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Arizona Corporation Commission
1220 W Washington
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RE: Docket NO. E-01345A-12-0290 and E-01345A-10-0394 E-01933A-12-0296
2013 Renewable Energy Standard (RES) Implementation Plan E 04204A-12-0297
Technical Conference on Distributed Energy and Net Metering

To All Interested Parties:

This letter represents an offer by Arizona State University's (ASU) Global Institute of Sustainability to assist the Arizona Corporation Commission Decision 73636 mandated technical conference as it evaluates the costs and benefits of distributed renewable energy and net metering.

Renewable energy particularly solar energy is a serious energy source for Arizona that has major economic and energy implications. It is a technology that should be treated seriously with time and thought given to gathering and analyzing as much real time data as possible to determine the costs and benefits going forward. ASU is in a position to redeploy its research assets to assist in this endeavor by analyzing the costs and benefits of over 18MW's of distributed systems on ASU campuses. The attached report submitted by honors student Natasa Vulic demonstrates the value of such an undertaking. While her research was limited to two working systems, Ms. Vulic was able to offer new protocols leading to improved cost effective installations and an analytical approach that would appear to offer new insights into an effort that focused on refreshing old studies or relying on experience from states having different climatic conditions.

I have asked Dr. Harvey Bryan to lead the ASU research team in providing the needed assistance to the technical conference process. He can be reached at 480-965-6094 or harvey.bryan@asu.edu

Sincerely,

Gary Dirks
Director, Global Institute of Sustainability
Arizona State University

Arizona Corporation Commission
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SOLAR POWER PURCHASE AGREEMENTS FOR 10MW_P DISTRIBUTED GRID-TIED PHOTOVOLTAIC SYSTEMS AT THE ARIZONA STATE UNIVERSITY MAIN CAMPUS: ESTIMATED VS. ACTUAL ENERGY OUTPUT

By

Natasa Vulic

A report submitted in fulfillment of the honors thesis requirement.

EEE: 493 Honors Thesis
School of Electrical, Computer and Energy Engineering
Arizona State University
December 10, 2012

The majority of the 52 photovoltaic installations at ASU are governed by power purchase agreements (PPA) that set a fixed per kilowatt-hour rate at which ASU buys power from the system owner over the period of 15-20 years. PPAs require accurate predictions of the system output to determine the financial viability of the system installations as well as the purchase price. The research was conducted using PPAs and historical solar power production data from the ASU's Energy Information System (EIS). The results indicate that most PPAs slightly underestimate the annual energy yield. However, the modeled power output from PVsyst indicates that higher energy outputs are possible with better system monitoring.

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I. INTRODUCTION

Solar Power Purchase Agreements, or SPPAs, have led to an increase in solar PV installations on school, non-profit, and government entities by providing affordable electric rates with little or no upfront cost. Instead of purchasing a solar system, a public entity agrees to host the system and enters into a contract that outlines the terms of purchasing electricity produced by the system on a fixed monthly payment or a per kWh charge over the 15-25 year period, with the option of extending the contract or purchasing the system at the end of the term (Environmental Protection Agency, 2012). A simplified outline of the third party PPA structure has been presented below

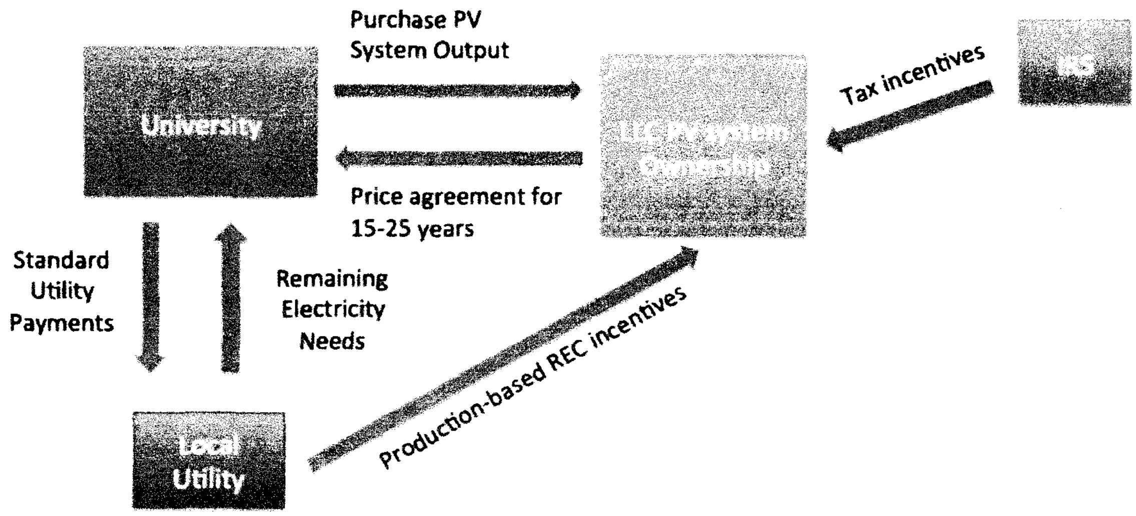

Figure 1. *Third-party PPA structure*

PPAs have become a preferred method of financing among the public subset of the market as tax-exempt entities are not eligible for solar commercial tax credit established with the passage of the American Reinvestment and Recovery Act in 2009 that currently assist in making solar energy more affordable. The third party financier is able to take advantage of available federal and state tax incentives that are not available to tax-exempt entities, passing on the savings to the consumer in the form of more affordable rates (Kollins, Speer, & Cory, 2010).

In 2008, Arizona State University entered into the first commercial solar PPA in the state (Bentzin, 2009). PPAs led to a rapid expansion of solar energy across the university's four campuses, significantly contributing to 15MWp of installed capacity, which is the largest in the U.S. for a single university (ASU's solar projects earn climate impact recognition, 2012). Out of the 58 solar PV installations, 53 have been installed under the PPA financing structure, with plans for an additional 5 MW by February 2013. The installations include fixed and single-axis tracking, located on building rooftops, parking structures, surface parking, and open land (ASU Solar, 2012). The pioneering work of the university has led to more school, non-profit, and government entities choosing to enter into a PPA.

The expansion of distributed solar energy is helping meet the Arizona Corporation Commission (ACC) Renewable Energy Standard requiring that utilities must generate 15% of their electricity from renewable energy resources by 2025, with 30% non-utility distributed generation (Renewable Energy Standard & Tariff, 2012). In order to meet this goal, Arizona Public Service (APS), a major utility in the state, has established Renewable Energy Credit (REC) purchase agreements under which APS pays the university for the transfer of RECs on a per kWh basis over the life of the system, with a cap on 40% of the total project cost. REC incentives further help to offsetting the cost of solar energy (Non-residential solar and renewable incentives , 2012).

Above all, the solar installation systems are expected to provide significant energy savings as the utility rates continue to rise. The average retail price of electricity for the commercial sector in the state of Arizona has increased about 29% since 2000. Although PPA rates that the university pays are currently above the utility prices, most systems are expected to be on par with utility rates in the next few years.

This study aims to evaluate the impact of PPAs on the growing number of solar installations on the Arizona State University's main campus, which hosts 52 of the systems. Out of the 52 installations, 50 have been installed through a PPA, and together account for 9.7MW_p of installed capacity. The study extends from 2009 to 2012, analyzing the trends in installed capacity over the four years. In addition, the study looks at environmental benefits of these installations with respect to offsets in Green House Gas (GHG) emissions and water usage. This is followed by a discussion on project cost trends. Furthermore, PPA estimated power outputs are compared to actual power outputs. Finally, a case study on two of the installed systems using PVsyst solar power simulation software is presented to evaluate the performance of these solar systems and offer recommendations on more effective monitoring methods.

II. REACHING 10MW AND ITS IMPACT

A. Growth in electricity supplied by solar energy

While the first solar system on the Arizona State University campus was installed in 2004, the expansion of solar installations accelerated with the drafting of a first PPA that led to a 711kWdc installation. A number of other installations soon followed under the same financing structure. As a result, the fraction of electricity supplied by solar energy at the Arizona State University has been steadily increasing.

Figure 2 below shows the trend in installed capacity from 2009 to 2012, together with the fraction of total electric consumption generated by solar.

