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PANGAN-AN ISLAND PV SYSTEM: A CASE STUDY EXAMINING ITS ACTUAL CONDITIONS WITH SIMULATION OF THE EXISTING ELECTRICAL INFRASTRUCTURE USING HOMER LEGACY

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ABSTRACT
The endeavor of bringing electricity to growing rural communities in the Philippines has taken a major leap by integrating renewable energy into its system. However, several grid systems have experienced challenges that hinder them from asserting sustainability for very long-term operations. This study delves into providing a thorough analysis of the actual conditions of one of the grid systems in the Philippines, the Pangan-an Island PV System. Through employing two simulations using HOMER Legacy, a software that facilitates an optimal combination of resources, configuration, and operating cost of a system, one has shown favorable outcomes which resulted to least excess energy (46.1%), least LCOE ($1,686/kWh), and greatest share of renewable fraction (95%) while the other depicted an unfortunate result as it reflects the actual conditions of the aforementioned PV system in its first years of operation which was a declining performance. An upgrade of the system is best sought as its system is no longer at its best capacity to maintain economic vitality and provide energy security employing renewable energy.

Keywords: Rural Electrification, Renewable Energy, Pangan-an Island PV System, HOMER Legacy.

THE PROBLEM

A. INTRODUCTION

Affordable and Clean Energy is one of the 17 Sustainable Development Goals (SDGs) proposed by the United Nations [1]. As the world's population has reached 8 billion in 2022 and is gradually increasing [2], modern grid technologies have started integrating renewable energy systems which include energy supply from solar, wind, hydro, biofuels, geothermal, and ocean amidst the campaign for attaining the latter goal [3]. In the Philippines, about 15% of the total installed capacity comes from renewable energy as of 2020 [4]. The government has implemented policies such as the Renewable Energy Act of 2008 which offers legal frameworks that promote the use of renewable energy and the introduction of a Feed-in Tariff System that encourages investors to put up renewable projects. These initiatives have skyrocketed the integration of renewable energy in the Philippines.

The endeavor of integrating renewable energy in the Philippines has reached its rural electrification aspect. With the initiative of the government to implement the Electric Power Industry Reform Act of 2001 (EPIRA), an off-grid and hybrid energy system based on the use of renewable energy is considered to be an optimal solution to provide energy for rural communities not connected to the grid [5]. However, several grid systems in the Philippines have experienced challenges regarding their sustainability due to multiple reasons. Some experienced uncertainties include lack of coordination among governing bodies, reluctance of financial institutions to finance the electrification grids, consumers' unwillingness to pay for the electricity even though the supply is readily available, unstable and seasonal income of the customers, and inability to afford the electricity cost, and the lack of locally available technicians [6].

The purpose of this study is to formulate a thorough examination of the actual condition of one of the existing off-grid systems in the Philippines- the Pangan-an PV System. A simulation is also conducted to navigate an optimal combination of resources, the system setup, the operating cost of a system, and the distributed energy resources. With the analyses, possible solutions can be recommended to resolve the discovered issues.

B. EXECUTIVE SUMMARY

This paper presents the Pangan-an Island case study on the existing PV system. It starts with a discussion of the geographical background of the area including the socio-economic status of the locals and the current status of the plant. In particular, much is emphasized in the existing situation of the PV system, including the conditions of the electrical accessories such as the batteries, inverters, and the solar panels themselves. Inventories of the accessories are presented including their current status. Photo documentation is included to best illustrate the present conditions of the solar panels.

