

Article

The Power of Electricity: How Effective Is It in Promoting Sustainable Development in Rural Off-Grid Islands in the Philippines?

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Abstract: Electrification plays a crucial role in the advancement of rural communities but establishing its impact to the communities' sustainable development remains a challenge. This paper presents a pragmatic framework for assessing how electrification affects sustainable development at the grassroots level with eight indicators in the economic, technical, social, and environmental dimensions highlighted. An exploratory factor analysis approach is applied to determine how these dimensions contribute to the community's overall sustainable development. The framework is applied in two islands in the Philippines of less than 500 households and varying electrification levels. Results indicate that Gilutongan Island, which has less than 24-h electricity access rarely find productive uses of electricity and still make use of conventional fuels for lighting. Meanwhile, Cobrador Island, which has 24-h access see improvements in almost all aspects, although they are slightly burdened by the unaffordability of tariffs. This means that islands with limited hours for electricity access rarely experience positive impacts to their socioeconomic development while the opposite is true for islands with longer access. The framework can be a useful tool for decision- and policy-makers to assess electrification in rural off-grid communities and to streamline efforts in helping these communities achieve sustainable development.

Keywords: rural electrification; electricity access; sustainable development assessment; energy trilemma; multi-tier framework



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1. Introduction

Electrification is regarded as one of the most significant breakthroughs that has brought about the improvement and advancement of people's lives. The uses of electricity are seen in everyday activities such as those in communications, business, transportation, education, and domestic life. In remote areas where most people are poor, electrification is seen to alleviate poverty, increase access to basic services, and advance social systems [1,2]. The importance of electrification is echoed in the United Nations' Sustainable Development Goals with universal access to electricity and increased renewable energy adoption envisioned by the year 2030 [3]. As of 2017, there are 840 million people who are still without electricity [4]. The majority of the unelectrified population live in rural, isolated areas with marginalized economic capabilities and poor living conditions [5]. Because of these constraints, effective electrification of most of these populations rely on off-grid or decentralized systems, usually with renewable energy deployments [6].

Global efforts have been directed on energy access in unelectrified regions and international agencies have reported a slight increase in electricity access given to rural areas over the past years [7–9]. However, the pragmatic impact of these electrification systems to sustainable development still continues to be a challenge [10,11]. In some cases, systems are

limited in capacity and are incapable of meeting household demand [12–14]. In other cases, the high capitalization cost of off-grid systems, particularly those that integrate renewable energy technologies and where battery storage systems are required, results in high electricity tariffs and becomes an obstacle to implementation [15–17]. Sustainable development (SD), in this study, is defined as the principle wherein electrification systems support for the socioeconomic progress and growth of end-users by providing for adequate electricity use, affordable electricity tariffs, safe electricity use, and cleaner electricity source [18,19].

While efforts are already underway to extend electricity access to rural communities either through off-grid systems or grid extensions, it is also necessary to establish the ability of these systems to support SD [20,21]. Determining how electrification systems promote SD is a challenge for policy- and decision-makers considering the multi-faceted dimensions influencing such development. Specific to rural and isolated islands in the Philippines, electrification is challenged by proximity to the main transmission grid, poor economic conditions of residents, the perceived low demand/low capacity to pay, and the inability to find productive uses of electricity [22]. In most cases, these islands obtain roughly from 4 to 8 h of electricity from diesel generator systems running on conventional fossil fuels [23]. The promotion of SD in these small islands is not merely reliant on increasing access to electricity but more so about empowering the community and improving access to basic services [24]. Moreover, there is a need to determine, from users' perspectives, the difference between merely having electricity access and of being able to use electricity to improve their quality of life [25].