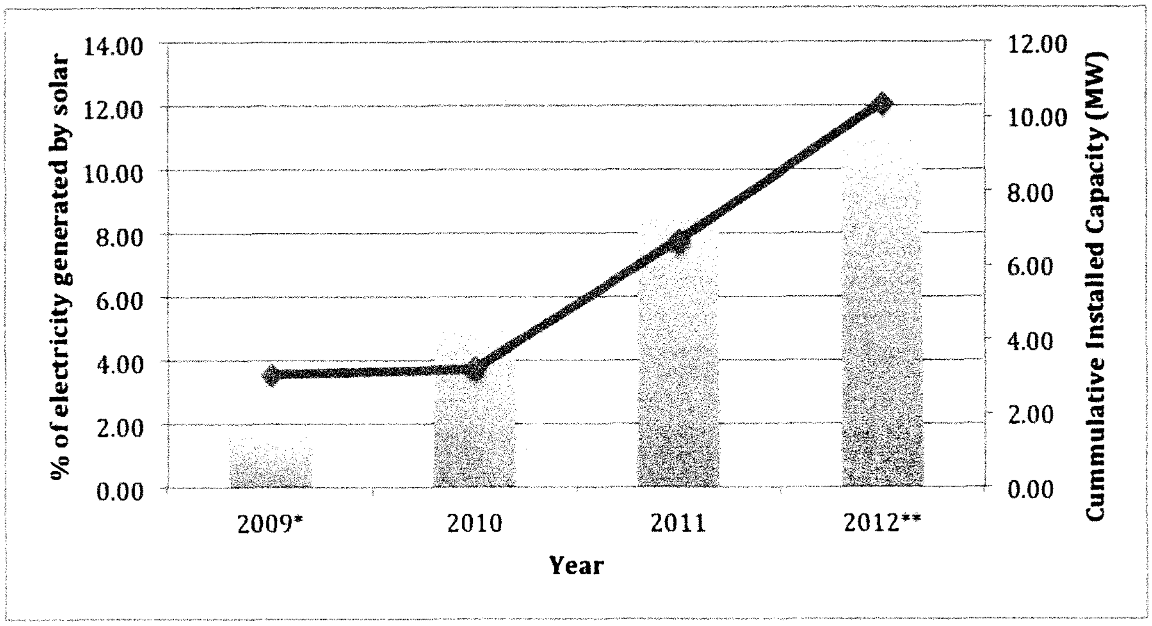

Figure 2. Cumulative installed capacity and % of electricity generated by solar (2009-2012) for systems governed by PPAs at the Arizona State University's Main Campus. *starting March, 2009; **ending November, 2012

Over the course of the study (2009-2012), the cumulative installed capacity at the Arizona State University main campus rose from 1.7 MW_p in 2009 to 9.7MW_p by the end of 2012. This accounts for the majority of the total installed capacity of 15.3MW_p across the ASU's four campuses. During the same timeframe, the fraction of electricity generated by solar has been rising steadily from 3.6% to 12.1%. Overall, the solar installations on the main campus have produced around 31 GWh of electricity thus far.

B. Environmental Impact

1. Offsetting Peak Power Generation

Solar PV offsets a portion of the energy supplied by traditional generation methods. Figure 3 below represents electric consumption patterns over a sample of weeks in January, March, and September, shown in blue. The energy generated by solar PV is shown in red, and the resulting net energy consumed (electricity consumed – PV electricity generated) is shown in green, demonstrating the impact of solar systems on peak shaving throughout the year.

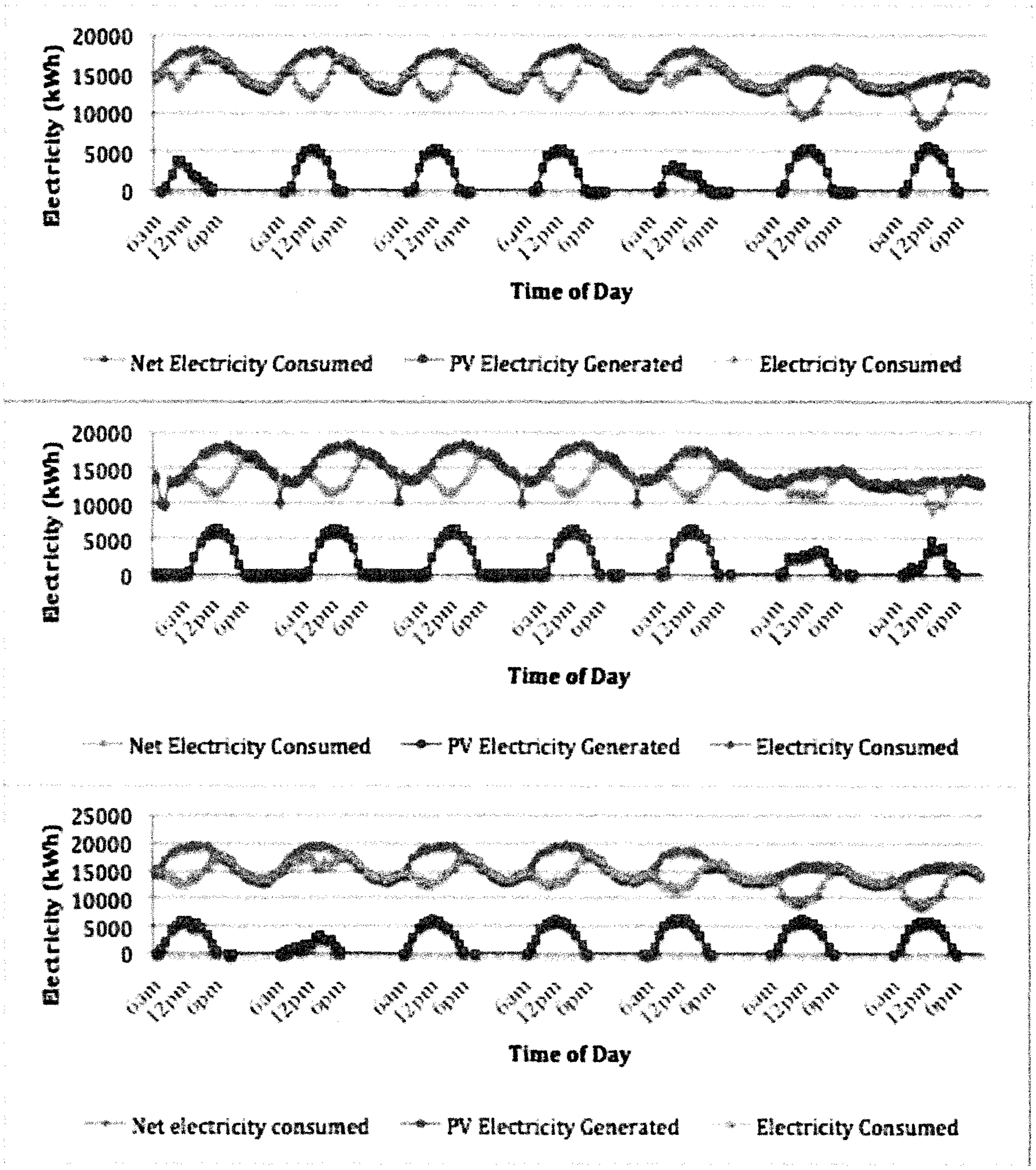

Figure 3. The impact of peak shaving in a) a week in winter, b) a week in spring, c) a week in summer.

As seen in the figure above, the electricity generated by solar PV peaks around 12pm. On the other hand, energy demand is highest around 3pm, resulting in asymmetric peak shaving. This reduces and shifts the peak of net electricity consumed to around 6pm. During the weekends, energy needs of the university are reduced, leading to an inverted peak in the net electricity consumed.

Overall, the solar systems help reduce the peak demand for the university, which can help reduce the demand charge. Large users of electricity, such as a university, are often required to pay for the right to have energy capacity available to them (whether or not they're using it) at all times. This is called the "demand charge." The demand charge is often determined using the "peak demand" occurring during a monthly billing period. This demand charge is billed at a fixed per kW basis, charged over the entire billing cycle (APS , 2012). The energy produced by the solar systems has the capacity to reduce the demand charge since the systems can achieve measurable peak shaving even during cloudy days.

In addition to the financial impact of peak shaving, there is a significant environmental impact in reducing energy demand from the utility. The environmental impact of peak shaving depends on the electric generation portfolio of the local utility. Currently, the electric generation portfolio for the main campus' utility (APS) consists of coal, natural gas, nuclear, and renewable energy (APS, 2012). The proportions of each are presented in the Figure 4 below.