It was found out that the solar PV plant in Pangan-an Island is considered a dead system. Technically, its purpose of serving energy to the locals in the span of 20 years since its inception has not been met. It served energy to the locals in the first 4-5 years of implementation but the performance of the PV system has decreased since then. The decrease in the plant performance can be attributed to several factors. First, the PV plant lacks a maintenance program and well-trained personnel to man and oversee the daily plant operation. Second, the panels and the electrical accessories are not housed well in the Powerhouse. Although the batteries and inverters are housed properly in the first years of implementation, it can be observed that the house is almost dilapidated, which exposes the electrical components to severe material degradation and malfunctioning due to weather exposure. Third, solar panels are left unattended with vegetation growing nearby, and fences and houses contribute shading that may potentially affect the power output of the PV system. Fourth, what is envisioned to be a sustainable community approach to handling the PV plants operating expenses, the Pangan-an Island Community Cooperative for Development (PICCD) has not served, at least its purpose of ensuring financial transparency to its consumer members. The cooperative is so technically bankrupt that it can no longer provide financial assistance to repair the PV system. Several other reasons may have aggravated the declining performance of the PV system both in the technical and administrative aspects of operation.

At present, the locals depend on the diesel generators provided by the Lapu-Lapu City government. The fuel allocation sometimes is derailed by bad weather conditions. In effect, there could be times when there is no electricity on the island in a week or even in a month.

SUBJECT DETAILS

The section presents the specific details of the subject matter which include the geographical background, the present condition, and the inventory of Pangan-an Island PV system.

A. Geographical Background

The Pangan-an Island is a part of the **Olango Island Group** that is found in the Central Visayas region of the Philippines with the coordinates of 10°13'12"N 124°2'13"E. Olango Island is composed of 6 satellite islets named: the Sulpa, Nalusuan, Gilutongan, Caohagan, Camungi, and Pangan-an. Olango Island and its neighboring islets have a total land area of approximately 10.3 square kilometers (4.0 sq mi) [7]. The island group is under the jurisdiction of the City of Lapu-Lapu and the Municipality of Cordova. The island group is a part of Cebu Province. It is a major tourist destination in Cebu that lies 5 km east of Mactan Island.

Pangan-an has a population of 2,592 which constitutes the 247 households living on the island [8]. The main source of livelihood for the locals is fishing and sea shell handicrafts (see Figure 2). The socioeconomic status of the locals is driven by the abundance of sea resources. However, in terms of energy consumption, Pangan-an Island depends on the diesel generators supplied by the Lapu-Lapu City Government.

Figure 1. Pangan-an Solar Power Plant

Figure 2. Locals Doing Some Seashells Handicraft

B. Present Condition of the Pangan-an PV System

Bushes, weeds, and trees are observed to be growing within the vicinity of the installed solar panels (see Figures 3 and 4). Vegetation is seen growing and most of the plants are covering the solar panels. Though there are still several solar panels installed, most of them are not operating. Panels are seen dumped near the powerhouse (see Figure 5).

Figure 3. Condition of the Solar Panels of the PV System

Figure 4. Vegetation Growing Near Solar Panels

Figure 5. Defective panels of Pangan-an Solar Plant

C. Inventory of the PV Plant

The tables below report the components, component status, and the power alternative details of the PV plant.

Table 1. Pv Components [9]

Items	Specifications
PV Array	Total Number of PV Modules: 504 units 80W (36- cell) modules: 270 units 90 W (40 cell) module: 234 units 80 W x 270 +90 W x 234= 40,320 W Total Installed Capacity= 40 kW Unit String: 9 modules in series 80 W (36 cell module) string: 30 90W (40-cell module) string: 26 Unit sub array: 4 strings in parallel (14 sub arrays) 80 W string: 2, 90 W string: 2
Battery Bank	Total Number of Batteries: 118 units (2V, 1800Ah) Two strings: 59 units in series per string
Charge Controller	14 Control Units
Inverter	230 V, 50 Hz 12.5 kVA 2 units (Master and Slave)
Powerhouse	AC Panel's Cable
House Wiring	30 m Solid Copper Service Drop Wire: PDX#10 Service Entrance Conductor PDX#12 &PDX#14 Inside House Circuit Layout Single Phase two wire kWh Meter with two 13-W CFL
AC Distribution	220 V-AC using copper conductors and 30 feet wooden poles (NEA Specifications) with street lighting: Luminaire type with two 20W fluorescent lamps

Table 2. pv Components Status [9]