1.1. Impacts of Electrification to Sustainable Development

Energy access is already recognized as a crucial enabler of socioeconomic development and is seen to contribute to the improvement of living conditions of rural populations [26,27]. The provision of electricity to rural areas is acknowledged to have a positive impact on household activities through the increased ownership and use of appliances, reduction of fuel wood use, improved education, and improved employment [28,29]. Electricity access is also seen to improve productivity, promote gender equality, and stimulate socioeconomic growth through the promotion of productive uses of electricity [30,31]. However, while electricity access in rural areas is seen to foster socioeconomic growth in the communities, there is an inclination for positive impact to benefit communities with higher average household expenditures and with relatively higher incomes [32]. Moreover, the availability and reliability of the power supply are asserted as crucial parameters in encouraging significant and longer use of electricity among rural consumers [33–35]. Rural electrification programs fail not just because of poor design considerations and over- or under-estimation of demand but also because of weak regulatory frameworks and vague policies [36–38]. It must also be emphasized that while financial schemes have a significant impact to rural electrification due to its high capitalization, the dependence on subsidies or donations and the concept that electricity could be free should be eradicated in the cultures of rural consumers, to promote a more sustainable consumption of electricity [39].

1.2. Assessing Sustainable Development Impacts

The sustainability of electrification systems and technologies have been extensively studied in literature with sustainability indices already developed [40–42]. However, the impact of electrification systems to SD, especially from the end-users' perspective, has not been significantly explored, although analysis has been done for mini-grids in Kenya [43], renewable energy implementation in sub-Saharan Africa [44], and small-scale hydropower projects in India [45]. Thus, the development of an assessment framework for SD impacts follows closely the approaches for sustainability assessment as sustainable development is seen to be a pathway towards sustainability [46]. Sustainability assessments generally follow the monetary, biophysical, and indicator-based methods (see Figure 1) [47] with the monetary and indicator-based methods as the typical tools of choice when accounting for the social, economic, and environmental impacts of energy projects due to their flexibility in

quantifying these dimensions [48–51]. However, as sustainability evaluations now adapt a multidimensional approach, the indicator-based approach is the most preferable tool in various studies due to its ability to capture the multifaceted nature of sustainability, with both quantitative and qualitative attributes already being considered in its measurement [52–54].

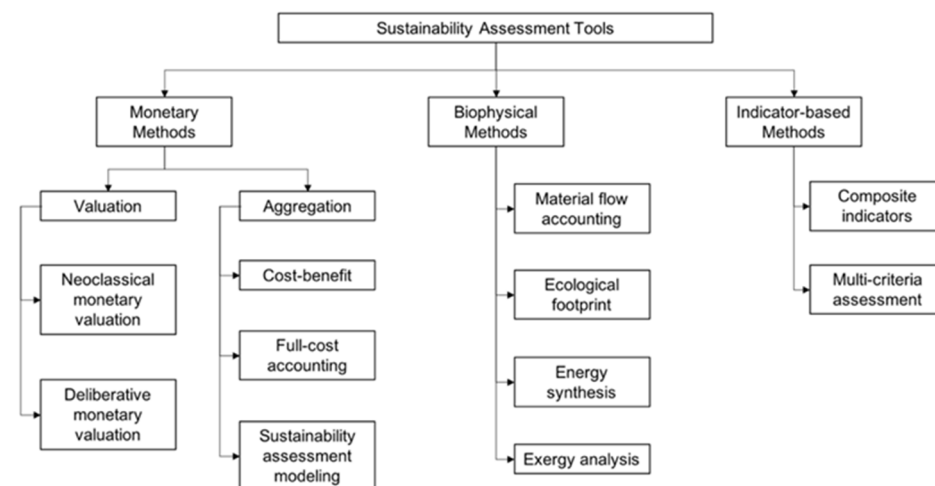


Figure 1. Categories of Sustainability Assessment Tools. Adapted from Gasparatos and Scolobig (2012) [32].

The indicator-based approach allows researchers to define attributes to sustainability that best fit the requirements of certain rural electrification projects, such as the case of hydropower projects that require indicators that uniquely influence the environmental aspect of installing hydropower plants [55]. In defining indicators, typical sustainability studies look at the triple bottom line approach considering the environmental, economic, and social dimensions [40,56–58]. These typical dimensions have been expanded over the years to consider several other factors to sustainability such as the technical and institutional aspects [59]. The study of Ilskog (2008) has provided an in-depth framework in the sustainability evaluation of rural electrification projects, covering 39 indicators in five dimensions—technical, economic, social/ethical, environmental, and institutional [60], which has already been adapted in several works [22,61].