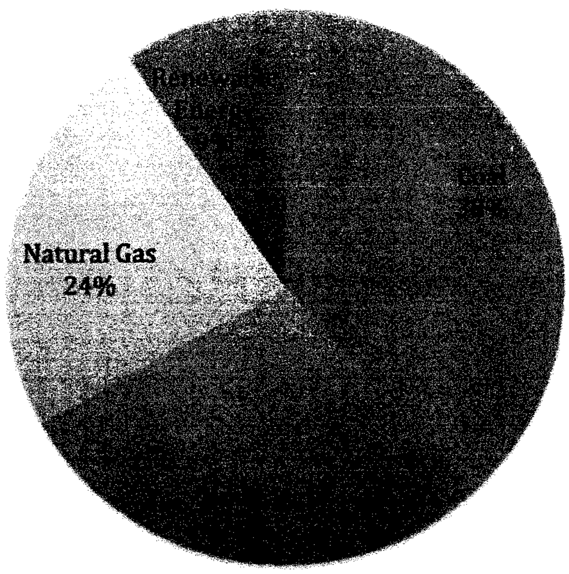

Figure 4. *APS Electric Generation Portfolio*

Energy is supplied by three types of electric generation: baseload, intermediate, and peaking. Coal and nuclear are baseload generation resources that supply continuous energy output 24 hours a day, 365 days a year. Intermediate resources, such as Combined Cycle Natural Gas Powerplants provide energy over long periods of the day. On the other hand, peaking powerplants operate a few hours each day to provide energy on a very short notice. These are usually natural gas combustion turbines (APS, 2009). Figure 5 below illustrates the energy generation breakdown throughout the day.

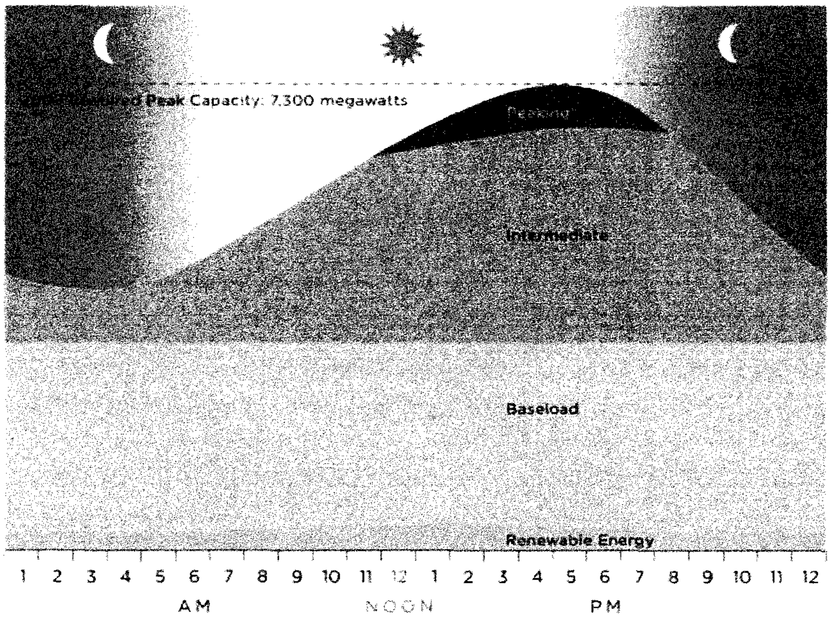

Figure 5. *Meeting the Daily Energy Demand*

Currently, solar PV energy does not have the necessary capacity to economically displace electric generation from baseload powerplants without the adequate energy storage technologies. As a result, most of the energy generation offset will occur in the intermediate and peaking regions, supplied by natural gas.

2. Emission offsets and water usage

The environmental impact of increase in solar PV is dependent on the energy portfolio of the local utility provider. With the bulk of the solar power generated between 9am and 3pm, solar PV has the potential to offset some peaking generation units, and therefore the environmental impacts associated with them.

In calculating the emission offsets, a few key assumptions have been made:

- The generated solar power offsets the power that would have traditionally been generated by peaking generation plants. In this case, these are natural gas combustion turbines
- Although natural gas combustion turbines may have different characteristics with respect to emissions per kWh depending on efficiency, the analysis will use the average emission rates in the United States for natural gas-fired generation
- The emissions are associated with operation (as opposed to lifecycle analysis)

Air emissions associated with natural gas-fired generation include nitrogen oxides (NO_x) and carbon dioxide (CO_2), but in lower quantities than burning coal or oil. Methane, a primary component of natural gas and a greenhouse gas, can also be emitted into the air if natural gas is not burned completely. On the other hand, emissions of sulfur dioxide (SO_2) and mercury compounds from burning natural gas are negligible.

The average emissions rates in the United States from natural gas-fired generation are: 1135lbs/MWh of carbon dioxide, 1.7lbs/MWh of nitrogen oxides, and 0.1lbs/MWh of sulfur dioxides (US EPA, 2012). The data is summarized in Table 1 below together with the estimated emissions offsets.

Table 1. Estimated emission offsets from solar energy generation at the main campus

		CO_2 (lbs)	NO_x (lbs)	SO_2 (lbs)
Average Emissions (per MWh)		1135	1.7	0.1
Estimated Emissions Offset	2009	3,192,743	4,782	281
	2010	4,975,166	7,452	438
	2011	10,748,175	16,099	947
	2012	16,330,446	24,460	1,439
	Total	**35,246,530**	**52,792**	**3,105**

The energy produced by the solar systems has offset an estimated 35 million pounds of carbon dioxide, 53 thousand pounds of nitrogen oxides, and about 3 thousand pounds of sulfur dioxide over a period of three and a half years.

Natural gas-fired power plants use very little water. As a result, the water savings associated with the displacement of energy generation from natural gas combustion turbines is assumed to be negligible. On the other hand, baseload generation from coal and nuclear power plants can be very water intensive, requiring water for steam generation and cooling. However, solar PV does not currently affect baseload generation.

III. DIFFERENCES BETWEEN PPA ESTIMATED AND ACTUAL POWER OUTPUT

A. PPA Estimated vs. Actual Energy Output

Most of the 50 solar power installations are exceeding PPA estimates (ASU Solar, 2012; AMERESCO, 2012). The table shows 43 out 50 systems on the Tempe campus that have been operating for at least a full year. Two of the systems are comprised of 9 and 10 smaller systems respectively and have been grouped together for ease of analysis. The figure shows the absolute difference between the first year measured and PPA estimated energy output, together with the percent difference.

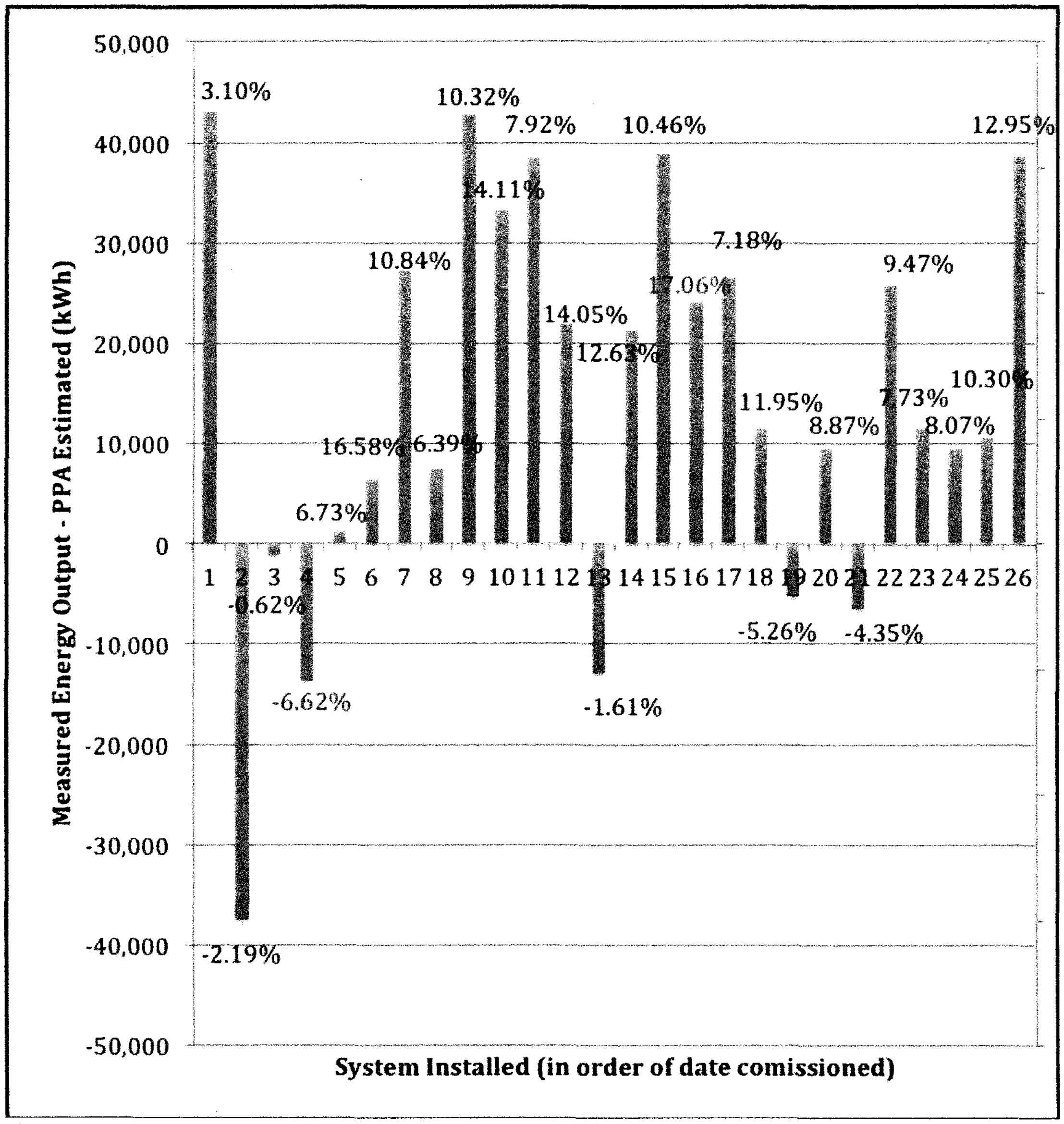

Figure 6. *Difference between the measured and PPA estimated power output together with the respective percentage for the first year of operation*

