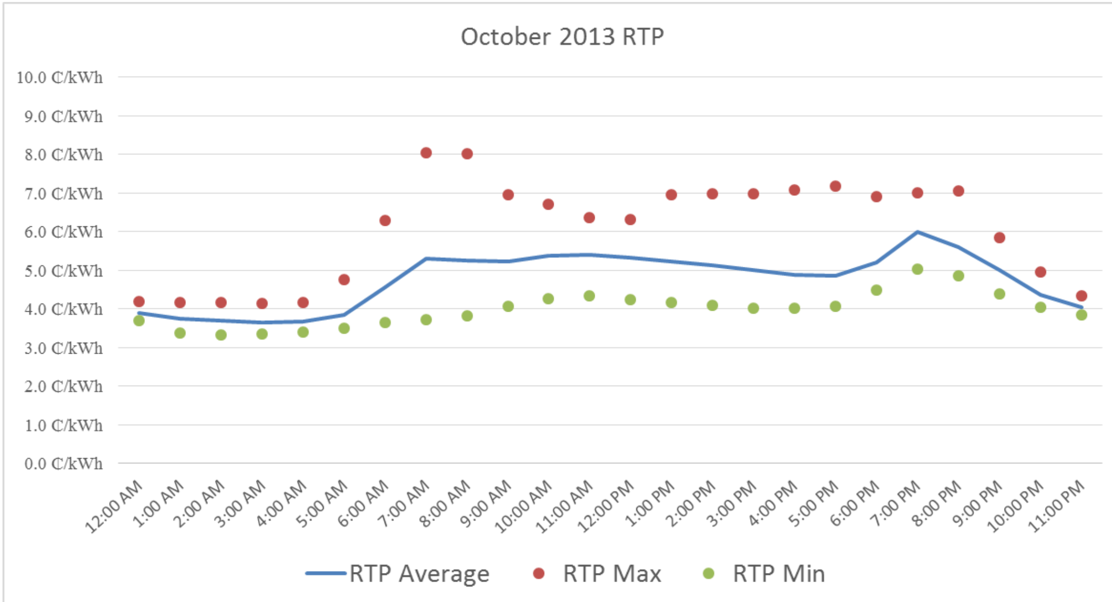
Normalized Solar Production


October 2013 RTP
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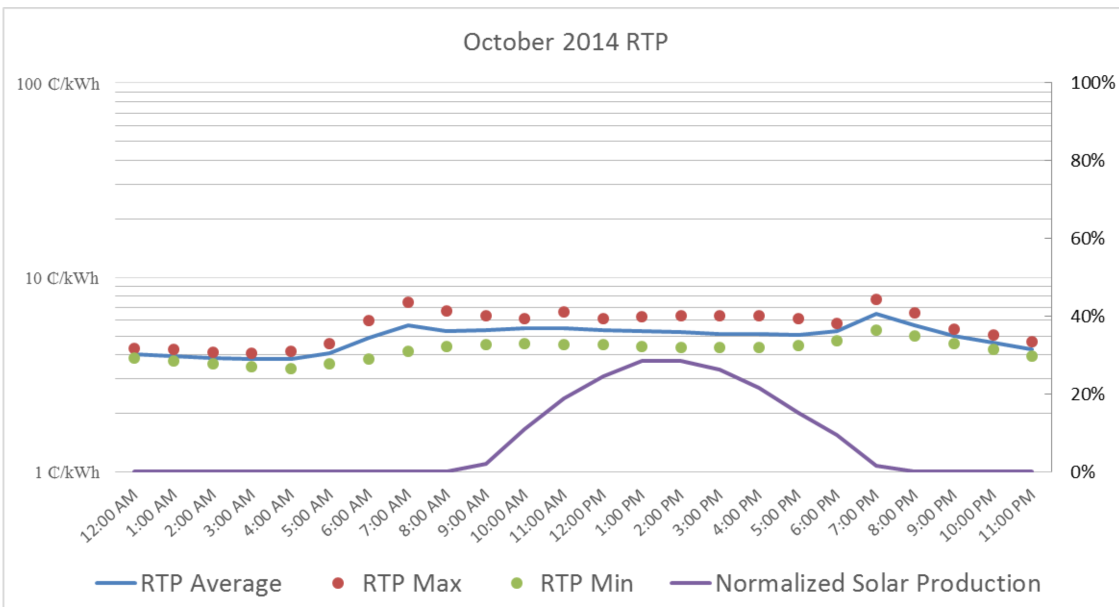
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