Defining the indicators to sustainable development is crucial in developing a relevant assessment of how rural electrification projects impact the growth and development of rural communities. Indicators such as emission mitigation, adequacy of supply, reliability of supply, affordability of supply, stewardship, improvements in productivity, and institutional alignments are typically considered in studies [62,63]. Several studies have purported that some renewable off-grids become unviable and unsustainable due to high electricity charges and low demand, negatively impacting the socioeconomic development of the communities [64,65].

The studies reviewed clearly indicate that the choice of approach and framework greatly depend on the assessment goals. Moreover, the types of indicators must be carefully chosen to be able to develop a sound basis for measurement. The overarching nature of sustainable development also makes it necessary to prudently define boundaries with which the assessment is to be made in order to create a reasonable framework for evaluation. There is also a need to understand how indicators correlate with each other such that indices should not be myopic in only considering indicators according to certain dimensions. The use of multivariate techniques such as principal component analysis (PCA) is also seen as a helpful tool to address the multidimensional aspect of sustainability [54,66,67]. With compounded numbers of indicators to consider, some assessment methods require dimensionality reduction to consider only the most relevant factors to sustainability, performing factor analysis (FA) to draw out only the causal indicators of sustainability in varied industries [68–70].

1.3. The Focus of This Study

Sustainability assessments are seen to support decision-making and policy development and have become a common practice to help decision- and policy-makers develop plans and policies that will ultimately lead to sustainable development [71]. The significant role of sustainable development in electrification assessments has been highlighted in several studies as crucial in establishing the sustainability of electrification projects [72–74]. This paper draws from the different insights presented in literature about sustainability assessments and is grounded on the conclusion that no existing assessment framework has been made to determine how electrification systems impact sustainable development, particularly for rural off-grid island communities. The primary basis for this paper is the energy trilemma such that the framework and the indicators lean on the three pillars of energy security, energy equity, and environmental sustainability [75]. The framework explores the grassroots perspective of SD impact assessment and is applied in the rural, islandic setting in order to gain good insights into the ability of rural electrification systems to support developmental growth for its consumers. Specifically, this paper aims to determine the impact of electrification on the sustainable development of the community and its end users through developing a simple and pragmatic assessment framework. This assessment could be a good baseline for future rural electrification projects to ascertain the different contributing factors to sustainable development and could assist policy and decision makers in determining whether rural electrification systems contribute to the community's sustainable development. The study is further divided into subsections where the methods, conceptual framework, and sustainable development impacts framework are discussed in Section 2. The results of the assessment are discussed in Section 3. Implications to Philippine rural electrification are discussed in Section 4 of the paper and finally the conclusions of the study are discussed in Section 5.

2. Materials and Methods

2.1. Conceptual Framework

According to the World Bank, the socioeconomic development of the poor communities is the primary objective of expanding electricity access to rural areas [76]. It is considered that electricity provides the crucial factors that allow communities to achieve poverty alleviation, gender equality, good health, better education, and sustainable living. In this paper, the sustainability of electricity systems in rural and isolated areas is regarded as dependent on how these systems can help the communities and end users achieve sustainable development. Sustainable development was first proposed in the Brundtland Report to bridge environmental and human development [77]. This was then expanded by the United Nations in 2015 whereby seventeen sustainable development goals were identified, and goal 7 is to ensure access to affordable, reliable, sustainable, and modern energy for all [78]. Among the targets are ensuring universal access to modern energy services and increasing the proportion of renewable energy in the global mix by 2030.

The World Energy Council has developed an index that addresses three core dimensions to policy—energy security, energy equity, and environmental sustainability. Called the energy trilemma, it takes into consideration energy reliability and capacity, affordability, and mitigation of harmful climate change impacts [79]. The Energy Trilemma has been linked with sustainable electrification and the framework has been used in several sustainability studies and sustainable development planning in the least-developed regions [80]. Particularly among the poor in rural areas, where energy inequity is widespread, addressing the Energy Trilemma has been highlighted in the efforts to extend electricity access to isolated communities [81]. Likewise, the Energy Trilemma framework has been used in measuring national energy performance [82], in studies on mitigating energy poverty [83], and in providing sustainable power systems to islands [84].