Six of the PPAs have overestimated the performance by 0.62 - 6.62 percent. The rest of the PPAs underestimate the solar energy output by 3.1 - 17.06 percent. Overall, the systems are producing 371,632kWh above the estimate, or 4.39 percent more.

The monthly or per kWh rate at which the university purchases power from the system owner is based on the estimated power output over the length of the contract. The difference between the estimated and actual power output affects the expected cash flow for the third party financier. With most of the systems performing better than expected, more reliable system modeling could lead to lower rates for the consumer. However, long term data is necessary to analyze year to year variability.

B. Declining System Costs

The capital cost of solar PV installations has been decreasing over the course of the study. The table below outlines the overnight engineering-procurement-construction (EPC) cost from the Cost Report by the National Renewable Energy Laboratories (Black and Veatch, 2012).

Table 2. Average overnight EPC cost for different PV systems in 2008 and 2010

Year	100kW non-tracking	1MW non-tracking	1MW tracking
2008	5.61	4.61	5.28
2010	4.79	3.48	3.82

However, under the financing structure of the PPA, the third party financier incurs additional costs, that are then passed on to the consumer. These costs include

- Administrative and legal costs
- Cost of financing
- Insurance costs

The table below summarizes the average cost per Watt DC installed for the projects involved in this study.

Table 3. Average cost per Wdc for systems at the Arizona State University main campus

	Single-axis tracking ($/Wdc)		Fixed tilt ($/Wdc)		
Year	500kW	1MW	100kW	500kW	1MW
2008	-	8.59	-	-	-
2009	-	8.31	8.57	-	-
2010	10.40	-	8.90	-	-
2011	-	-	5.84	5.09	3.77

There is some ambiguity over actual project costs without the access to the cost breakdown. The system owners are only obliged to provide total project cost amount. However, the Renewable Energy Credit Purchase Agreement (CPA) between the local utility and ASU indicates that the total project cost may include costs associated with financing the installation of the system. CPA defines total project cost as "costs directly associated with the installation of the equipment necessary to produce solar energy [...] The Total Project Cost may also include costs associated with financing the installation of the System [...] and provided further that such costs will be included at a rate not to exceed the Financing Rate" (APS, 2012). The utility sets a cap on the financing rate that may be calculated into the total project cost as "the Prime Rate as of the reservation date plus five percent (5%), regardless of the actual interest rate that may be charged to ASU, or its designee" (APS, 2012).

Depending on when these projects were financed, the total project cost may vary significantly. At the beginning of 2008, the prime interest rate was 7.25 %. From beginning of 2009 onwards, the prime interest rate has been at the all-time low of 3.25% since the 1950s (Federal Reserve, 2012). While the solar panel prices have been falling over the period of study as indicated by the EPC cost in Table 2 above, the impact of the interest rate may have been more pronounced in decreasing the total project cost for ASU solar installations as shown in Table 3. However, there are also differences in the way projects are financed. Depending on the debt fraction and length of the term, the third party financiers may end up with greatly different total project costs. In addition, without the long-term system performance studies, the financial viability of these solar systems is often questionable among the lending institutions. As a result, obtaining a favorable interest rate on, for example, a $3 million dollar system over the course of 20 years can significantly impact the total project cost, and similarly, the per kWh rate obtained by the customer. More research is needed in the area of long term system performance (as compared to the PPA estimated) in order to increase financial viability of these systems.

In addition, non-financing costs further influence per kWh rate obtained by the customer. PPAs often carry high administrative and legal costs, especially for tax-exempt entities such as schools and governments. It requires a close look at city codes, state statues, and constitutions in order to ensure compliance. By establishing the first commercial PPA, the university encountered many of these issues and made improvements along the way. The standardized PPA template later became a resource for other school and government entities.

Third party financiers also have an obligation under the contract to obtain property insurance for the system which ensures against physical loss or damage to all property incorporated into the system. Insurance underwriters charge high premiums for PV installations since the technology is still viewed as high risk and the relatively low number of projects leads to inability to spread the risk.

Currently, the per kWh rate at which ASU purchases power from the third party financier ranges from 13.3 cents per kWh to 16.39 cents per kWh. In addition, some of these prices are fixed, some include an annual escalation, and three are tied to the consumer price index (Humphries, 2012). The average rate of electricity for the business sector in the state of Arizona is 10.22 cents per kWh (EIA, 2012). The figure below shows the trend in the average price of electricity for the state of Arizona from 2000-2012.

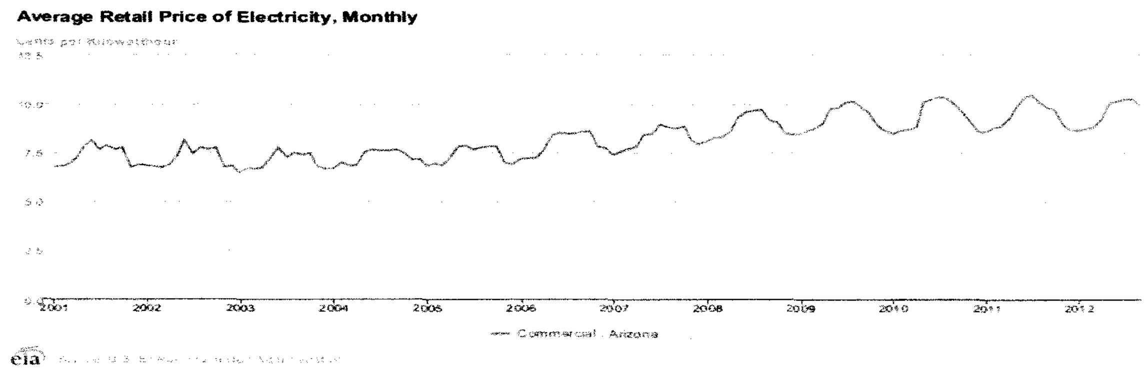

Figure 7. *Average Retail Price of Electricity for the Commercial Sector, State of Arizona*

The price of electricity has increased by 29% over the course of last 12 years and is expected to continue to rise. While PPA rates are currently higher than the average rate of electricity, the predicted rise in electric rates is expected to surpass PPA prices in the next 2-3 years for most of the solar installations, providing a net benefit over the life of the systems. The cross-over point for energy savings is expected to occur sometime in the next 5-10 years (Brixen, 2011).

While reducing system cost is an important aspect in reducing the cost of solar energy, the following issues also need to be addressed

1) Decreasing legal and administrative costs through standardization of PPAs
2) Decreasing insurance and financing costs by reducing the risk of investment through a comprehensive performance assessment of current solar installations.

The university has been able to standardize the PPA for subsequent installations thus decreasing some of the administrative and legal costs. In addition, the university made the template available to other school and government entities looking to enter into a PPA. The cooperation led to an increase in solar power installations across the state.

On the other hand, a comprehensive study of installed systems can mitigate the risk of investment. The study of solar installations at ASU could provide a guideline for assessing the risk of similar systems.

IV. SOLAR SYSTEM PERFORMANCE ANALYSIS

A. Using PVsyst in evaluating system performance

The performance of a solar system can be evaluated with respect to the modeled power output using a solar system design software. The software used in this analysis is PVsyst, popular PC software for the study, sizing, simulation, and data analysis of complete PV systems among the industry professionals (PVsyst, 2012). The program uses the hourly weather data, manufacturer's specifications for the system components, as well as default values for system losses as inputs to calculate estimated power outputs.

