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Sustainability of the Installed Battery-less PV Panel Systems at Two Government Institutions in Pampanga

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***Abstract*— *One of the most prominent energy alternatives available today is the solar energy. Innovation has made this more affordable and reachable to the public both in the resident and commercial areas. Solar energy was harnessed in two buildings from two different organizations through the installation of photovoltaic (PV) solar panels in the two locales. However, these solar panel systems needed to be assessed empirically. Also, during the initial operation, several technical problems led the researcher to use the result of the assessment procedures as basis for a proposed operation, maintenance, and troubleshooting manual for the users. Engineering management intervened in the study through the tools which were helpful in organizing the activities done in the course of the research. The PV solar panels were assessed in a quantitative approach. The energy and cost generated after the installation of the systems were compared to the energy and cost prior to the installation through the analysis of percentage difference and t-test. The efficiency and return on investment (ROI) of the PV solar panels were also assessed. The contents of the manual was based on the survey checklist distributed among the four (4) respondents from the locales and the interview checklist conducted by the researcher on the installer of the panel systems. In summary, no significant difference was observed between the energy and cost generated before and after the installation of the PV solar panels using t-test. But the percentage difference assessment reflected a significant difference in the energy and cost generated before and after the installation. Specifically, there was a positive decrease in the energy cost of the electricity generation in the two locales. Furthermore, the return on investment of the PV systems were discovered to be less than the expected life span which means that the projected payback could be harvested within the utilization of the PV solar panels. Lastly, a manual was made at the end of the study addressing the common issues and problems encountered by the users and how to troubleshoot them and operate the system properly. This manual was made for the sole purposeof maximizing the utilization of the solar PV panels and promoting sustainability.*

***Keywords*— *Engineering management, solar, photovoltaic panels, efficiency, manual, sustainability*.**

I. INTRODUCTION

Electricity is considered to be one of the vital needs in aintaining the progress of a continuously improving society. It facilitates the technology innovations of the current generation. It also establishes the wide range of products and services that improve not only the quality of life but also the economic status of a nation [1].

The updated Philippine Energy Plan (PEP) 2012-2030 conducted a nationwide roadmap of the total final energy consumption (TFEC). Based from the roadmap, the country's total final energy consumption (TFEC) is expected to increase at an average rate of 4.2 percent annually, from 29.8 million tons of oil equivalent (MTOE) in 2015 to 54.9 MTOE in 2030.

Disregarding fluctuation of oil prices in the world market, PEP stated that demand for petroleum products will increase by an average of 3.9 percent per year from 2015 to 2030. Diesel and gasoline will continue to be the most widely-used petroleum products, with the average shares of 50.5 percent and 28.4 percent in the total oil demand, respectively.

Coming after petroleum, electricity is projected to be the second most-consumed fuel after oil and is expected to contribute an average of 22.1 percent share to the final energy demand throughout the planning period and is projected to grow by an average of 5.7 percent annually. Its utilization in the transport sector is seen to expand by ten (10) times its 2015 level of 8 thousand tons of oil equivalent (kTOE) to 80 kTOE in 2030.

Still inferring from PEP, the country's total primary oil supply is projected to grow by 3.4 percent per year on

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average in the business-as-usual scenario, from 17.7 MTOE in 2015 to 29.1 MTOE in 2030.

Considering the continuously increasing rate demand and the decreasing rate of supply of petroleum based from the data, scarcity is not an impossible assumption by the year 2030.

Solar energy which is one of the previously mentioned, however, is considered to be one of the most effective alternatives to fossil fuels and other sources of electricity. It is a renewable resource that will not run out any time sooner than any other resource. Although some of its disadvantages are the lack of sunlight in cold places and the presence of too much heat in arid desserts, the efficiency of photovoltaic panels are continuously being improved through hybridization [2]. Solar and photovoltaic panels are being produced to generate solar energy in an increasing level.

Solar energy is the unique renewable (i.e., neglecting entropy creation by the Sun) resource in the world, where hydro and wind constitute secondary forms of the same source. From this perspective, it could be very convenient to directly convert solar energy into electricity by using the highest possible efficient physical process. Solar energy conversion techniques can involve thermal, electromagnetic or a combination of both forms of energy that attain our planet. The conversion of solar radiation into electricity has been extensively studied [3].