Items	Status as of July 2011
PV array	115 out of 504 panels are defective
Battery Bank	36 out of 118 units are defective
Charge Controller	Fair Condition
Inverter	Master: Functional Slave: Defective
Power House	Operational
House Wiring	247 connected households 3 households with defective circuit breaker
AC Distribution	All posts are in fair condition All street lights were condemned

It is mentioned that the locals have been provided with private generators to supplement the existing PV plant. As far as the PV plant is concerned, it can no longer deliver its full installed capacity, thus residents have to connect to the generators. In effect, the residents have two options of payment scheme with different rates in terms of energy usage. As listed in the inventory, few components need replacements and these deteriorate over time if not complemented.

Table 3. Power Alternative Details [9]

Power Source	Lighting Hours	Pricing Scheme
1998		
Generators (Private Supply)	Houses connected availed for a 20-Watt incandescent bulb which can be lit for 4 hours per night	The private suppliers charged Php5.00 for one (1) 20-Watt incandescent bulb for the 4 hours of operation; gasoline price was at Php40.00/liter in year 1999. Users would average Php150 per month for nightly usage with an accumulated 2.4 kWh/month of electricity consumption.
Solar PV	The plant could provide 24 hours of electricity	The electricity price was at Php23.00/kWh. The minimum consumption per household set by the management was 9 kWh per month which totaled to Php210/month.
2010		
Generators	Houses connected availed for an 11-Watt CFL bulb which can be lit for 4 hours per night	The private suppliers charged Php25 for one (1) 11-Watt CFL bulb for the 4 hours of operation; gasoline price was at Php60/liter in year 2010.
Solar PV	The plant productivity declined to less than 12 hours of power per day	The electricity price was at Php15.00 per kWh. The minimum consumption per household set by the management was 3 kWh per month which is roughly Php50.00 per month.

AN AUDIT FOR BARANGAY PANGAN-AN ENERGY SYSTEM

The centralized solar power plant was donated by the Belgian government in 1999, targeting to light about 300 households. The panels are ideally to last 20 years, but a recent visit to the plant revealed there are already numerous defective panels. Moreover, the accessories to complete the plant such as batteries and inverters only have a lifespan of 10 years or less, but the plant has been operating for 16 years now. Unfortunately, the defective and inefficient components were not replaced. The panels' efficiency is estimated to be 50% or even lower. This number is just estimated because the electric meter of the plant is found to be defective (reads 199.8 kWh and not counting). The batteries are technically dead. These factors resulted in the present situation wherein the plant is only servicing during sunny daytime. In addition, the energy produced by the panels is not enough for the needs of all users. To emphasize, there is no electricity on a rainy daytime. From 6:00 pm to 10:00 pm, a diesel-fueled generator partially services the barangay.

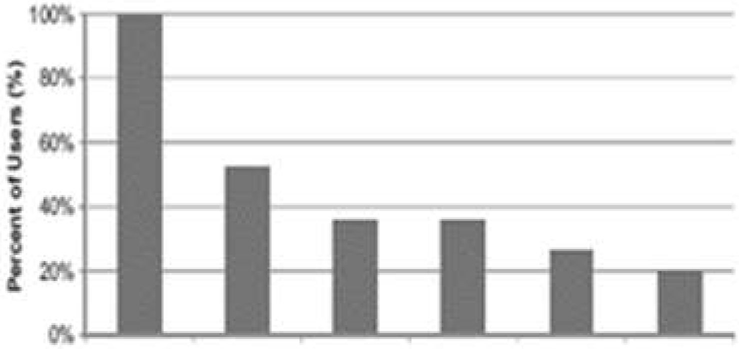

Figure 6. Usage of electricity produced from the PV system [10].