By independently testing each of the algorithms, PVsyst has identified uncertainties related to measurement and parameter's determination, and those inherent in the modeling. The accuracy of the global results of the simulation is to the order of 2-3% (MBE). As such, the program is a reliable way of evaluating the performance of the system (University of Geneva, 2010).

Uncertainties in the measured weather data are due to the uncertainties in the instruments used to measure the irradiation data. The pyranometer used to measure Global Horizontal Irradiance (GHI) on the university premises has ±5% uncertainty (Cambell Scientific , 2012). Another uncertainty comes for the fact that the EIS system on campus uses a central weather station for meteorological data. The weather data measured by the pyranometer located at a system site is slightly different than that from the Energy

Information System (EIS) database. In addition, periodic missing data on system generation and irradiation further adds to uncertainty. Uncertainties associated with manufacturer's specifications for modules and inverters are often unknown.

1. Process Outline for Evaluating System Performance

The diagram that follows outlines the process used to establish a reliable model for power output to be compared to the actual. First, the weather data is obtained from the EIS database, including GHI, ambient temperature, and wind speed for a specific year of interest to be used in PVsyst. Then, the project parameters are defined for the system:

- geographic site location
- number of modules, rating and manufacturer
- number of inverters, rating and manufacturer
- orientation and tilt of the modules

In addition, specification of system losses is defined, including module quality, mismatch, thermal, wiring resistance, and incidence angle. The default heat transfer coefficient for free air circulation around the collectors of $29W/m^2$ K was used in modeling the power output. In addition, Nominal Operating Cell Temperature (NOCT) was adjusted in an iterative process to obtain a suitable model, involving a study of residuals, defined as the difference between modeled and measured power output. A seasonal trend in residuals is strongly associated with the modeling of thermal losses, requiring some adjustment in the respective parameters. The standard test conditions under which modules are rated rarely occur during normal system operation [$1000W/m^2$, Air Mass 1.5, and cell temperature of 25°C]. An alternative rating, NOCT, sets conditions of $800W/m^2$, 20°C ambient temperature, and 1 m/s wind speed and is used in combination with the max power point temperature coefficient to estimate the effect of cell temperature on performance. Manufacturers publish the NOCT for modules, and PVsyst uses these values as default. However, at $1000W/m^2$, modeling a module assumed to operate at a 10°C higher temperature from NOCT with a power coefficient of 0.5%/°C will lead to a 5% lower output of power. If the model is overestimating during the summer months, NOCT is iteratively increased until residuals have been minimized. If the model is underestimating during the summer months, NOCT is iteratively decreased until residuals have been minimized. The uncertainty in NOCT value has been found to be ±4°C (Cameron, Stein, & Tasca, 2011).

Once a good correlation has been established between the measured and PVsyst modeled power output, the system outputs are further analyzed for performance-based discrepancies in data. Once daily discrepancies are identified, hourly profile is analyzed to help further explain the possible problem with the system. If possible, a system owner can provide maintenance records to confirm the findings as well as to analyze the response time – the time between when the problem occurs to when it is detected.

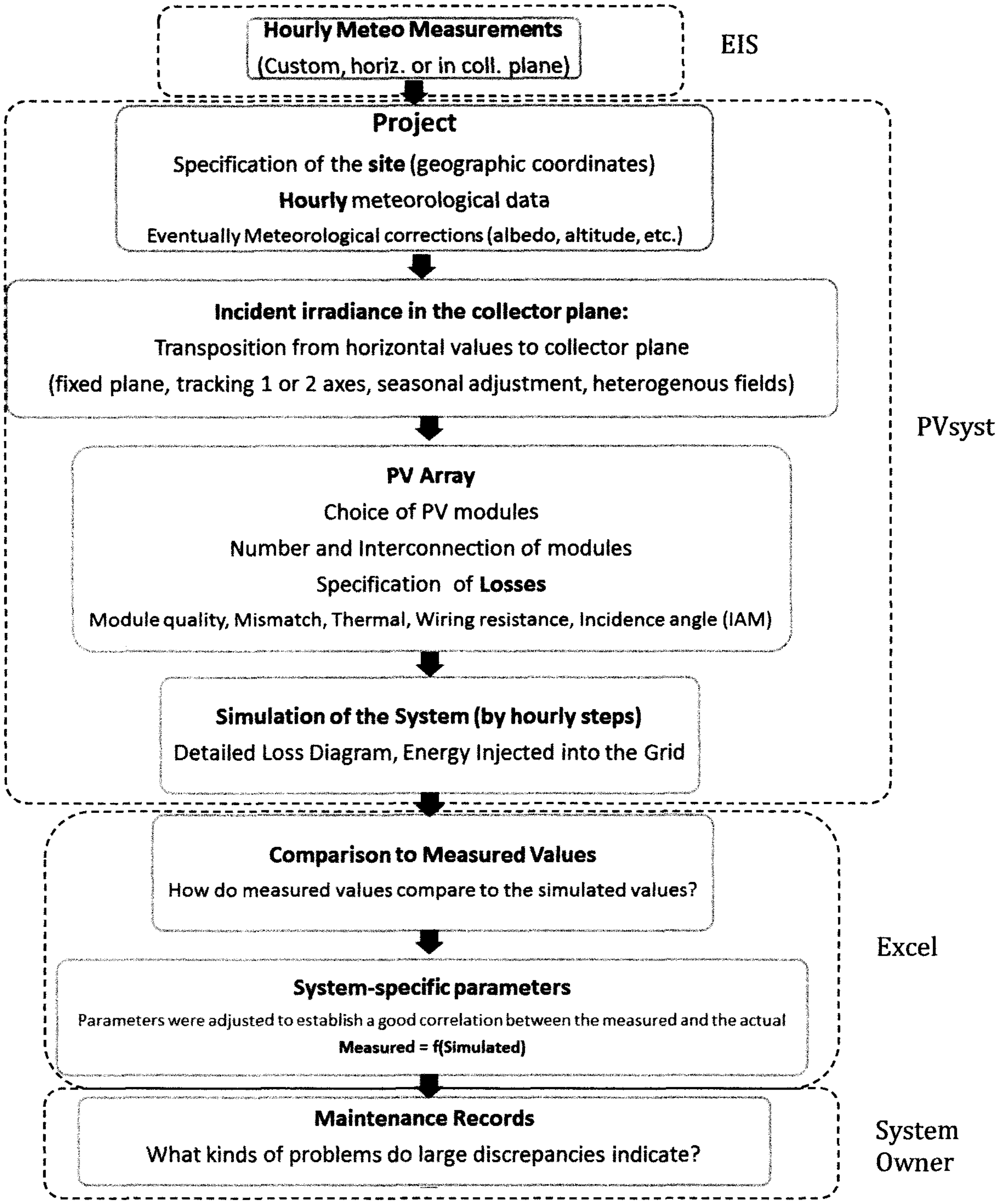

Figure 8. *Process Outline*

2. Case Study

The analysis that follows will focus on two medium solar installations, featuring tracking and non-tracking systems.

Table 4. Solar installations used for the purpose of a case study

	Installed Capacity (kWdc)	Installation type	Date Commissioned
System 1	880	20-deg fixed	10/2009
System 2	711	1-axis tracking with backtracking	12/2008

a. System 1

The table below summarizes how the measured power output compares to the PPA estimated power output and PVsyst modeled power output.

Table 5. PPA Estimated and PVsyst modeled power output compared to the measured

Year	Measured Power Output (kWh)	PPA Estimated Power Output (kWh)	% Δ (Measured - PPA)	PVsyst Power Output (kWh)	% Δ (Measured - PVsyst)
2011	1,681,632	1,477,148	13.8	1,693,341	-0.7

Data indicates that the system was over performing with respect to the PPA estimated by 13.8 percent in 2011. The system performed very well when compared to the PVsyst power output, staying within one percent.

The figure below compares the measured and PVsyst estimated power output over the course of 2011.