In particular, photovoltaic (PV) cells allow the energy transported by electromagnetic waves (i.e., photons) to be directly converted into electricity. The mechanisms that allow this energy conversion to take place are based on photon-electron interactions that occur in PN junctions formed by appropriately doped semiconductor materials (Mono-crystalline and polycrystalline silicon cells currently found in the market). A photovoltaic panel, or array, is composed of several unitary cells connected in series and/or in parallel. Depending on the available surface area exposed to the Sun, PV panels can be employed in small- and large-scale applications as auxiliary electric generators in buildings and stand-alone power plants. Nowadays, this type of solar energy conversion is expanding very rapidly, consequently, predicting the performance of PV panel which is essential for design engineers. Even though the most important electrical characteristics of PV panels are usually provided by manufacturers, in general, they are determined under Standard Test Conditions (STC).

The PV panel operating temperature is dependent upon many factors: solar radiation, ambient temperature, wind speed and direction, panel material composition, and mounting structure. For a typical commercial PV panel, a proportion of the solar radiation is converted into electricity, typically 13-20%, and the remainder is converted into heat [4]. One of the main obstacles that faces the operation of photovoltaic panels (PV) is overheating due to excessive solar radiation and high ambient temperatures. Overheating reduces the efficiency of the panels dramatically [5]. Due to this setback, hybrid Photovoltaic/Thermal (PV/T) solar system was made and is one of the most popular methods for cooling the photovoltaic panels nowadays [6]. In areas with limited sunlight, however, the lack of solar energy could also affect the efficiency of the PV panels. A study was conducted in Hong Kong regarding the analysis of local weather data patterns which showed that solar power and wind power can compensate well for one another, and can provide a good utilization factor for renewable energy applications, thus another hybrid solar panel [7]. Solar cells change the received solar energy into electricity, thus they have received attention as clean energy devices which do not release hazardous pollutants into the environment. The efficiency of the photovoltaic (PV) systems has been increased, while their production cost reduced which contributed to the expansion of PV systems globally [8]. Forced convection also plays a major role in determining the thermal response of the PV panel and a diverse range of values for the forced coefficient is available [9]. These equations were developed from fundamental heat transfer theory [10], wind tunnel measurements [11], and field measurements [12].

he 6th Environment Action Programme (EAP) is a decision of the European Parliament and the European Council adopted on 22 July 2002. It sets out the framework for environmental policy-making in the European Union (EU) for the period 2002–2012 and outlines the actions that need to be taken to achieve them. The 6th EAP identifies four priority areas: climate change, nature and biodiversity, environment and health, and natural resources and waste.

Solar panels, like any other electronic component existing today, operates within a limited life span. Although they are already considered as electronic waste, inactive solar panels are being subjected to recycling nowadays. Panels must be taken down and collected before recycling can take place. V.M. Fthenakis and P.D. Moskowitz – at the Brookhaven National Laboratory, National Photovoltaics Environmental Research Center in the USA – proposed three collection models in The Value and Feasibility of Proactive Recycling, available on the BNL website.

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Specifically, this study aimed to describe the PV system, energy consumption and efficiency of the system installed in the two government institutions in Pampanga. It is also aimed to determine the Return on Investment (ROI) for the said PV System.

II. METHODOLOGY

The study utilized a descriptive type of research. It focused on the empirical inquiry regarding the energy consumption of the building before and after the installation of the solar PV panels. Specifically, it sought to describe the energy profile of the building two buildings. These historical data were used to describe the generated cost and generated energy of the electrical lines installed in the building before the installation of solar PV panels.

Quantitative approach to research was then deployed in assessing and determining if there is a significant difference between the generated energy and cost before and after the installation of the solar PV panels.

According to Creswell, quantitative approach is one in which the investigation primarily uses measurable data claim for developing knowledge (i.e., cause and effect thinking, reduction to specific variables and hypotheses and question, use of measurement and observation, and the test of theories). It employs research techniques such as experiment and survey and collect data on predetermined instrument that yield statistical data to be interpreted and analyzed later on.