To manage the plant maintenance and collection of fees, the Pangan-an Island Community Cooperative for Development (PICCD) was created alongside the solar plant. However according to a study, "the cooperative remained dependent on external technical support while financially the people found it difficult to pay the high cost of the PV service [3]." These statements may be concluded as rational considering the residents who craft shells and earn only about forty-five pesos (Php45.00) per day. However, as reflected in a 2010 survey, 18% of the users consume more than 9 kWh of energy. Further, 20% of the consumers regularly use a DVD player, which explains that they also use the more common appliances and essential devices (light, TV, radio, phone charger, and electric fan) (as shown in Figures **6** and **7**).

If this fraction of users are large consumers and they have an income sufficient for buying appliances, then they also can pay their electric bills. If their consumptions are the largest, the collections of must also be proportionally large considering this large consuming group.

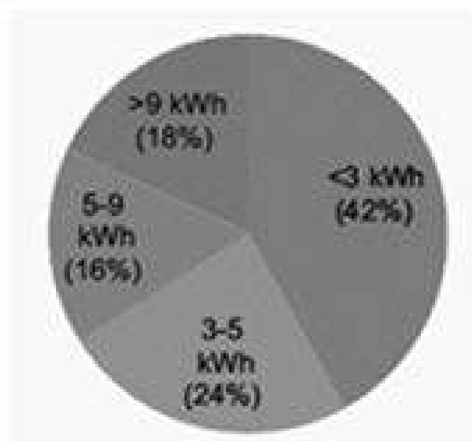

Figure 7. Monthly power consumption of PV system users in kWh [10].

The 2010 survey also collected data on the plant's target and actual revenues. The target revenue is calculated to be the amount sufficient for the maintenance of the power plant. Since the initial year of operations, collections have been much lower than the target. The cooperative points to the low number of connections, figuring out that the plant is underused. The power costs Php210.00 for the first 9kWh plus Php30.00/kWh for additional consumption back then. In 2003-2006, the rate was reduced to Php110.00 for the first 9kWh and a fraction thereafter to encourage more residents to use modern lighting in place of their kerosene lamps. The number of users, as seen in the graph below, increased at a fast rate. This factor, together with more strict policies in payment deadlines increased the collections as well, but it still didn't hit the target. In 2007, the cost was increased to Php15.00/kWh, but the collections just dropped as the plant's efficiency was also dropping fast. From then on, the plant was unable to service the needs of consumers, resulting in even lower revenues.

Looking into the scenario as a whole, the PV plant was seriously mismanaged by PICCD, technically and financially. During the recent visit, for instance, it was discovered that the engineer-in-charge is always not around and does not have a defined duty schedule for evaluating the plant's performance. The whole plant is entrusted to only one caretaker who also was not around. This is a clear manifestation that the cooperative's management is unconcerned about the plant's deterioration. The defective meter mentioned in the first paragraph is also proof that the cooperative is not monitoring how damaged the plant is, or if there is still consistency between the produced energy and the collected payments.

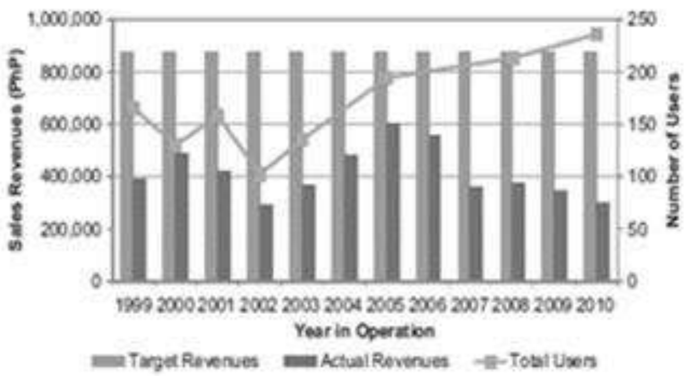

Figure 8. Yearly Electricity Sales (target and actual) and the number of users connected to PV system [10].

There are two recommendations related to this concern: First, review the contract between the cooperative and the technical staff, especially the engineer-in-charge, and push necessary changes that will result in the plant's improvement; and second, technically train additional residents on the solar plant's basic troubleshooting and maintenance. The second will need external assistance, but it will near the plant into an independent and consistent operation.

