

## Article

# The Viability of Providing 24-Hour Electricity Access to Off-Grid Island Communities in the Philippines

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**Abstract:** Techno-economic viability assessments of rural electrification projects, especially those that integrate renewable energy technologies, typically look at system design optimization that would yield the most favorable cost and investment scenarios. However, the true viability of these projects relies more importantly on their impact to the rural communities while ensuring positive financial returns to the project developers. This paper aims to expand the viability assessment of electrification projects in off-grid island communities in order to mainly address the apparently opposing needs of the major stakeholders at play by developing a viability assessment framework considering the techno-economic dimensions as well as the socio-economic impacts to the consumers. The analysis follows a two-phase approach, where system design optimization and financial impact calculations are done in the first phase and the socio-economic viability is accomplished in the second phase. Results suggest that high capital investment for renewable energy has a better pay-off when there is higher demand for electricity. On the other hand, consumers also tend to receive higher economic benefit as they consume more electricity. However, the low income of rural consumers strains their capacity to pay, which necessitates their engagement in more economically-productive uses of electricity. The viability assessment framework can be a useful tool for both investors and consumers as this provides important insights which can be translated into impactful interventions that may include government support through improved policy implementation that can positively sustain electricity access in off-grid communities through renewable energy.

**Keywords:** rural electrification; techno-economic viability; socio-economic viability; renewable energy; electricity access



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## 1. Introduction

Electricity is regarded as a fundamental enabling component to the achievement of socio-economic growth and development such that global efforts are now directed towards last-mile connections in order to provide affordable, reliable, and sustainable universal access to the 840 million people who are still living without electricity [1,2]. The dilemma, however, is that most of the unelectrified households live in isolated and least developed regions that are deemed unviable to electrify. It has been recognized that the best option for more than half of the population without access to electricity is decentralized generation (i.e., microgrids or minigrids), ideally supplied from renewable energy (RE) sources [3]. Several studies have already explored the practical implementation of decentralized systems integrated with RE in increasing electricity access to certain developing regions [4–7], and even in developed countries like Ireland [8]. In the Philippines, over 2.7 million households still live in the dark [9]. The poor economic status of majority of these households is further exacerbated by their remote location as most of them live in small island villages

that are financially and technologically impractical to electrify through grid extensions. Some electrified island villages simply rely on diesel generator sets to provide electricity for restricted hours while others have been more fortunate to secure financial assistance for bringing in renewable energy systems that provide them with longer access [10,11]. The enactment of Republic Act 9136 or the Electric Power Industry Reform Act (EPIRA) and the creation of the Missionary Electrification Development Plan (MEDP) has prompted the shift from a predominantly government-initiated electrification effort to an increased private sector participation in making electricity available, especially to remote and off-grid areas where grid extensions are not viable [12,13], necessitating rural electrification projects to become financially-viable endeavors to attract private capitalization. It is widely recognized that we now have better technologies to support decentralized electricity generation, but there still remains a challenge especially on cost reduction, planning, better integration to local and national development pathways, and other technological barriers—such as system inefficiencies and weak electrical network infrastructure [14–17]. Several studies have also expressed the need to look beyond the cost of electricity or the optimal design derived from techno-economic analysis of rural electrification projects and consider how to efficiently provide electricity to low-income consumers while also attracting private capitalization [18–20]. However, most studies are still geared towards better development of technical parameters that yield the best design options [21–23], more often omitting the socio-economic impacts to the consumers.

This study aims to expand the viability assessment of providing 24-h electricity access to rural off-grid communities through the integration of renewable energy technologies by also considering the socio-economic impacts of increasing electricity access to rural communities. While the study performs an optimization analysis, the study does not aim to provide a new approach to electrification systems design and optimization or to load profiling methodologies. Instead, this study develops a framework to evaluate the viability of providing 24-h electricity access from the techno-economic and socio-economic perspectives in order to address the important needs and requirements of major stakeholders in an electrification project. The analysis follows a two-phase approach in order to determine the viability and sustainability of providing 24-h electricity access in off-grid island communities. First, the optimal system design is determined and techno-economic analysis is performed from a business perspective; and second, the design is evaluated for socio-economic viability considering pre-defined parameters. The framework is applied and tested in Pangan-an Island and validated in a solar photovoltaic implementation in Gilutongan Island. This paper is further divided into sections, where Section 2 presents a review of viability studies of rural electrification initiatives and Section 3 describes the research locale and the methodology. Section 4 presents the results of the techno-economic and socio-economic viability assessments, as well as the validation of the framework. Section 5 presents the discussion of results, which is geared towards the importance of providing programs to capacitate low-income household consumers in engaging in productive uses of electricity. Section 6 discusses the policy implications of the viability assessment results and conclusions are drawn in Section 7 of the paper.

## 2. Viability of Rural Electrification Initiatives

There is a perceived positive impact when 24-h electricity service is provided in rural communities that go beyond mere electricity service [24]. With access to electrification considered to be fundamental to social and economic development, increased access, especially during day-time use, paves the way for more productive activities that lead to income generation and social growth. Moreover, smart grid approaches such as broadband over power line (BPL) or power line communication (PLC) applications are seen to improve access to telecommunications and internet while also providing power through renewable energy sources in rural areas, further opening up these isolated communities to the world [25–27]. However, despite the progressive implication of 24-h electricity access in rural communities, there lies a question of whether or not it is a socio-economically viable

endeavor to pursue, especially in poorer regions where daily living is not dependent on electricity use and where incomes are relatively low [28].