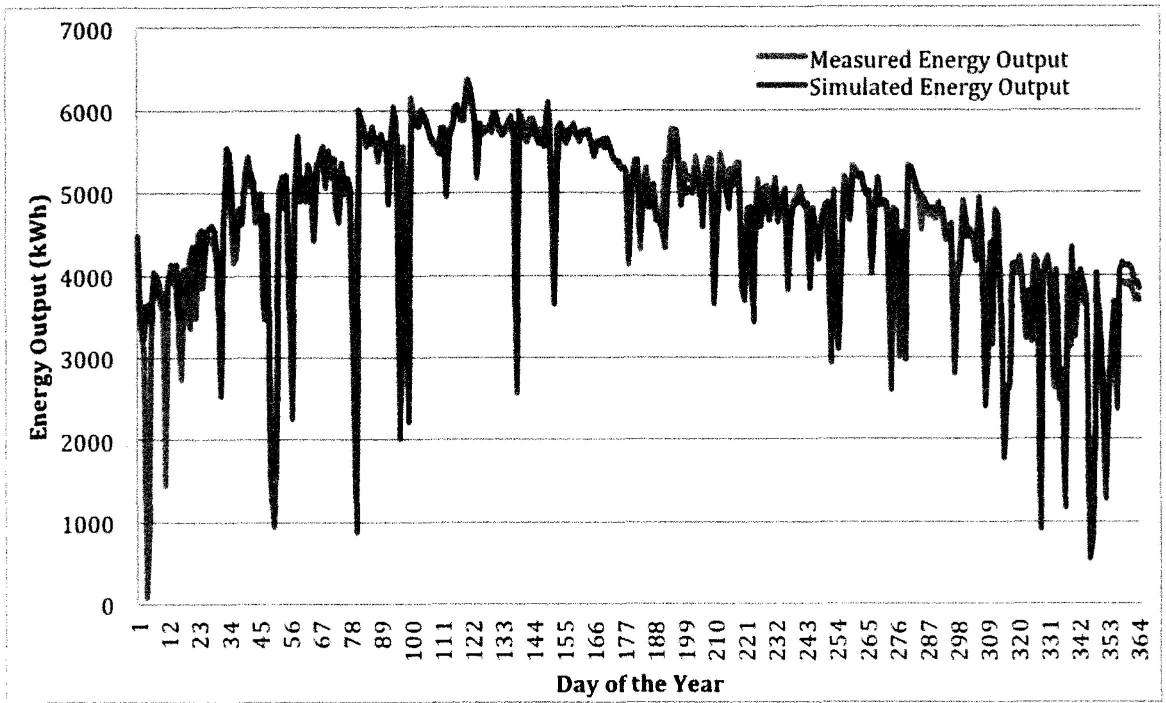

Figure 9. *Measured and PVsyst Simulated Power Output for System 1 in 2011*

To further evaluate the reliability of the model, the correlation between measured and simulated values is analyzed. Most of the values are evenly distributed around the perfectly correlated line. Outliers are further analyzed to determine the cause of large discrepancies between the measured and simulated values.

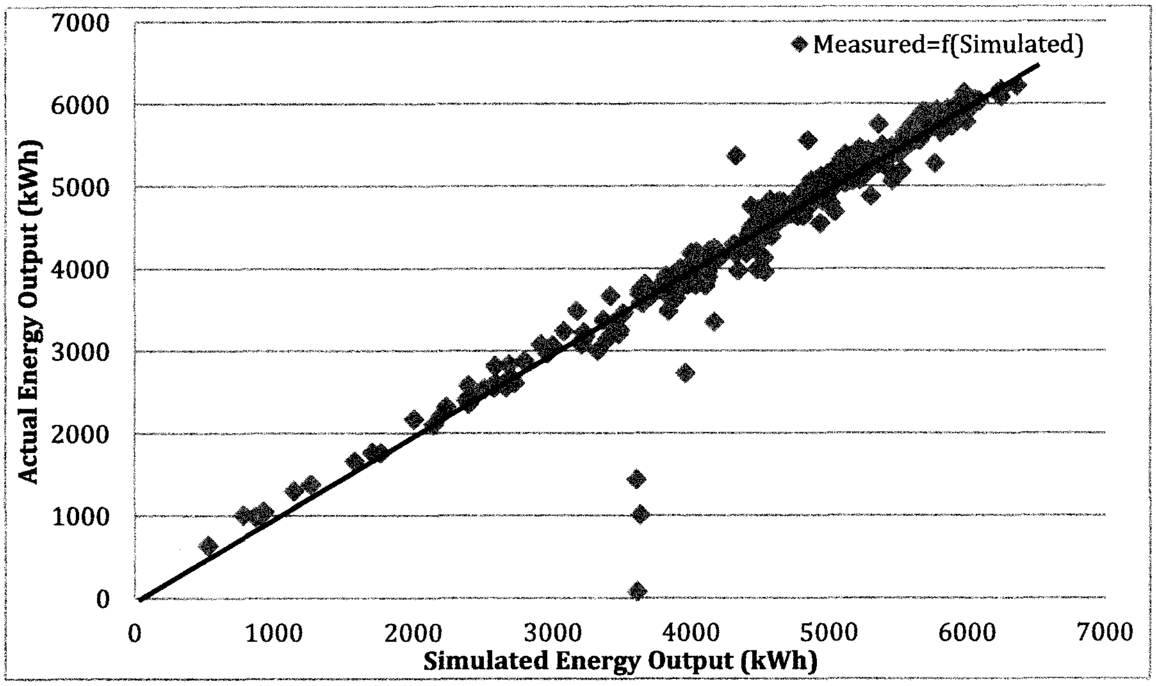

Figure 10. *Correlation between PVsyst simulated power output and measured power output*

Analysis of the two graphs indicates possible issues at the beginning of the year. The 15-min plots have been reproduced for the dates of interest to determine possible causes.

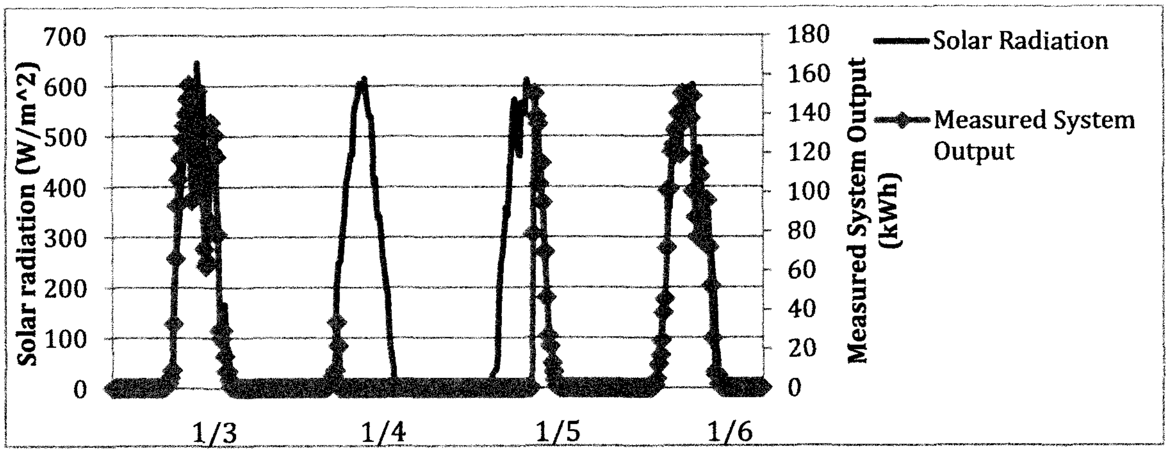

Figure 11. *Measured System Output and Solar Radiation 15-min daily plot*

The system could either be completely offline or there might be a communication problem between the system and the database. As indicated by the graph, the problem persisted for over 24 hours after which the measured system output indicates normal operation.

b. *System 2*

The table below summarizes how the measured power output compares to the PPA estimated power output and PVsyst modeled power output for System 2.

Table 6. System 2 PPA estimated and PVsyst modeled power output compared to the measured for 2010 and 2011

Year	Measured Power Output (kWh)	PPA Estimated Power Output (kWh)	% Δ (Measured - PPA)	PVsys Power Output (kWh)	% Δ (Measured - PVsyst)
2010	1,214,112	1,386,060	-12.4	1,437,639	-18.4
2011	1,409,102	1,376,357	2.4	1,474,355	-4.6

The data indicates that the system was underperforming in 2010 by 12.4% from the PPA estimated values. The system performed much better the following year, exceeding the PPA estimated value by 2.4 percent. When compared to the PVsyst output, the percent difference is about 6 percentage points below the percent difference for the estimated PPA power output.

The figure below shows the measured and estimated power output for the year 2010.