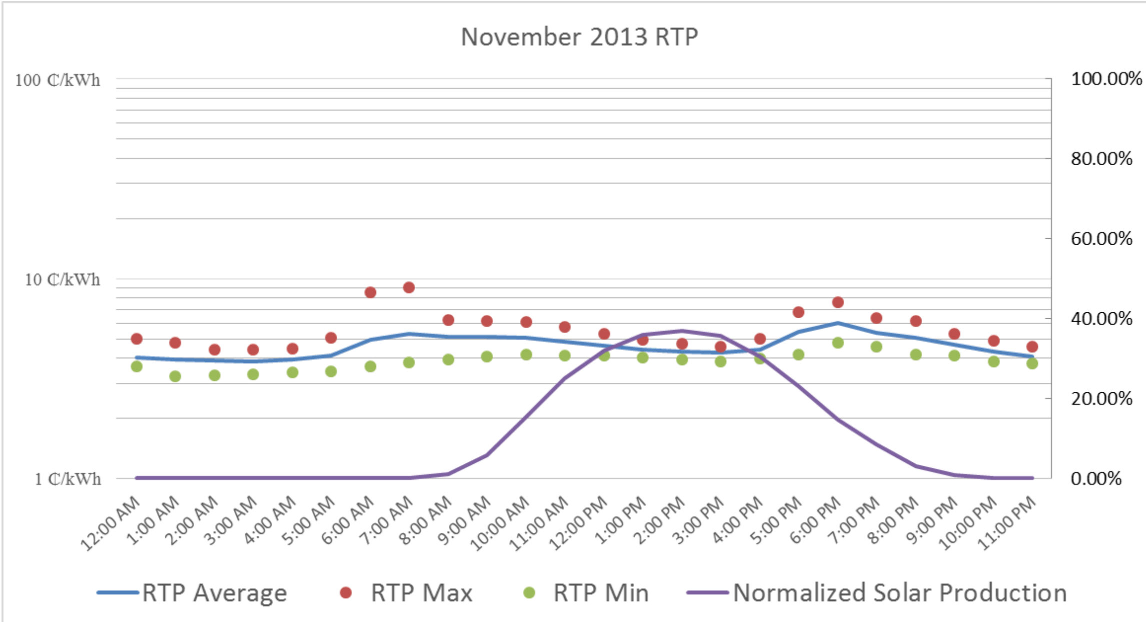
Normalized Solar Production


November 2013 RTP
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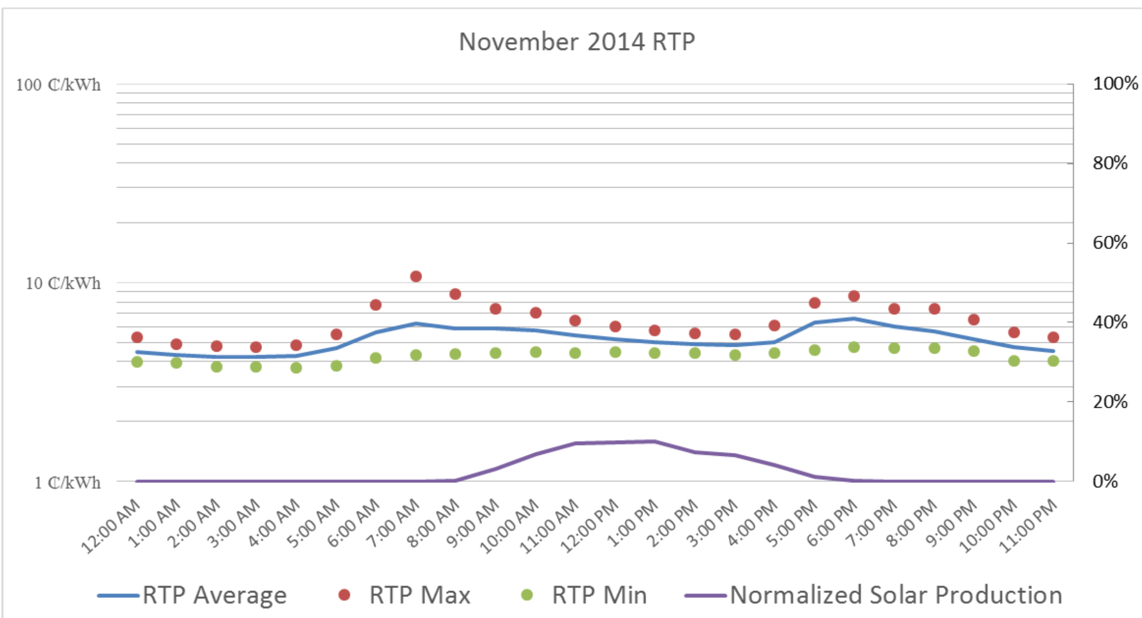
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