Costello (2018) highlighted the crucial role of consumers in the promotion and advancement of renewable energy in rural electrification projects, identifying the need to emphasize not just the long-term economic impacts of low electricity costs or the environmental impacts of transitioning to low-carbon sources but also the associated social benefits and individual economic efficiency to entice the market to embrace renewable energy [29]. Consumers in rural areas, with low demand and low incomes, tend to undervalue the future benefits of renewable energy developments due to its perceived high capitalization costs and are most likely to think of individualistic economic impacts instead of looking at the holistic consequences of shifting to renewable energy sources. This leads consumers to further make inefficient energy choices [30]. It is also argued that while electricity access leads to a certain improvement in domestic activities in rural areas, such as increased lighting and use of household comfort appliances, it does not have a distinctive impact on stimulating economic development as typical livelihoods in rural communities are not reliant on electricity [31]. Moreover, while households in rural communities might be keen to get connected, they might be deterred by their inferior socio-economic status and low incomes to consume electricity [32].

However, cost might not always be the highlighted issue of rural households where electrification is concerned. Consumers are also sensitive to other attributes of rural electrification systems and the viability of such projects also depends on whether these attributes are delivered or not. Issues such as reliability of connection and the quality of electricity are determined to be more influential factors in the viability of microgrid electrification [33,34]. In the electrification efforts in rural Mexico where solar home systems are deployed, household consumers expressed the importance of service levels and that system sizing options must be put in place to cater to potential increases in household demand [35].

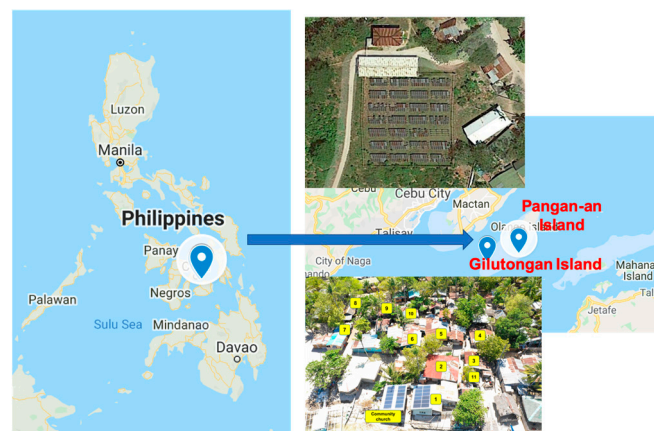
Despite vigorous efforts in expanding rural electrification efforts, there are still unfavorable results. The inadequate understanding of the effects of electricity access on socio-economic attributes leads to poor planning and design [36]. Tariff setting and demand fulfilment are key factors that also dictate the proactive consumption of electricity users [37]. The socio-economic demographics of consumers—such as household expenditure, household size, and appliance ownership—should also play part in the projection of load demand [38]. Moreover, conventional approaches to rural electrification systems design need to be re-evaluated and design solutions must be conceptualized to achieve reliable, affordable, and sustainable electrification despite uncertain load development and very low demand [39]. While the estimation of load demand is considered crucial in the design and sizing of electrification systems [40–42], other factors related to the sustainability of electrification systems are also equally vital. Consequently, it is also important to ensure that policy interventions are in place, especially through financial measures such as subsidies and incentives, particularly when private sector investment is required [43].

### 3. Materials and Methods

#### 3.1. Research Environment

Gilutongan and Pangan-an Islands are small islands located off the coast of Mactan Island in Cebu (see Figure 1). In 1999, Pangan-an Island (10°13'12" N, 124°02'20" E), an island barangay in Lapu-Lapu City, was a beneficiary of a Php 22-million 45 kWp centralized solar power facility donated by the Belgian government in coordination with the Lapu-Lapu City government and the Philippine Department of Energy [44]. Operated and maintained by a local cooperative called Pangan-an Island Community Cooperative for Development (PICCD), it provided 24-h electricity access to some of the island residents. However, in 2011, the facility discontinued its operations due to degradation of the solar modules and the battery storage systems with no replacements made [45]. Several issues have been considered for the electrification setback in Pangan-an, of which the definition

of true electricity tariff and capacity of consumers to pay are at the forefront [44]. From the time of discontinued operations until the present, most of the island residents rely on the community diesel generator to provide four hours of electricity every night, with some residents installing their own solar home systems and others opting not to be connected to electricity at all. The residents connected to the 35 kW community diesel generator get electricity access from 6:00 pm to 10:00 pm at a cost of US\$5 per 7 kWh consumption with a US\$0.50 per additional kWh of consumption (roughly US\$1.21 per kWh). The original facility is composed of 504 solar PV modules of 90 Wp capacity, 118 units of 2 V 1800 Ah lead acid batteries, 2 units of bespoke 12.5 kVA inverter, charge controller, and low voltage distribution system. At the time when 24-h electricity was provided to the island, the minimum load of 1 kW was recorded at 6:00 am and the maximum load of 10 kW was recorded at 7:00 pm [45]. There were previous plans to rehabilitate the solar PV facility, but these plans have not come to fruition.