Then, descriptive inquiries regarding the problems being encountered with the operability of the solar PV panels were answered and were used as basis for a proposed manual for the solar PV panels.

III. RESULTS AND DISCUSSION

Table 1: Energy Consumption Profile of Institution A for the Year 2017-2019

kWhr Billing for the Year 2017 to October 2018			
Month /Year 2017	kWhr w/o PV	Month /Year 2018	kWhr w/PV
January	10540	January	11420
February	9520	February	9540
March	9600	March	9600
April	10160	April	8880
May	11640	May	10080
June	10420	June	9700
July	11640	July	9120
August	10080	August	9080
September	9420	September	9200
October	9500	October	11260
November	9880		
December	5420		
Total	117820		97880
Average	9818.33		9788.00
Difference	30.33		

Based from the historical data gathered on the locale of the study, for the year 2017, the total actual generated energy was computed to be 117,820 kWhr and 115,280 kWhr with a total cost of ₱1,117,604.28 and ₱1,087,866.43 for the year 2017 and 2018, respectively. The average total generated energy was computed to be 9,818.33 kWhr.

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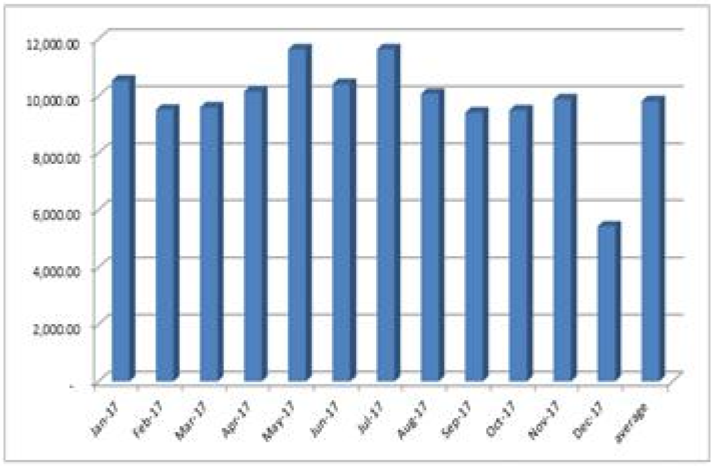
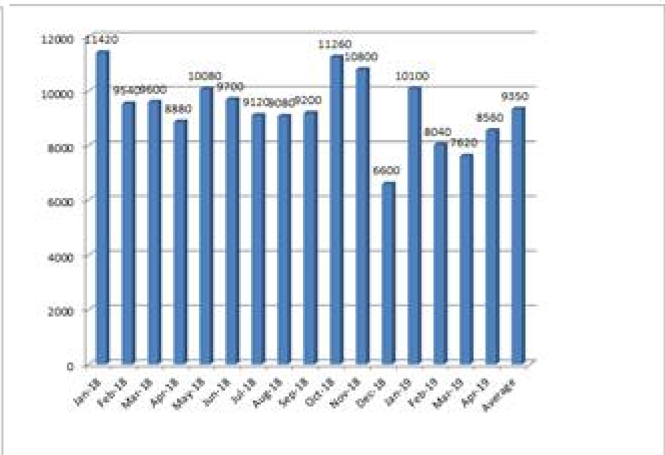


kWhr Consumption prior to installation of PV Panel, Year 2017



kWhr Billing after PV installation, Jan. 2018- April 2019

Fig 1 and 2: Comparison of Energy Before and After the Installation of the Installation of Solar PV System

Based on Table 1, the installation of the solar PV panels generated savings on the energy and cost of electricity being supplied in the government agency building. The average energy generated by the solar PV panels is 9,788.00 kWhr which is lower compared to the energy generated by the usual electricity provider which is 9,818.33 kWhr. The average cost of energy after installing the PV panels is ₱92,883.30 which is also less compared to the last year's average generated cost of ₱93,133.69.