Conventionally, a trilemma is presented as an “impossible trinity” where one goal is sacrificed in pursuit of the other two. The Energy Trilemma breaks this traditional definition and requires striking a balance to achieve all three goals. The framework to

assess the impact of rural electrification on the community's sustainable development is largely based on the three pillars of the Energy Trilemma, considering four dimensions, as shown in Figure 2. Energy security, defined as the capacity to meet current and future energy demand reliably, is linked to the technical dimension of sustainability. Energy equity, defined as the ability to provide universal electricity access at an affordable price, is linked to the economic dimension. Environmental sustainability, defined as the transition of energy systems towards climate change mitigation, is linked to the environmental dimension. At the core of these three dimensions is the social dimension, denoting that the social impact of electrification systems is central to addressing the Energy Trilemma and should be the foremost consideration for sustainable development [85]. Social acceptance, improved social services, and livelihood enhancements are consequential to sustainability and it is necessary for electrification policies to factor in these aspects [61,86]. In the context of Philippine electrification, the deliberation of the social dimension becomes necessary as rural electrification initiatives have shifted from government-initiated efforts to private sector participation [87]. This means that the future of rural electrification is now subject to private capitalization and the subsequent need for the private sector to generate profits from such projects [21]. It then becomes necessary for rural communities to realize the benefits of electrification by ensuring that such systems provide for the socioeconomic growth and sustainable development of the end-users.

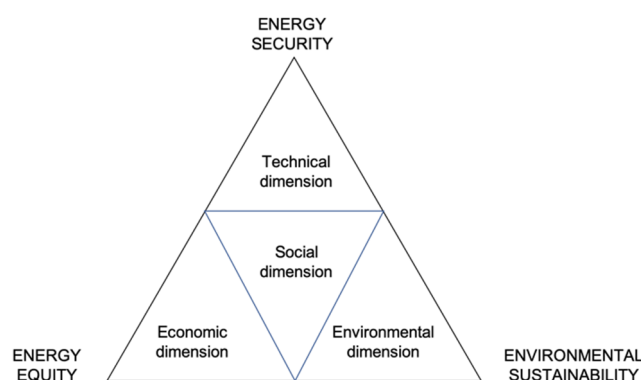


Figure 2. Conceptual Framework.

2.2. Case Environment

The analysis undertaken in this study considers the electrification systems of two case islands in the Philippines (see Figure 3) that are classified as isolated *barangays* (villages) and have experienced two different electrification levels, with different energy technologies implemented. Gilutongan Island ($10^{\circ}12'00''$ N, $123^{\circ}59'00''$ E) is an island *barangay* in Cordova, Cebu. It is currently powered by a 194 kVA diesel generator set donated by the provincial government that provides electricity to the island residents for 4.5 h every night from 6:00 P.M. to 10:30 P.M. Locals own 30% of the land while private families not living on the island own the remaining 70% [88]. Island residents pay US \$0.14 (Php 7) per light bulb connected and US \$0.16 (Php 8) per power outlet. Cobrador Island ($12^{\circ}39'40''$ N, $122^{\circ}14'21''$ E) is a *barangay* in the province of Romblon, Philippines [89]. In March 2016, the island secured 24-h electricity through a hybrid 30-kW solar photovoltaic (PV) with Li-ion battery and 15-kW diesel generator hybrid system installed through the efforts of the Asian Development Bank (ADB), Korean Energy Agency (KEA), National Electrification Administration Office for Renewable Energy Development (NEA-ORED), and the Romblon Electric Cooperative (ROMELCO) [90] with island residents paying US \$0.3 (Php 15) per kWh consumption. Prior to this system, the island obtained 8-h electricity access from a 15 kW diesel generator set operated by ROMELCO at a tariff of US \$0.6 (Php 30) per kWh.



Figure 3. Gilutongan and Cobrador islands (courtesy of Google maps).