**Figure 1.** Pangnan-an and Gilutongan Islands, Philippines (Image courtesy of Google maps).

Gilutongan Island ( $10^{\circ}12'00''$  N,  $123^{\circ}59'00''$  E), an island barangay in Cordova, Cebu City, obtains electricity from a 194 kVA diesel generator donated by the Cebu provincial government in mid 2010s and requires a daily tariff of US\$0.14 per light bulb and US\$0.16 per power outlet. The diesel generator operates for 4 h every night and is maintained by the local government unit of the *barangay*. A 7.92 kWp solar photovoltaic system with a 28.8 kWh battery energy storage system was installed last March 2020, providing 24-h electricity to 11 household beneficiaries composed of 44 individuals. The solar PV system was installed on two rooftops located within the vicinity of the 11 households, with the electrical distribution system for the households also improved according to Philippine electrical standards. Each household pays a flat rate of US\$0.4 per day provided that their daily consumption does not exceed 1 kWh, while an additional tariff is computed based on the rate of US\$0.4 per kWh for any additional power consumed.

### 3.2. Research Methodology

Figure 2 presents the research framework. The viability assessment framework follows a two-phase strategy, where electrification projects are assessed according to the techno-economic and socio-economic viability. The techno-economic viability is primarily useful to project implementors or investors as this provides the financial standpoint of the project. The socio-economic viability is targeted toward the consumers and how end users can benefit from the project and could also be helpful for project implementors in defining project parameters. With this strategy, the major stakeholders and their respective needs and requirements are recognized and given equal importance. Electricity consumption data for Pangnan-an Island was obtained through a survey of selected households. One hundred ninety-seven households were surveyed in Pangnan-an, a representative sample of the 405 households living in the community [46]. The techno-economic assessment is done using optimization results derived from simulation and calculating financial returns, and

the socio-economic assessment is done through calculations of the economic benefit and capacity to pay. Validation, in terms of techno-economic and socio-economic viabilities, is done considering actual data obtained from the solar installation in Gilutongan Island.

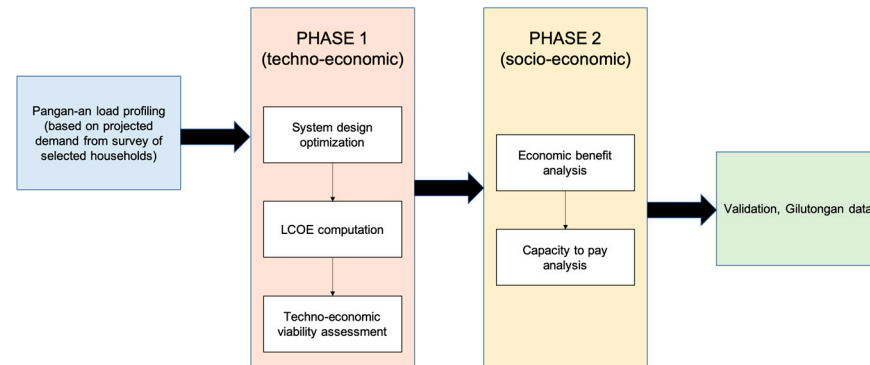


Figure 2. Research framework.

### 3.3. Load Profiling

The daily load demand profile for Pangan-an Island corresponds to the projected future demand of the households obtained through the survey. Because only a sample of the households was surveyed, total electricity usage for each appliance ( $E_a$ ) was computed based on the proportion of respondents projected to use certain appliances over a given period of time, as shown in Equation (1)

$$E_a = \left(N * \frac{m}{n}\right) * \left(P * \frac{\sum_{x=1}^m t_x}{m}\right) \quad (1)$$

where  $(N * \frac{m}{n})$  refers to the proportion of the respondents projected to use the appliance multiplied to the total population of the island with  $m$  referring to the number of households responding to use the appliance,  $n$  referring to the total sample population, and  $N$  referring to the total population of the island;  $P$  refers to the wattage of the appliance; and  $\frac{\sum_{x=1}^m t_x}{m}$  refers to the average number of hours of usage per appliance per household [47].

Two load demand profiles were created for 24-h consumption, considering load with fridge and load without fridge. The load demands were generated corresponding to the economic profile of the households with consideration that each economic profile will purchase and use different types of appliances with different power requirements. Three income classifications were considered: lowest income bracket corresponding to poor households earning less than US\$160 (Php 8000) per month; middle income bracket corresponding to low-income households earning between US\$160 (Php 8000) to less than US\$300 (Php 15,000) per month; and the highest income bracket corresponding to lower middle-income households earning between US\$300 (Php 15,000) to less than US\$600 (Php 30,000) per month. The income groups were based on the profile of income classes in the Philippines by Albert, et al. (2019) of the Philippine Institute for Development Studies [48].

### 3.4. Techno-Economic Viability Assessment

The techno-economic viability assessment looks at the levelized cost of electricity, investment requirements, and financial returns. Optimization of the electrification system using HOMERPro, a software typically used in studies involving off-grid systems [49,50], is done for Pangan-an Island. Input parameters are the load demand profile, technical components, economic components, and the solar resource since only solar PV is considered. The optimization considers solar energy and diesel generator set as the primary sources of electricity. Battery energy storage system (BESS) is integrated into the design configurations. The technical components considered in the simulation are independent of



the existing components of the decommissioned facility of the island. The solar PV module is Canadian solar—a flat-plate, monocrystalline panel with 290-watt peak power. The inverter is a Fronius Symo 24.0-3 and the battery is Trojan SAGM 12 75, 12 V with 1.99 kWh capacity. The diesel generator set is a 30 kW Kohler generator. The inflation rate between a one-year period covering June 2019 to May 2020 ranged from 0.8% to 2.9% [51]. The average for this 12-month period is 2.05% and this average is considered as the inflation rate in the simulation. The latest interest rate published by the Bangko Sentral ng Pilipinas (BSP) from April 2020 is already with consideration from special circumstances brought about by the COVID-19 pandemic, thus the base nominal rate considered in the study is the one published by BSP in December 2019 at 4.0% [52]. The island sources out its diesel from the mainland at US\$0.90 (or Php 45) per liter. Systems fixed capital cost includes installation, transportation, and other incidental costs related to the implementation of the system. Exchange rate is assumed to be Php 50 to US\$1.00.