PICCD needs a third-party auditing body to evaluate its existing policies in payment schemes for its consumers, budget allocation, and service conditions. The cooperative had failed from the very beginning in its Php210.00 minimum payment policy for they haven't considered that many of the residents will only subscribe for lighting purposes. With the help of an auditing body, they can come up with a new policy that will be fair for both micro and large consumers. The tighter payment collection practice, then, can be implemented with minimum negative feedback. Everybody will be more supportive of improving the health of the organization, and thus the performance of the solar plant.

The cooperative has yearly financial reports as to how the funds were spent, which is a good practice. However, these reports do not directly reflect the appropriateness of expenditures. This uncertain, yet important information will all be determined on the said third-party audit. As a result, the cooperative then can allocate funds for the replacement, one after another, of the damaged devices, instead of using the money for useless miscellaneous expenses. The maintenance will increase the plant’s efficiency, so as the income, and with consistency, the plant can operate back at its highest efficiency.

HOMER SIMULATION

The available data shown in Table 1, the costs of solar PV panels, inverter, battery bank, and generator were collected to be able to run a simulation using Homer. The following additional information regarding the parameters used in the homer simulations will be discussed.

A. Solar Data of the Plant

The solar data used in this simulation is downloaded from Homer Legacy for the Visayas region, Philippines. Using the SOL file for cell number 2190, the GMT+0800 time zone, and the coordinates 11'N 123'E, the solar resource is set.

B. Cost of Components

Per availability on the internet, the prices of the components are canvassed. The cost for the solar PV panels was based on the LG-LG300N1C-G3 neON solar panel system pricing. A 10.8-kW system with a grid-tie inverter has a base price of $22,137. To separate the value of the PV panels from the inverter, the cost of the latter was canvassed. The inverter in the abovementioned system is the SMA Sunny Boy 5000TL-US and the grid-tie 5-kW inverter cost is $2,365. These values were used as a benchmark and it has been noted that both the inverter and the solar panels are not off-grid components. After calculating, the final estimated cost of the 40-kW solar PV panels is $69,628 (which is a reasonable cost) and the 40-kW inverter costs $18,920. The battery bank selected for the simulation is the Trojan T-105 which costs $175 for a single unit. The total cost of the battery bank (118 units) is $20,650. Standard costs and sizes of generators were used in the simulation. A 1-kW, $1500 generator was used with alternative 8-kW and 10-kW generators.

C. Load Profile

The load profile was derived from the averaged power consumption ratings of the appliances used in the 247 households in Pangan-an island. The appliances include television, DVD players, electric fans, refrigerators (limited to very few residences), radio, and light bulbs. There were three optimized results in the homer simulation. Of the hundreds of simulation results, only three simulations showed the optimized results.

PV (kW)	Label (kW)	T-105	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
40		118	40	$ 128,118	28,687	$ 494,832	1.942	1.00	0.02		
40	1	118	40	$ 129,618	28,942	$ 499,594	1.944	0.99	0.01	164	731
40	8		40	$ 119,468	38,076	$ 606,211	2.405	0.73	0.04	7,747	5,480

Figure 9. Optimization results for Pangan-an Island Solar Plant.

This is based on the following hourly data. The loads are averaged based on the common appliances in the localities. Load Analysis Profile shows that the highest energy consumption falls between 6-10 PM which is justifiable noting that locals switch their appliances and bulbs on simultaneously.

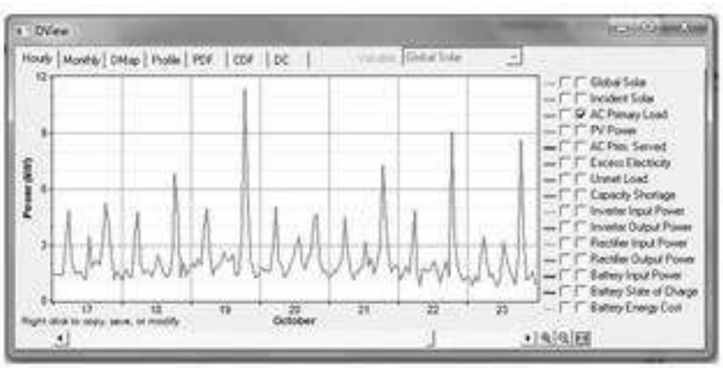

Figure 10. Hourly data plot of the power consumption of the Pangan-an Island household.