2.3. Sustainable Development Indicators

The assessment is carried out considering the technical, social, economic, and environmental dimensions. Eight indicators are chosen and regarded as good measures of the impact of electrification to the sustainable development of isolated island communities in the Philippines. Table 1 summarizes the indicators used in this study. Affordability is seen to have a direct impact to the sustainability of electrification systems with several studies indicating that such systems fail due to expensive tariffs. In coastal communities in the Philippines where economic activities are non-reliant on electricity and where households typically earn very low income, finding economically-valuable uses of electricity becomes an important measure of sustainability. Being able to use electricity for productive means leads to increased income and subsequently to buying power and capacity to pay. Adequacy of supply, duration, reliability, and safety of service are also crucial measures as end users tend to be dissuaded to use electricity if supply is low and unreliable. Electrification systems are also seen to support sustainable development if electricity replaces conventional fuels for lighting and is sourced from renewable energy sources.

2.4. Data Collection and Treatment

Data were primarily gathered through grassroots survey with island residents as well as through on-field observations. For the survey, a sample population was surveyed for each of the two islands, computed based on Cochran's formula, modified for smaller populations.

$$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}} \quad (1)$$

where $n_0 = \frac{z^2 pq}{e^2}$, and with z at 1.96 for confidence level of 95%, margin of error (e) of 0.05, p and $q = 0.5$. Stratified sampling was done according to the island's village geographical division. Houses on the islands were numbered and the respondents were chosen randomly using these house numbers. Through close coordination with the local government units on the islands, all chosen respondents were surveyed over a period of one week per island. The sample population was computed based on household population and is shown in Table 2.

Table 1. Sustainable development indicators.

Indicator		Dimension	Definition	Measurement	References
I ₁	Adequacy of electricity supply	Technical	Ability of users to use electricity for lighting and powering up household electrical appliances	Actual electrical appliances used in the household	[33–35]
I ₂	Reliability of service	Technical	Availability of electricity service at expected times	Number of power disruptions experienced by users	[33–35,76]
I ₃	Duration of supply	Technical	Length of time electricity supply is available	Number of hours electricity is available	[76]
I ₄	Safety and security of the system	Technical, Social	Electricity has not caused accidents to human or to electrical appliances	Actual number of accidents related to electricity	[76]
I ₅	Affordability of tariff	Economic	The cost of electricity should not exceed 5% of the household's gross monthly income	Actual cost of electricity as a proportion to household gross income	[76,91]
I ₆	Support for household income	Economic, Social	Ability of users to use electricity for productive means	Number of households using electricity for income-generating activities	[92–94]
I ₇	Displacement of conventional fuels for lighting	Environmental	Users should be able to use electricity for lighting in lieu of conventional fuels	Proportion of households who no longer use conventional fuels for lighting	[91]
I ₈	Electricity source	Environmental	Renewable energy should be an alternative source of electricity	Actual sources of electricity	[76]

Table 2. Sample population per island.

Island	Total Household Population	Sample Population
Cobrador Island	244 ^a	149
Gilutongan Island	342 ^b	181

^a Household population from ADB [92]. ^b Household population based on 2017 *barangay* census of Gilutongan Island.

A survey questionnaire (see supplementary material) was designed to obtain information on the demographics of the respondents and the details of their electricity consumption. A representative from each household who is of legal age and is either the head of the family or with influential status in the household (i.e., income earner) was asked to answer the survey questionnaire. The questionnaire was reviewed a priori by the Ethics Review Committee of the academic institution to which the researchers belong. The respondents were also asked to sign a consent form, signifying voluntary participation in the survey.

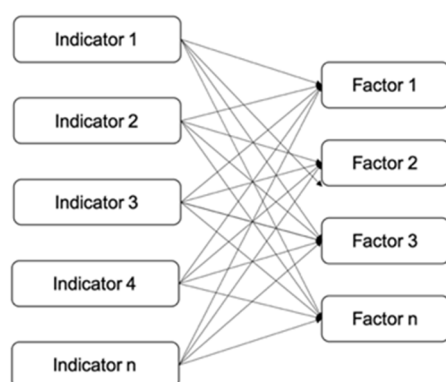
The proposed approach to data analysis is a two-step approach, where the first step measures the sustainable development impact as manifested in each household corresponding to the indicators and the second step focuses on the overall progress made towards sustainable development through a combination of these indicators. In the first step, survey results are processed and scores are assigned to each household for each indicator. A scoring matrix is shown in Table 3 where scores of 1 to 3 are assigned depending on how each household demonstrates electricity access and usage. A score of 1 designates the lowest positive impact to sustainable development and a score of 3 designates the highest positive impact to sustainable development.