The financial parameters used in the viability analysis are the payback period and return on investment. Although HOMERPro computes these parameters, the computation relies on the levelized cost of electricity (LCOE), which is just the break-even value of the investment [53]. It is necessary for investors to realize a profit margin, so in this analysis, the parameters are computed based on the cash flows generated from the simulation, on a tariff set at LCOE plus profit margin, and on equations provided below [54]. The profit margins are set at 10% and at 20% of LCOE, which are arbitrary and are defined for the sake of comparing one system from the other. Payback period is computed considering uneven cash flows and the equation

$$\text{Payback} = A + \left(\frac{B}{C}\right) \quad (2)$$

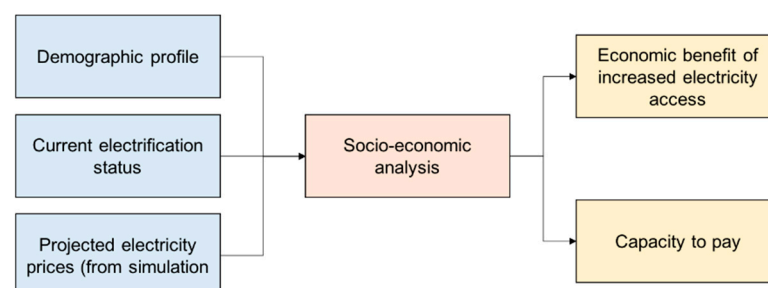
where  $A$  = the last year with a negative cumulative cash flow,  $B$  = the absolute value of the cumulative cash flow at year  $A$ , and  $C$  = total cash flow at year  $A + 1$ . The modified return on investment (ROI) is computed considering net cash inflow instead of net income per the equation

$$\text{ROI} = \left(\frac{\text{Average net cash inflow}}{\text{Initial investment}} \times 100\%\right) \quad (3)$$

where the average net cash inflow is computed from the nominal cash flows and the initial investment is the initial capital corresponding to the load scenario.

### 3.5. Socio-Economic Viability Assessment

The socio-economic viability assessment computes for the economic benefit of increased electricity access and the capacity to pay of consumers. Figure 3 shows the details of the framework for the assessment.



**Figure 3.** Framework for socio-economic viability assessment.

The National Rural Electric Cooperative Association (NRECA) defines economic benefit, in terms of electrification, as the monetary benefit that the consumers receive from the use of electricity as compared to using their current energy alternatives [55]. In this study, economic benefit is computed as the benefit of providing 24-h electricity access

through hybridization with renewable energy technologies. Economic benefit is computed per Equation (4) derived from NRECA (2010) and Choynowski (2002) [55,56]

$$D = [Q_a \times (P_a - P_e)] + \left[ \left( \frac{P_a - P_e}{2} \right) \times (Q_e - Q_a) \right] \quad (4)$$

where  $D$  = economic benefit of providing 24-h electricity access,  $P_e$  = price of 24-h electricity per kWh,  $P_a$  = price of current electricity system per kWh,  $Q_e$  = consumption of electricity at 24-h access, and  $Q_a$  = consumption of electricity at less than 24-h access. The electricity consumption values are based on the load profiles and the price of 24-h electricity is based on LCOE plus profit margin.

The capacity to pay is defined as the consumers' ability to pay the calculated electricity cost. It is analyzed according to the current economic status of the respondents and their expressed level of consumption. A consumer is considered capable of paying if the electricity cost is less than 5% of the household gross income as defined by the World Bank [57]. The capacity to pay is computed per Equation (5)

$$CtP = \left( \frac{COE \times EC_a}{HI_a} \right) \times 100\% \quad (5)$$

where  $COE$  = cost of electricity,  $EC_a$  = average daily electrical consumption ( $EC$ ) per household belonging to a given income classification ( $a$ ), and  $HI_a$  = average daily income per household belonging to a given income classification ( $a$ ). The cost of electricity is as defined in the techno-economic assessment where arbitrary profit margins of 10% and 20% are applied to the LCOE. The average daily electrical consumption per income class is based on the projected load demand for Pangan-an and the average daily income is computed on the current income obtained from the demographic information.

### 3.6. Validation

The techno-economic and socio-economic viability is validated considering the actual data from a solar PV system installation in Gilutongan Island, providing 24-h electricity access to 11 households. The daily load profile is computed as an average of the actual one-year energy consumption recorded for the 11 households between April 2020 and March 2021. LCOE is computed considering the net present value of the actual capital investment of the system and the annuities based on Equation (6) [58]

$$LCOE = \frac{NPV_{cost}}{NPE} \quad (6)$$

where  $NPV_{cost}$  is the net present value of the total investment and annuities consisting of the cost of the solar PV system components, installation costs, distribution costs, replacement costs, and operations and maintenance cost; and  $NPE$  is the net present value of the total energy output. In the computation, a base nominal rate of 4% is also considered with a project lifespan of 20 years. Techno-economic and socio-economic analysis are done as discussed in Sections 3.4 and 3.5.