In a series of simulation runs, Figure 11 shows the optimized results. As explained, the first years of implementation showed that the PV performance is at its highest. The renewable energy fraction of PV is at 95% with a yearly power output of 45.6 kWh. The generator contributes 5% of the total energy mix with a share of 2.42 kWh. The monthly average energy production is shown to be highest in months from March to April, the summer time in the Philippines. The average solar irradiance at this season is at 1000 W/m^2 or even higher effective 4.5-5 hours a day.

Component	Production (kWh/yr)	Fraction
PV array	45,610	95%
Generator 1	2,424	5%
Total	48,034	100%

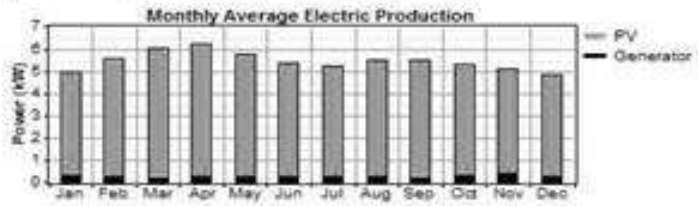

Figure 11. Electrical Component of the System report by the first Homer Simulation

In addition, it can be noticed that the share of the production of the PV array is acceptable. This is because while the majority of the contribution comes from the PV array, the diesel generator still contributes enough for the supply of electricity in the community. From a broader perspective, the energy share of the generator at 5% may result in a minimized fuel consumption which may result in a reduced environmental impact.

While the simulation proves to be promising with the RE shares in the energy mix at 95 %, the excess electricity at 46% proved otherwise. Fig. 12 shows the load consumption, excess electricity, and unmet load values. Ideally, excess electricity is considered a loss in the system. The loss in the system is attributed to the inefficient energy storage system which is usually a problem of any RE system. However, for a system like the Pangan-an PV system, an efficient storage system will not be of too much significance because, in the first years of implementation, the energy consumption of the locals is shifted in the daytime when most of the energy is produced by the PV system. At night time, the generators usually supply most of the energy for 4 hours. The PV system supplements the energy demand though. The demand side management can be invoked in the system on the basis that the maximum power of the PV system is produced in day time which also means the practicality of loads be shifted at day time as well.

Load	Consumption (kWh/yr)	Fraction
AC primary load	24,488	100%
Total	24,488	100%

Quantity	Value	Units
Excess electricity	17,984	kWh/yr
Unmet load	1,317	kWh/yr
Capacity shortage	1,586	kWh/yr
Renewable fraction	0.950	

Figure 12. Tabular Results of the Consumption and Wastes from the first run of Simulation.

In the next five years of PV operation, it is already considered that the performance of the PV system also deteriorates. In Table 2, 115 out of 504 panels and 36 out of 118 batteries are found to be defective which would mean an estimated gradual decrease of 22.82% of output power of the overall PV system. Clearly, the simulation in Figure 13 shows that the PV system is estimated to be sharing 73% of the energy mix.