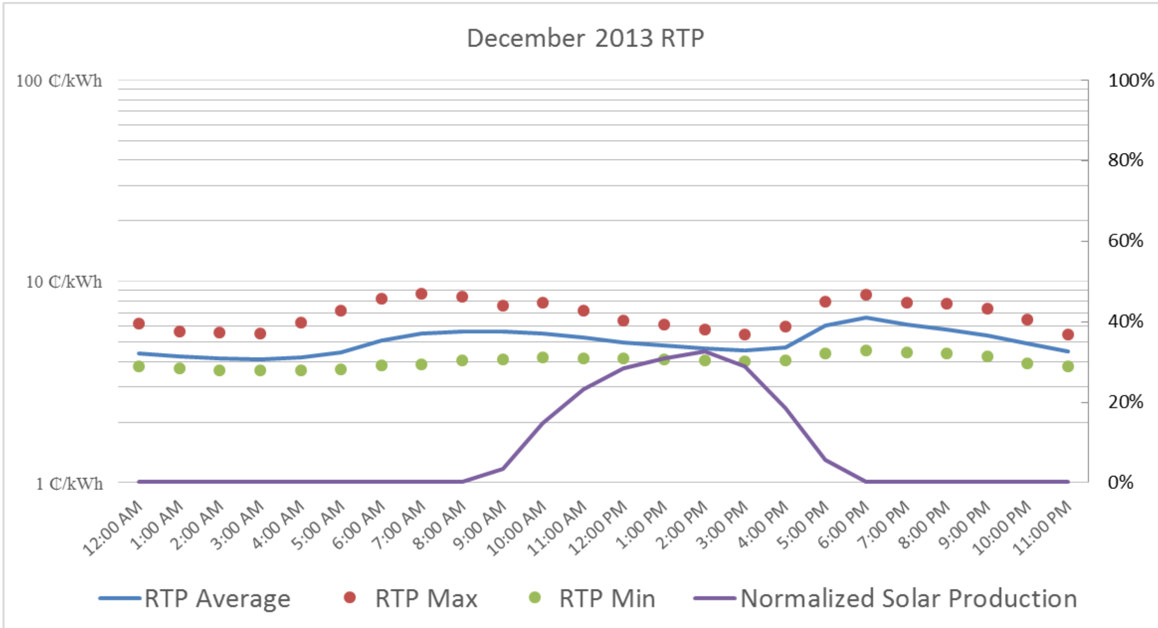
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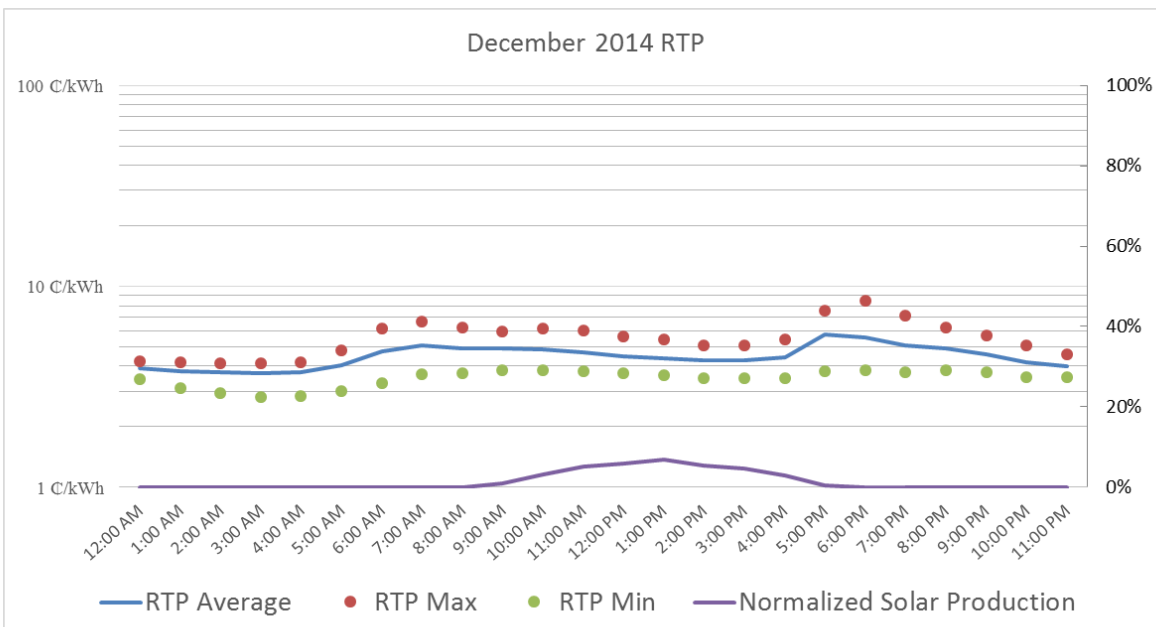
Normalized Solar Production


December 2014 RTP
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