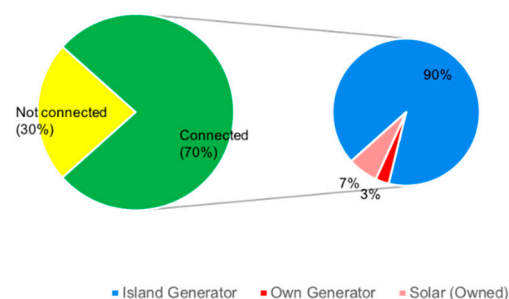
## 4. Results and Discussion

The demographic profile of the respondents from Pangan-an Island are shown in Table 1. Almost half of the respondents did not graduate elementary school; while more than 70% of the households are average-sized with 4 to 6 members, or large-sized with more than 6 members; and 69% are classified as poor. The average household monthly income is Php 6268.72 (US\$125.37), which is mostly coming from manual labor, fishing, shell gleaning, souvenir selling, vending, and providing personal services.

**Table 1.** Demographic profile of Pangan-an Island.

Demographic Parameters	Pangan-an
Educational Background	
<i>Did not graduate elementary</i>	49%
<i>Elementary graduate</i>	24%
<i>Did not graduate high school</i>	0%
<i>High school graduate</i>	18%
<i>College level</i>	5%
<i>College graduate</i>	3%
<i>Post-college studies</i>	1%
Household size	
<i>Small-sized (1 to 3 members)</i>	23%
<i>Average-sized (4 to 6 members)</i>	47%
<i>Large-sized (above 6 members)</i>	30%
Average household monthly income (according to income cluster) [48]	
<i>Poor (less than US\$158 per mo.)</i>	69%
<i>Lower income (US\$158–316 per mo.)</i>	26%
<i>Lower middle income (US\$317–632 per mo.)</i>	5%

Figure 4 shows electricity access status of the households in Pangan-an, with 70% of the respondents being connected to an electricity source. Out of these, 90% are supplied by the community diesel generator while 3% get power from their own generators and 7% have their own solar home systems. The power supply from the communal generator is made available to residents from 6:00 pm to 10:00 pm daily. The electricity billing is done monthly and payment is collected by a representative from the local cooperative. Electricity is mostly used for lighting (74%) and mobile phone charging (35%), with very few residents also using it to power television sets (30%), electric fans (26%), and radios (20%).

**Figure 4.** Access to electricity in Pangan-an Island.

#### 4.1. Energy Market and Load Profile

Figure 5 shows the electricity load profile of Pangan-an Island based on projected electricity demand of island residents if supply is made available 24 h a day. The total daily usage is computed by adding the hourly usage shown in the figure. Two load scenarios are determined and shown in Table 2.



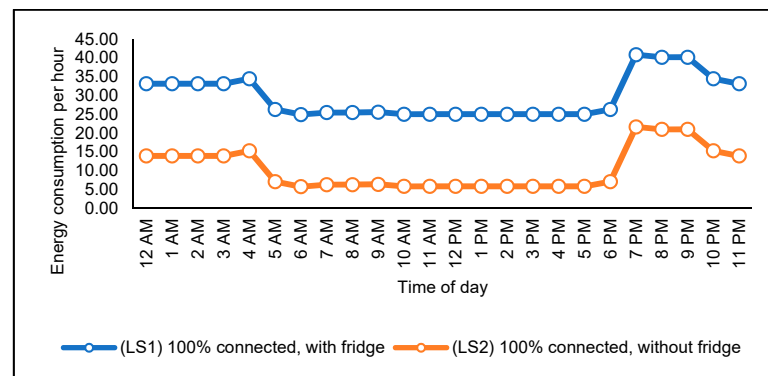


Figure 5. Projected daily electricity load demand for Pangan-an Island.

Table 2. Electricity load scenarios (Pangan-an).

Load Scenario	Hours of Access	Households Connected	With or Without Fridge
LS 1	24	100%	With fridge
LS 2	24	100%	Without fridge

Total expected daily usages are 709.48 kWh for LS 1 and 248.68 kWh for LS 2.

Respondents have expressed that if 24-h electricity will be made available on the island, they will be willing to purchase and use TV sets, electric fans, electric iron, and refrigerators on top of the usual lighting and mobile phone charging. The potential energy market seems ambiguous as residents seem to have an increased purchasing power but are also prone to consume less electricity (see Table 3 for a comparison of monthly income and electricity bill from a 2015 study [59] and the survey conducted for this work, where the average monthly income is significantly higher but the average monthly electricity bill is relatively lower).

Table 3. Comparison of monthly income and electricity cost in Pangan-an. 2015 [59] vs. 2018 (surveyed).

Attribute	Average	Std.	Min.	Max.
Monthly Income (in US\$)				
2015 data	52.81	51.21	0	164.00
2018 data	125.37	90.30	0 *	540.00
Monthly Electricity bill (in US\$)				
2015 data	6.42	2.12	5.00	15.00
2018 data	5.86	3.59	0 **	13.50

\* Some households indicated that their sustenance come from children working outside the island. \*\* Corresponds to 7% of the respondents who obtain electricity from personal solar home systems.

The latest data on electricity billing suggests that on average, a single household in Pangan-an consume roughly 8.72 kWh per month with the lowest household consumption recorded at 7 kWh and the highest household consumption at 24 kWh. Total consumption computed from the monthly electricity payments for all households connected to the island generator is 1124.2 kWh per month or 37.5 kWh per day, a value lower than any of the forecasted load demand shown in Figure 5. While the current demand is clearly constricted by the availability of electricity access on the island, the projected demand might be too optimistic and thus, careful energy market studies should be carried out by potential investors and project developers if electricity access should be increased.