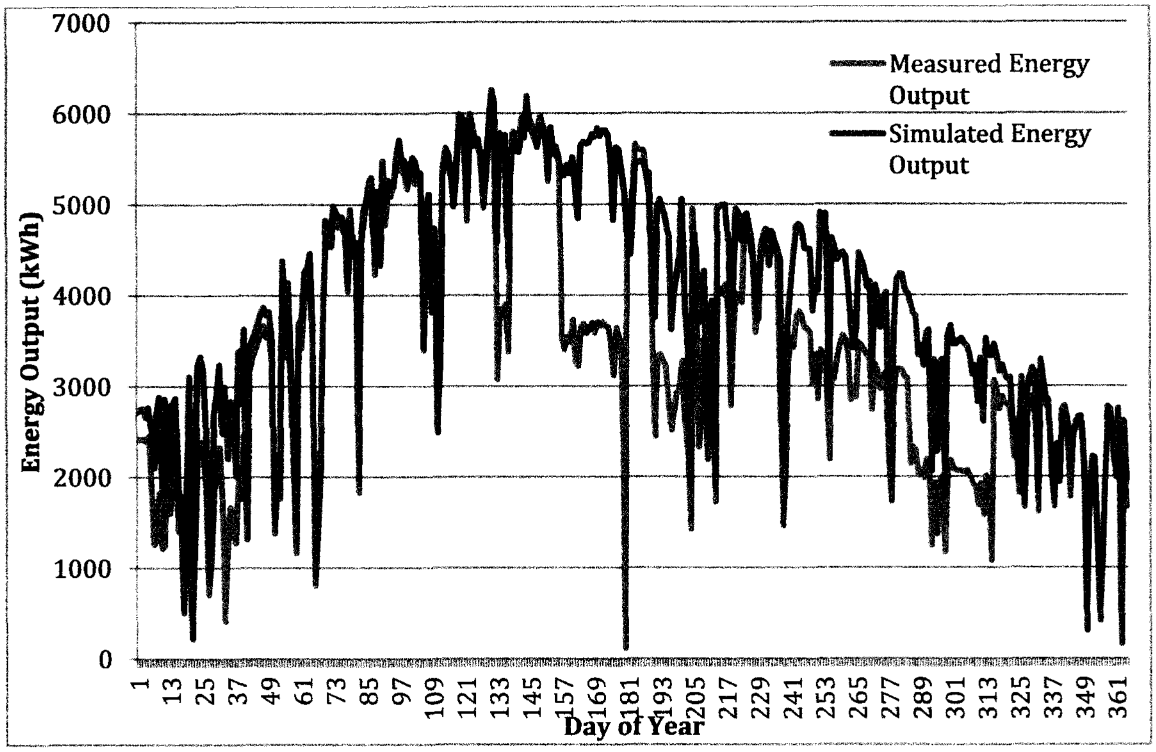

Figure 12. *System 2 Measured and PVsyst simulated power output for 2010*

The graph shows distinct drops in the measured energy output that continue for a period of time. The correlation plot further emphasizes these drops in performance.

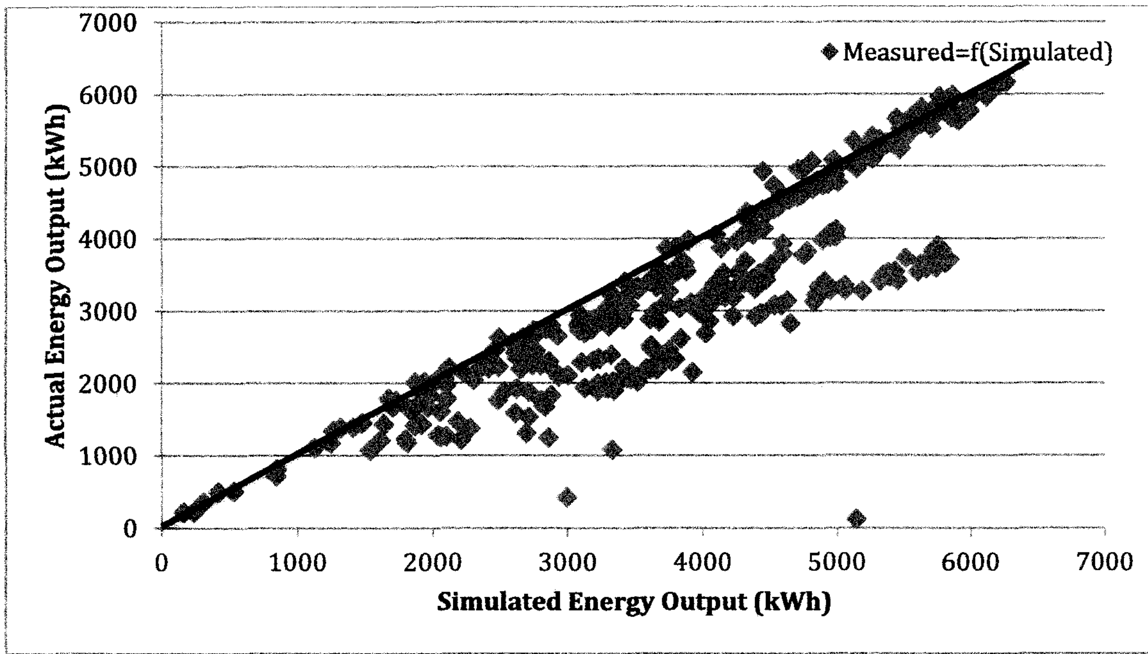

Figure 13. *Correlation between simulated and measured power output*

The 15-min day plots were analyzed to determine the possible causes of the sharp drops in performance. The shape of the daily plots offers some clues to the nature of the problem. On the other hand, the next year witnessed improved performance as indicated by the correlation plot.

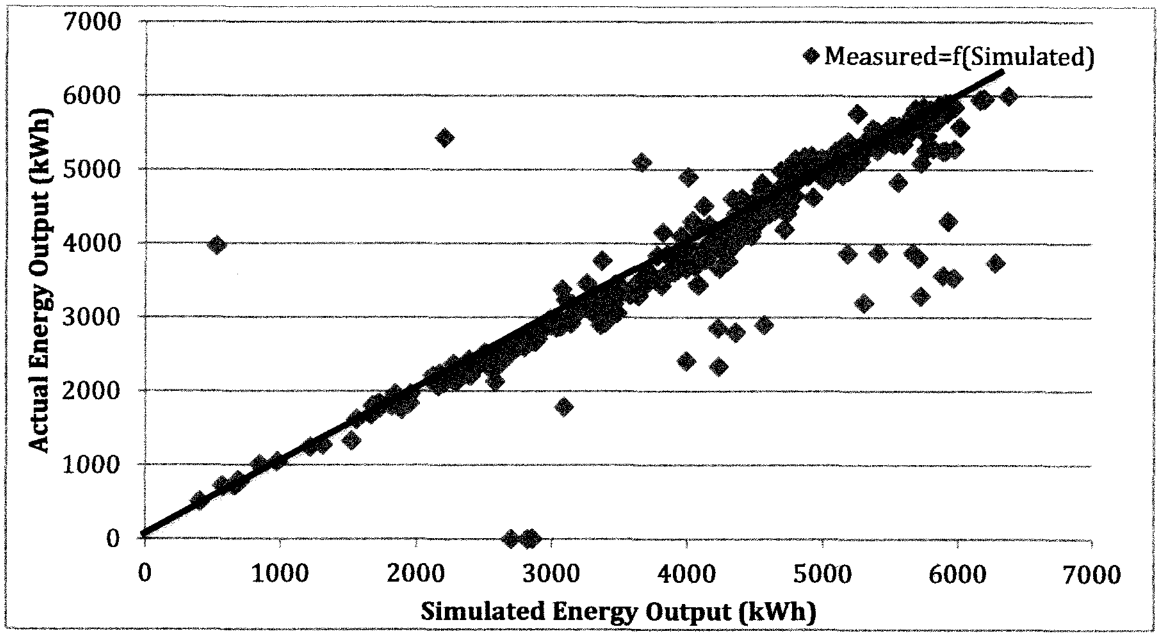

Figure 14. *Correlation between measured and simulated power output*

i) Reduced power output, no change in shape

The figure below shows the electric power output together with solar radiation before and after the indicated sharp drop in performance.