Table 2: Computed Efficiency of Solar PV Panels in Institution A

Institution A	Inverter		Total	Efficiency
	3kW	5kW	8kW	27.98%
Average Monthly kWhr harvest	352.023	187.438	539.462	
Installed kW PV Panel	2.7	4.86	1927.8	
No. of Hours Operating	8.5			

Table 3: Computed Efficiency of Solar PV Panels in Institution B

Institution B	Inverter		Total	Efficiency
	30kW	30kW	60kW	52.47%
Average Monthly kWhr harvest	3717.5	3749.03	7466.53	
Installed kW PV Panel	27	27	14229	
No. of Hours Operating	8.5			

Table 2 and 3 exhibit the computed performance efficiency of the solar PV panels installed in both locales within 8.5 hours of daily operation for a year. Based on the results, solar panels installed in *Institution A* showed 27.98% efficiency while the ones installed in *Institution B* showed 52.47% efficiency.

Table 4: Percent Decrease of Generated Energy in the InstitutionA for the Year 2017 to April 2019

Month	kWhr Consumption		Billing Cost	
	Percent of Decrease for the Year 2017-2018	Percent of Decrease for the Year 2018-2019	Percent of Decrease for the Year 2017-2018	Percent of Decrease for the Year 2018-2019
January	-8.35	11.56	-4.80	12.52
February	-0.21	15.72	- 0.03	10.53
March	0.00	20.63	- 4.43	27.97
April	12.60	3.60	16.14	3.35
May	13.40		10.80	
June	6.91		10.27	
July	21.65		23.81	
August	9.92		9.93	
September	2.34		5.96	
October	-18.53		- 23.92	
November	-9.31		- 10.54	
December	-21.77		- 28.03	
Average percent of decrease	0.72%	12.88%	0.43%	13.59%

Tables 5 and 6 show the import and export energy of PV solar panel. Number of PV panels are 180, capacity generating energy of PV panel is 54.6 kW. Number of the days were considered import and export where in, the researcher used 24 days on school days a month while 6 days on weekends for a month. As seen on the table, a manual sizing tool sun peak hour was used for computing the estimated value for import and export energy kWh and also energy save in peso.

Table 5: Theoretical Computation of Import and Export Energy (Institution B)

DESCRIPTION	NUMBER OF PV PANELS	CAPACITY OF PV	NUMBER OF DAYS	kWh/month	PESO
IMPORT	180	54.6 kW	24	5702.4	39201.149
EXPORT	180	54.6 kW	6	1425.6	7128
TOTAL:				7128	46329.149

Table 6: Actual Computation of Import and Export Energy (Institution B)

DESCRIPTION	NUMBER OF PV PANELS	CAPACITY OF PV	NUMBER OF DAYS	kWh/month	PESO
IMPORT	180	54.6 kW	24	5780.6	39738.424
EXPORT	180	54.6 kW	6	1445.2	7225.8
TOTAL:				7225.8	46964.224

In comparing the total values, the researcher interpreted that the actual value of the import and export energy of the solar PV panels installed in Institution B which is 7225.8 kWh is greater than the projected value which is 7128 kWh.

Theoretical Computation Using manual sizing tool

For import energy,
Number of PV panel: 180 at 80% harvest
Wattage of Panels: 54.6 kW
Used: 54.6 kW energy from PV panels
54.6 kW X0 .80 = 43.68 kW

Average kWh/day = 43.68 kW X 5.5 hours = 240.24 kWh

Used: 24 school days in one month,

EI = 240.24 kWh/day X 24 days = **5,765.76 kWh/month**

PESO = 9.83pesos/kWh x 5,765.76 kWh/month= **56,677.42 pesos**

For export energy,

Used: 54.6 kW from PV panels,

54.6 kW X .80 = 43.68 kW

Average kWh/day = 43.68kW X 5.5 hours = 240.24 kWh

Used: 6 days for weekends in a month,

EE = 240.24 kWh X 6 days = **1,441.44 kWh/month**

The DU's export energy rate is P5.50,

PESO = 5.5pesos/kWh x 1441.44kWh/month = **7,927.92 pesos**

Using Actual Energy Harvest of Inverters:

E1 = 3,717.5 kWh

E2 = 3,749.03 kWh

Average kWh/day inverter 1 = 3717.5 kWh / 31 days = 119.92 kWh/day

Average kWh/day of inverter 2= 3749.03 kWh / 31 days = 120.94 kWh/day

Total average Energy/day = 240.86 kWh/day

Used: 24 school days in one month,

EI = 240.86 kWh/day x 24 days = 5780.6 kWh/month

Used: DU's import energy rate is P9.83,

PESO = 9.83pesos/kWh x 5780.6 kWh/month = **56,823.30 pesos**

For export energy:

Used: 6 days for weekends in a month,

EE = 240.86 kWh/day x 6 days = **1,445.16 kWh/month**

Used: DU's export energy rate is P5.50,

PESO = 5.50pesos/kWh x 1445.16 kWh/month = **7,948.38 pesos**

Where in:

E1 = Energy Harvest in Inverter 1

E2 = Energy Harvest in Inverter 2

Table 7: Percent Decrease of Generated Energy in the Institution B for the Year 2017 to April 2019

	kWhr Consumption		Billing Cost	
Month	Percent of Decrease for the Year 2017-2019	Percent of Decrease for the Year 2018-2019	Percent of Decrease for the Year 2017-2018	Percent of Decrease for the Year 2018-2019
January	32.89	12.64	- 3.71	4.44
February	-1.02	5.91	- 1.93	3.50
March	-13.71	- 6.90	-30.36	- 9.66
April	-7.83	- 3.60	-18.30	4.13
Average percent of decrease	2.58%	2.01%	-13.58 %	0.60 %

Table 15 shows that there is a positive percent decrease of the generated energy for the periods 2017-2018 and 2018-2019 but a negative decrease was seen on the generated energy cost for 2017-2018. However, this is to be disregarded since the PV solar panels were not yet installed until the year 2019. A low but still positive percent decrease of generated energy cost can be observed in 2018-2019 because electricity was very much needed for the construction of the *Institution* B and other surrounding buildings in that time. Adding to the probable cause of low percent decrease is the dry season experienced from March to April. It can also be observed that the researcher only considered four months in the analysis of percentage off difference. This is because the solar panel systems were installed in January 2019 and the months after April is irrelevant to the analysis.

Based from the results, no savings have been acquired from the first three months of the operation of the PV panels. But in 4 out of 7 months, effective energy savings have been generated.

Hence, overheating reduces the efficiency of the panels dramatically (Akbarzadeh and Wadowski, 1996). This may be the cause why the efficiency of the installed Solar Photovoltaic Panel in the two buildings is low.

Return of Investment (*Institution A*)
Conversion of kWHR to fuel per gallon oil:
According to the standard American conversion factors, the heat content of one gallon of fuel oil roughly equals that of 41 kWh of electricity.

kg CO_2 emission = Fossil fuel consumption in volume unit X CO_2 emission factor (Ton per volume unit)
kg CO_2 emission factor (Ton per volume unit) =0.00265 for every liter of fossil fuel

kWhr computation:
AC rating = Average kWh per month / 30 days / average sun hours per day
Example: 903 kWh per month / 30 days / 5 hours = 6.02 kW AC
DC rating = AC rating / derate factor (.8 is conservative, but a range would be .8 – .85)
Example: 6.02 kW AC / .8 = 7.53 kW DC
Number of panels = DC rating / Panel R

According to the National Renewable Energy Laboratory (NREL), the generally accepted life span of PV solar panels is up to twenty (20) years. After 20 years of utility, the solar panel system is said to perform a lower rate of 92% of its performance.

Return of Investment (*InstitutionB*)
For the computation of return of investment, it will take 5 years to return the money that was used for installing the PV solar system at *Institution B.*

IV. CONCLUSION

Considering the analysis of the percentage of difference, savings were generally accumulated within the span of PV solar panel utilization.
The expected payback of the installation of PV solar panels (12 years and 6 years) is less than the usual life span of solar panels of 20 years, it shows that the capital used to procure and install these systems will eventually pay off within the usual life span of the PV solar panels.
Based from the problems reported by the end-users, a manual for sustainability is necessary.
The installation of the PV solar panels had a positive impact on the three pillars of sustainability. Increased energy generation is good for the users and the less cost of energy is also beneficial for the company. Overall, the PV solar panels installed in both locales is sustainable for the people, profit, and planet. However, the low score of awareness among end-users added determination for the researcher to propose a manual to guide them on how to operate, maintain, and troubleshoot the installed PV solar panels.

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