#### 4.2. Techno-Economic Viability Assessment

The optimal electrification system designs corresponding to the two load profiles generated for Pangan-an were determined using HOMERPro. The simulation tool was set to “optimizer” where the software is allowed to select the optimal system with the option

to select either an optimal system with diesel generator or an optimal system without generator. Results of the simulation, as well as the financial parameters computations, are shown in Table 4.

**Table 4.** System design optimization and economic results (Pangan-an).

Parameters	Pangan-an Island Load Scenarios	
	LS 1	LS 2
Solar PV size	50 kW	30 kW
Generator	Yes	Yes
Battery qty	200 strings	100 strings
Inverter size	22 kW	10 kW
<b>Levelized cost of electricity</b>	<b>US\$0.366</b>	<b>US\$0.405</b>
Net present cost	US\$1.83 M	US\$725,969
Operating cost per year	US\$86,971	US\$33,558
Initial capital investment	US\$110,977	US\$63,885
Renewable energy fraction	29.1%	32.8%
Load served (in kWh)	252,764	90,772
<b>Economics at 10% profit margin</b>		
Payback period	6.43 years	8.13 years
ROI	13.5%	10.8%
<b>Economics at 20% profit margin</b>		
Payback period	3.16 years	4.44 years
ROI	21.8%	16.6%

Optimization results suggest that all load scenarios would require a hybrid microgrid system with solar PV, battery energy storage, and diesel generator. The levelized cost of electricity is higher when demand is lower primarily because the price to break-even is higher. Better financial results (i.e., shorter payback and higher return on investment) are observed in LS1 with higher load requirements. The relatively high capital investment required for systems with renewable energy technology are likely to be profitable when consumption is high. Higher profit margins also yield better financial results.

#### 4.3. Socio-Economic Viability Assessment

The economic benefit of providing 24-h electricity access is computed for electricity costs defined at LCOE plus profit margin. The current electricity cost per kWh is based on the current tariff at the island, which is at US\$1.21 per kWh consumption. The current electricity consumption from the load profile (Section 3.1) is 1124 kWh per month. Table 5 summarizes the results.

**Table 5.** Economic benefit to consumers (Pangan-an).

Electricity Load Scenario	$P_e$ (in USD)	$P_a$ (in USD)	$Q_e$ (Annual)	$Q_a$ (Annual)	$D$ (in USD)
<b>LS 1</b>					
At 10% profit margin	0.4026	0.715	252,764	13,490	41,626.97
At 20% profit margin	0.4392	0.715	252,764	13,490	36,754.52
<b>LS 2</b>					
At 10% profit margin	0.4455	0.715	90,722	13,490	14,057.51
At 20% profit margin	0.4860	0.715	90,722	13,490	11,947.21

Table 5 shows that the benefit to consumers reasonably decreases as electricity cost per kWh increases. Substantial economic benefit is expected when electricity consumption is higher. The highest economic benefit is when consumers are expected to use refrigerators apart from the other typical household appliances and lighting. This somehow reinforces the notion that as households consume electricity beyond just simple lighting by finding more productive uses, they will experience greater economic benefit. However, if electricity is used simply for lighting and other consumptive uses, such as mobile charging and internet access, households will find less benefit from increased electricity access. Moreover,

the electricity prices being set are relatively lower than the current price that the consumers are paying, which significantly influences the computed values. If investors were to set higher profit margins, then the economic benefit would considerably be much lower.

The capacity to pay is computed at household level. The projected load demand in Figure 6 is sorted out per income classification and an average daily consumption per household is defined. The average daily household income is also obtained for each income classification with poor households earning on average US\$2.73 per day, low-income households at US\$6.66 per day, and lower middle-income households at US\$12.78 per day. The electricity cost is computed based on electricity prices derived from the previously defined profit margins (shown as  $P_e$  in Table 5). The results are summarized in Table 6.

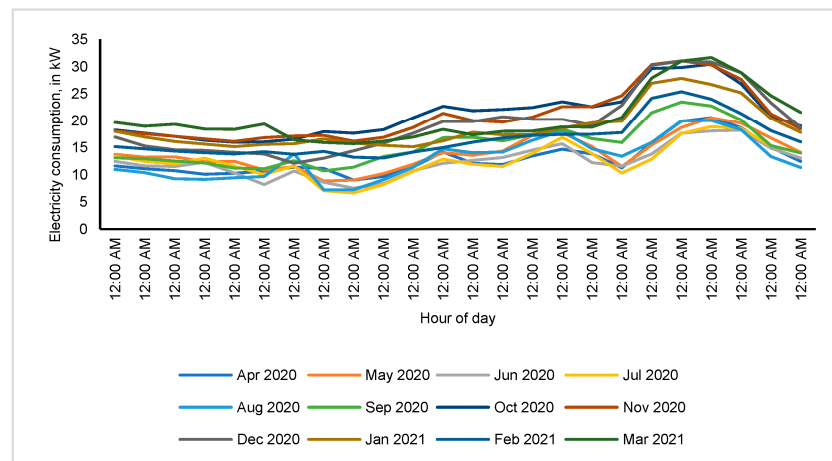


Figure 6. Actual electricity consumption for Gilutongan Island.

Table 6. Capacity to pay per household per income classification (Pangan-an).