Component	Production (kWh/yr)	Fraction
PV array	45,610	73%
Generator 1	16,958	27%
Total	62,568	100%

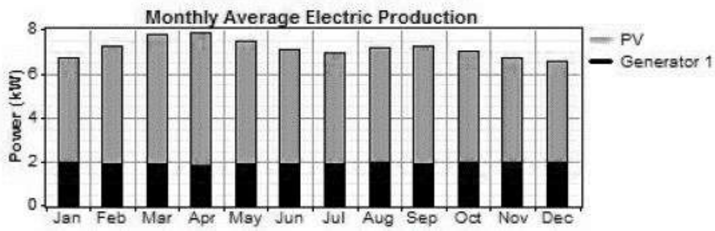

Figure 13. The electrical component of the System report of the second Homer Simulation

In the second simulation, the PV array indicates a performance decline sharing the energy mix at 73%. This means that a sudden increase in demand for the generator is expected to fill in the gaps in the PV system with a share of 27%. The original capacity of the PV system at 40 kW may suffer a decline in energy generation. As a result, the supply of energy may no longer meet the demand of the locals in the next five or ten years of operation. In the analysis, other contributing factors may aggravate the situation. First, the population may increase and second, the loads/appliances may also increase noting the economic vibrancy that the PV system brought in the first 5 years of implementation.

In addition, the change in the share of supply between the two sources affected the values for excess electricity, unmet loads, and power consumption. There were decreases in unmet loads and capacity shortages and an increase in excess electricity.

Load	Consumption (kWh/yr)	Fraction
AC primary load	19,721	100%
Total	19,721	100%

Quantity	Value	Units
Excess electricity	42,204	kWh/yr
Unmet load	536	kWh/yr
Capacity shortage	799	kWh/yr
Renewable fraction	0.729	

Figure 14. Tabular Results of the Consumption and Wastes from the second run of Simulation

From the economic perspective, the Levelized Cost of Energy (LCOE) of the first simulation yielded $1. 686/kWh while the second run yielded an LCOE of $2.405/kWh. This means that with a greater share of renewable sources, the LCOE will be cheaper (see Figures 15 and 16).

Total net present cost	$ 527,804
Levelized cost of energy	$ 1.686/kWh
Operating cost	$ 31,149/yr

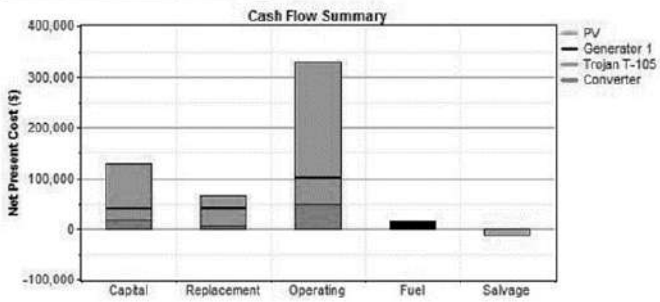

Figure 15. Cost Summary of the first Simulation Results

Total net present cost	$ 606,211
Levelized cost of energy	$ 2.405/kWh
Operating cost	$ 36,076/yr

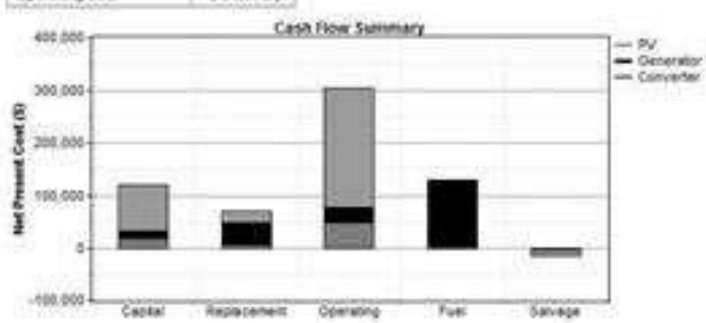

Figure 16. Cost Summary of the Second Simulation Results

CONCLUSION

In general, the first simulation is the most desirable based on the electrical characteristics for three reasons: least excess energy (46.1%), least LCOE ($1,686/kWh), and greatest share of renewable fraction (95%). While the second simulation proved a decline in PV performance, the results coincide with the actual conditions of the PV system after the first years of implementation in 2009 and 2010. However, in 2015 the PV system is no longer at its best capacity and an upgrade of the system is best sought to at least maintain the economic vibrancy of the island and ensure energy security through Renewable Energy.

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