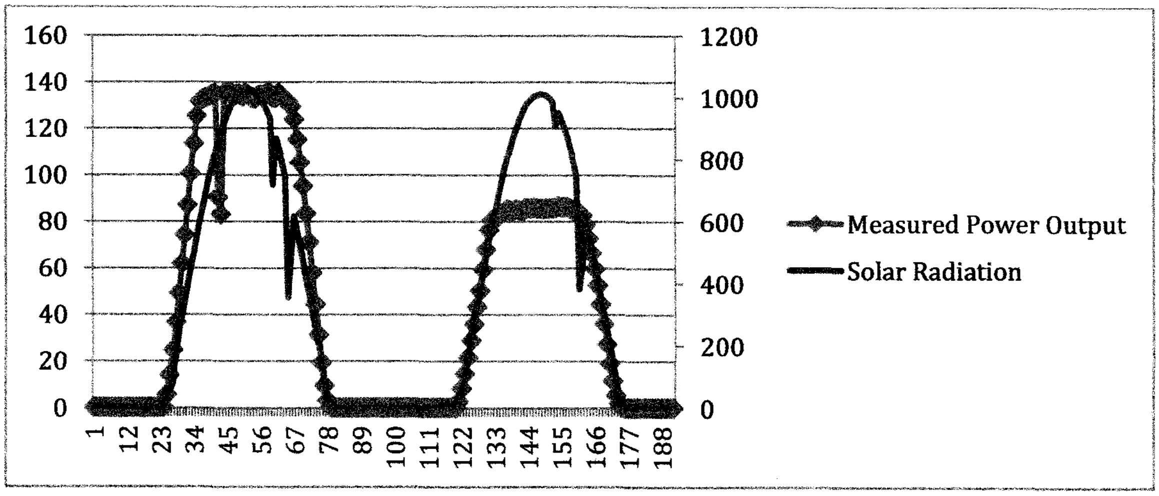

Figure 15. *15-min daily plot reduced power output*

The shape of the daily power output is similar for both days. This can eliminate issues with the tracker as they often cause shading losses in the morning and evening hours. Such proportional decrease in power can indicate a decrease in the number of strings supplying power into the grid. Simulation was used to verify this assumption. Possible cause may include faulty wiring or inverter outage. The power output for the second day is 35% below the power output for the second day. The system has 3 inverters. If one of the inverters is down, a decrease of about 33% would be expected. Nevertheless, it is possible that the system is generating power. However, one of the three junction boxes had communication issues that led to the missing data.

ii) Reduced power output, symmetric change in the plot shape

The figure below shows the electric power output together with solar radiation before and after the indicated sharp drop in performance.

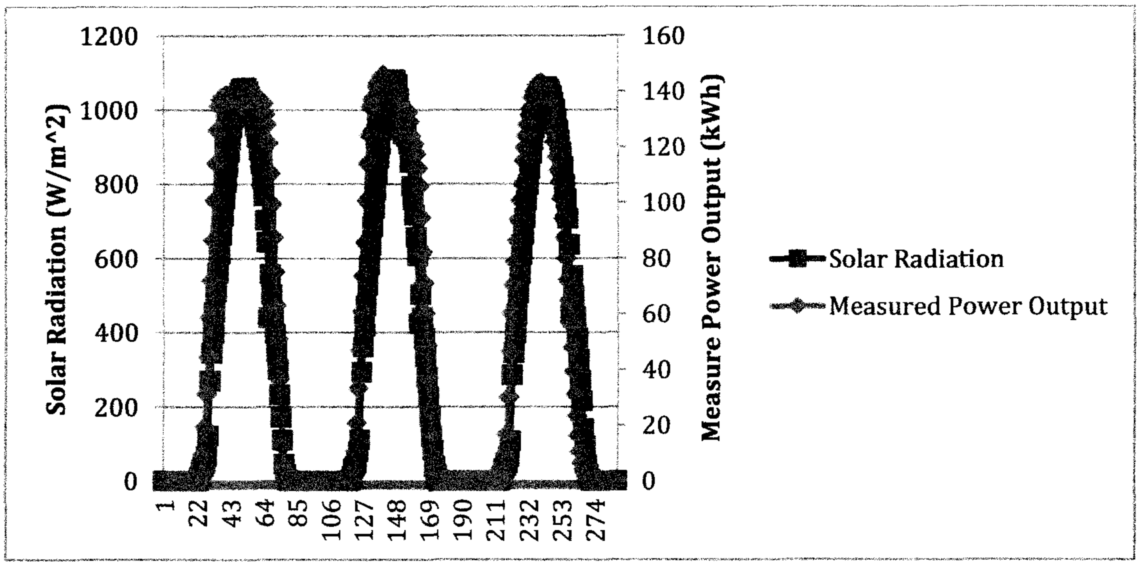

Figure 16. *15-min daily plot reduced power output*

The change in shape of the daily power output indicates some change in the orientation of the modules. If a system is tracking the sun, the measured power output has a wide base and a flat profile at the peak. There are minimal shading losses in the early morning and evening hours. If the system is not tracking, shading in the early morning and evening hours leads to a skinnier profile with a distinct peak. The assumption was later validated with a simulation.

iii) Reduced power output, asymmetric change in shape

The figure below shows the electric power output together with solar radiation before and after the indicated sharp drop in performance.

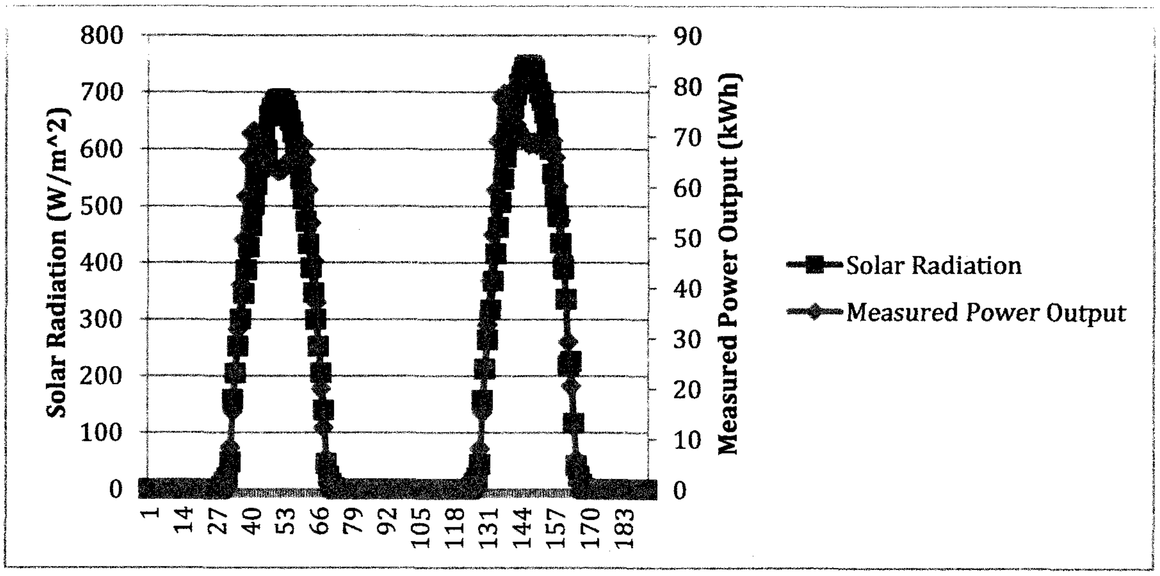

Figure 17. *15-min daily plot reduced power output*

The change in shape of the daily power output profile indicates a change in the orientation of the modules. The asymmetric change in shape indicates a greater impact from shading in the afternoon hours than morning hours, a trend that continued for the next two days.

Visual inspection of the modules showed four non-tracking strings facing west at an approximate tilt of 20 degrees. In the morning hours, those modules receive a lower portion of solar radiation than the tracking modules because they are facing away from direct incoming sunlight. However, in the afternoon, the greater tilt of the non-tracking modules with respect to the tilt of the tracking modules causes the non-tracking modules to cast shadows on the first tracking string. This leads to a disproportionately higher reduction in power output.

As indicated by the case study, the shading and tracking issues have specific performance signatures. As the solar system reads out its output, it can recognize the compromised performance if it has a real-time optimal output, in other words, a benchmark with which to compare it to. The use of real-time weather data, system specifications, and PVsyst can provide a reliable benchmark. The solar system's control software can then compare the systems expected optimal performance with its measured performance and determine whether there is a shading signature or compromised function (Trabish, 2012).

Remote performance monitoring can improve system performance without increased maintenance costs. In addition, proper monitoring provides more and better data to third party owners that could help address the financial risks associated with entering into a PPA.

V. CONCLUSION

The growth in solar power installations has been spurred by the use of PPAs in financing the system by addressing the problem of high upfront cost. However, these PPAs have their own set of flaws that need to be addressed. System modeling and monitoring are among some of them. In order to increase reliability of these systems, more research is needed in these areas, requiring access to reliable, quality data. Universities involved in solar PPAs with the access to this data have the potential in conducting research in the area.

This paper offers a framework for assessing system performance of solar PV systems using PVsyst software. By customizing the system parameters to each installation, the program can provide a reliable benchmark for system performance to be compared to the actual power output. Compromised performance could further be analyzed through a study of daily power output profiles. Access to reliable data and open cooperation with system owners is an integral part in continuing the research in this area.

The solar installations on Tempe campus have the ability to serve as a living lab for academics and research. While the Arizona State University leads the way in solar cell research and module testing, solar systems have not been a significant topic of research. Increasing solar cell efficiency and module testing are important aspects of decreasing the cost of solar PV. However, the performance of these systems in the field is just as, if not more so, important. With over $15MW_p$ of installed capacity, the university has an opportunity to become a leader in solar system modeling and monitoring for small and medium-size distributed systems. Distributed energy will play an important role in meeting the energy demand. Being able to effectively monitor a large number of smaller systems will be crucial in securing successful integration of solar PV.

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