Income Classification/Load Scenarios	Average Consumption (in kWh per Day)	Electricity Cost (US\$ per Day)	Percentage of Income Spent on Electricity
<b>LS 1</b>			
At 10% profit margin			
Poor	0.45	0.18	7%
Low income	2.15	0.86	13%
Lower middle class	2.41	0.97	8%
At 20% profit margin			
Poor	0.45	0.20	7%
Low income	2.15	0.94	14%
Lower middle class	2.41	1.06	8%
<b>LS 2</b>			
At 10% profit margin			
Poor	0.45	0.20	7%
Low income	0.95	0.42	6%
Lower middle class	1.21	0.54	4%
At 20% profit margin			
Poor	0.45	0.22	8%
Low income	0.95	0.46	7%
Lower middle class	1.21	0.59	5%

Table 6 shows that households belonging to the poor and low income class expend more than 5% of their income on electricity for all load scenarios with the low income households spending more than 10% in LS 1, where they are expected to use refrigerators. Poor households show better capacity to pay than the low-income households at these load scenarios, spending between 6% to 8% of their income on electricity because these households were considered to be non-fridge users. Calculations are favorable for lower middle-class households who spend between 4% to 5% of their income on electricity when they are not using refrigerators. While the majority of the results are not ideal, it is important to note that the capacity to pay is calculated based on current income of the

households. If consumers can find ways to improve their income with the increased access to electricity, then capacity to pay will also increase. Moreover, if investors should choose to increase profit margins, this would negatively sway the results unfavorably.

The viability of rural electrification projects does not solely depend on the financial parameters that determine risks and rewards for project implementers nor on the technological factors that dictate system design and energy sources. More importantly, the viability of these projects also relies on the community, especially on whether the community has adequate electricity demand and whether the consumers within the community exhibit the capacity to pay for increased electricity access at a tariff set above the calculated levelized cost of electricity. Moreover, the economic benefits offered by increased electricity access must be explicitly defined for the community and consumers must be encouraged to use the available electricity supply, especially through productive means, to realize these benefits.

#### 4.4. Validation

Since March 2020, 11 households in Gilutongan Island were provided with 24-h electricity access, with only 17 recorded instances of power interruptions over a one-year period. Figure 6 shows the actual hourly electricity consumption for the 11 households in Gilutongan Island between April 2020 to March 2021. Since the provision of 24-h electricity, households are able to use household electrical appliances for longer hours. Moreover, some households are able to buy refrigerators and water vending machines that allowed them to earn additional income. The total electricity consumption of the 11 households for the one-year period is 4742.109 kWh.

Table 7 presents the actual costs of installation and the results of the techno-economic viability assessment. The payback period and the ROI are computed based on the actual consumption of the households, with the assumption that no increase in consumption is expected for the succeeding years. The payback period is relatively longer and the ROI is relatively lower, primarily due to the lower actual consumption of the 11 household beneficiaries (see previous figure) which is only roughly 44% of the expected energy output of the system as presented in the table. This is also indicative of the significance of rational load profiling and appropriate system sizing to ensure that installed systems are optimal in terms of meeting load demand. However, when more productive uses of electricity are implemented by the households, the payback period and ROI of the system are expected to be more favorable due to the increased demand and usage of renewable energy.

**Table 7.** Economic results for Gilutongan Island.

Parameters	Values
Solar PV System	US\$9400.00
Distribution and installation	US\$8699.11
Annual operations and maintenance	US\$464.00
Annual energy output	10,713.60 kWh
<b>Levelized cost of electricity</b>	<b>US\$0.264</b>
Net present cost	\$38,438.99
<i>Economics at 10% profit margin</i>	
Payback period	9.14 years
ROI	10.93%
<i>Economics at 20% profit margin</i>	
Payback period	8.39 years
ROI	11.93%

Table 8 shows economic benefit calculations for the 11 household beneficiaries in Gilutongan. The lower economic benefits can potentially be explained by the low demand of the households, considering only roughly 1480 kWh increase in electricity consumption between  $Q_a$  (4.5 h electricity access) and  $Q_e$  (24-h access). This also strengthens the results of Pangan-an, where higher economic benefits are expected when demand is higher.

**Table 8.** Economic benefit to consumers (Gilutongan).

Electricity Load Scenario	$P_e$ (in USD)	$P_a$ (in USD) *	$Q_e$ (Annual)	$Q_a$ (Annual)	$D$ (in USD)
At 10% profit margin	0.2904	1.21	4742	3259	3679.02
At 20% profit margin	0.3618	1.21	4742	3259	3573.40

\*  $P_a$  and  $Q_a$  is from Lozano, et al. [47].

Table 9 presents the results of the analysis on the households' capacity to pay. Average daily consumption among the 11 households is within the range of 0.5 to 1.5 kWh per day. Some of these households have only increased their consumptive use of electricity with the increased electricity access, while only a few who belong to the low-income bracket have found productive uses of electricity. This has greatly impacted the capacity to pay, especially for the poor households where electricity cost is more than 10% of their household income.

**Table 9.** Capacity to pay per household per income classification (Gilutongan).

Income Classification/Load Scenarios	Average Consumption (in kWh per Day)	Electricity Cost (US\$ per Day)	Percentage of Income Spent on Electricity
At 10% profit margin			
Poor	0.96	0.2788	12%
Low income	1.02	0.2969	5%
At 20% profit margin			
Poor	0.96	0.3041	13%
Low income	1.02	0.3239	5%

## 5. Significance of Productive Uses of Electricity

The crucial role of the private sector in extending reliable, sustainable, and affordable electricity access to last-mile regions is already extensively discussed in literature [60–62]. However, scarce demand and impoverished community conditions that could lead to unfavorable financial returns deter investors from pursuing rural electrification projects. The economic viability of providing increased access to rural isolated communities through renewable energy relies primarily on the electricity consumption of the residents. Better returns are expected for high capital investments when demand is also high, which necessitates the active contribution of consumers in rural electrification efforts.

Rural consumers must be urged to use electricity for economic growth in order to stimulate high demand and to realize the high economic benefits of increased electricity access. Encouraging the marginalized consumers in isolated areas to engage in productive uses of electricity (PUEs) fosters socio-economic growth and motivate them to consume electricity [63–65]. However, as economic activities in these isolated communities rarely utilize electricity, the challenge of finding appropriate PUEs becomes daunting. Investors and project implementers must take this into consideration when instigating rural electrification projects, expanding their approaches to mentor the community and guide them to use electricity to generate more income and to improve their productivity. This, in turn, will generate higher electricity demand, which translates to economies of scale and favorable returns for the investors.

Increasing the access of reliable, affordable, and sustainable electricity to isolated rural communities cultivates for the improved welfare of the affected households [66]. It promotes for better education through the use of modern teaching equipment in schools and increased studying hours for students at night. It provides better access to health services. It enables gender equality as women with electricity access will now have better opportunities to earn a living, to study, or to ease the burden of domestic activities. Moreover, promoting increased electricity access and stimulating PUEs break the cycle of electricity poverty experienced by these marginalized populations [67].



## 6. Policy Implications

Despite being an early recipient of renewable energy technology, Pangan-an Island was not able to sustain their electrification system and was forced to utilize conventional electrification means after the decommissioning of the island's solar PV facility. Studies indicated that the failure to sustain this system resulted from the inability of the island residents to find more meaningful uses of electricity, merely using the increased access for lighting and household entertainment, and in defining the true cost of electricity. While the Philippine Department of Energy calls on private sector participation to increase electrification in the rural areas [13], guaranteeing the financial practicality of implementing electrification projects, especially those integrating renewable energy technologies, in poor isolated communities becomes a requisite to spur the sector into participation.

Installing microgrids while considering cleaner energy sources typically requires high capital investment that the marginalized populations usually cannot afford. It becomes essential to explicitly define the benefits that consumers expect to receive with increased electricity access for them to willingly adapt renewable energy. The implied economic benefit to consumers tends to be higher as their demand also becomes higher, but low economic status inhibits them from consuming more. It is also crucial for consumers to find suitable PUEs in order for them to improve their economic well-being, subsequently allowing them to pay for higher electricity consumption. As such, policies must be in place to encourage recipient communities to actively engage in PUEs, as electricity is made more available to them, in order to stimulate higher demand and in order to increase capability to pay for higher demand. This is clearly demonstrated in the solar PV installation in Gilutongan Island. While consumptive use of electricity has proliferated for the 11 households, it does not really provide them high economic benefits unless they found more productive uses of electricity.

The determination of implementing PUEs might prove to be a challenge for consumers who earn income without relying on electricity. Thus, it falls on those implementing the project to help the consumers find ways to use electricity for productive means. It is therefore necessary to include, in the mandate of these implementers, a program that will stimulate productive uses of electricity. Moreover, the program could focus on existing livelihood in these isolated communities and assess measures on how to "electrify" these livelihoods to encourage PUEs and improve efficiency and productivity. In most coastal communities in the Philippines, household income is highly dependent on fishing or vending, thus refrigeration could be a potential option to be explored. Water is also scarce in these communities and households source out potable water from the mainland at expensive costs such that desalination systems powered by renewable energy could also be a viable option to consider. Technological advancements and smart grid applications like broadband over powerline (BPL) and powerline communication (PLC) could also be explored further to provide increased access to telecommunications while providing electricity access through renewables in these isolated island communities. Policies integrating electricity and telecommunications could be investigated to increase socio-economic benefits and further rationalize capitalization costs.

## 7. Conclusions

Techno-economic viability studies in relation to rural electrification projects seldom capture the latter's impact on the socio-economic aspect of the communities. However, sustainability of such projects greatly relies on the crucial role that consumers play in their advancement. The study provided for a viability assessment framework that would determine not just the economic impact of rural electrification to investors but also the socio-economic outcomes to consumers. A two-phase approach was used where the techno-economic viability was assessed in the first phase and the socio-economic viability was evaluated in the second phase. Techno-economic parameters considered were levelized cost of electricity, initial capital cost, net present cost, payback period, and return on

investment. Meanwhile, economic benefit of increased electricity access and capacity to pay were considered as socio-economic parameters.

Results of the study suggest that rural electrification projects will provide better pay-offs for investors if electricity demand is high, as this results in economy of scale. Moreover, the economic benefits of increased electricity access for consumers is greater when their consumption is high. However, consumers might not be motivated to consume more electricity, especially when electricity cost is high and electricity usage is limited to lighting, household entertainment, and other consumptive uses. With low household income, the capacity to pay is compromised especially when the electricity tariff is steep. For consumers to consume more, they must be able to afford the electricity cost. As such, increasing their income-generating capacities through productive uses of electricity becomes the most pragmatic option as this allows investors to push for increased capacity and encourages consumers to use more; thereby achieving mutual benefits for the major stakeholders. Finding uses of energy that could help augment income for the users should be thoughtfully considered and should be put in place where increased electricity access is desired. Moreover, the framework presented in the paper could be useful for project implementers as well as for consumers, as this provides significant insights into the techno-economic and socio-economic impacts of increasing electricity access in off-grid communities.

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