Table 3. Scoring matrix for sustainability assessment.

	Indicator	Low (1)	Moderate (2)	High (3)
I ₁	Adequacy of supply	Uses electricity only for lighting	Uses electricity for lighting, TV, fan	Uses electricity for lighting, TV, fan, cooking, refrigeration
I ₂	Reliability of services	More than 3 power disruptions per week	-	At most 3 power outages per week
I ₃	Duration of supply	Less than 8 h electricity supply	Between 8 to 12 h of electricity supply	24-h electricity supply
I ₄	Safety and security of system	Accidents attributed to electricity	-	No accidents attributed to electricity
I ₅	Affordability of tariff	Electricity cost >10% of gross monthly income	Electricity cost between 5% to 10% of income	Electricity cost <5% of gross monthly income
I ₆	Support for household income	Does not use electricity for productive means	-	Uses electricity for productive means
I ₇	Displacement of conventional fuels for lighting	Still uses conventional fuels for lighting	-	No longer use conventional fuels for lighting
I ₈	Electricity source	Electricity sourced from conventional fuels	-	Electricity is sourced from conventional fuels and renewable energy sources

According to the World Bank, electricity tariff is said to be affordable if consumers spend less than 5% of their gross income on electricity bills [76]. Productive uses of electricity is measured based on the ability of the respondents to use electricity in their income-generation activities. Adequacy and reliability of supply is measured according to the actual electrical appliances used by the households, considering the number of power interruptions they experienced. Electricity as a replacement for conventional fuels is measured considering the number of respondents who still use conventional fuels for lighting despite being connected to an electrification system as opposed to the number of respondents who no longer use conventional fuels for lighting.

In the second step, an exploratory factor analysis is used to analyze the processed results. Here, all indicators considered as independent with having equal status and interdependences are identified, taking into consideration the correlation among variables and their underlying relationships. Moreover, it is the argument in this research that while indicators are arbitrarily grouped according to the dimensions they belong to, their impact to sustainable development might be better understood according to how they correlate with the other indicators outside of their arbitrary categorization (see Figure 4).

**Figure 4.** Concept of exploratory factor analysis.

Factor loadings are determined following Equation (2) and considering the Kaiser criterion where components with eigenvalues of under 1.0 are dropped:

$$s_{ai} = \sum_j \lambda_{aj} F_{ji} + \epsilon_{ai} \quad (2)$$

where s_{ai} refers to a standard score of each household for each indicator, λ_{aj} refers to the factor loading for each factor, F_{ji} refers to the factor influencing the observed variables and ϵ refers to the factor unique to a single observed variable. Results from the first step (survey) are loaded into SPSS simulation software to generate the factor loadings using principal component method for factor extraction and varimax for rotation. The factor loadings are then used to determine how each of the distinct factors of electrification influences sustainable development in the community through descriptive statistics and a comparative analysis is done for the two island cases.

3. Results and Discussion

Majority of the respondents in both islands are electrified with 94% in Cobrador and 96% in Gilutongan. The 6% of those not connected in Cobrador are primarily households that are waiting for their electricity connections to be installed. The 4% unconnected households in Gilutongan opted to have no electricity access.

3.1. Results of the Survey

Residents in Gilutongan have relatively unsophisticated use of electricity with 76% of the respondents using electricity to power TV sets or electric fans and 24% using electricity for lighting. This might be due to the limited hours of electricity availability, thereby restricting residents to use household appliances and other power tools. In Cobrador, 15% of the residents are able to use rice cookers, refrigerators, freezers and power tools. Only 3% of the residents are limited to using electricity for lighting while the remaining 82% are able to use TV sets, radios, and fans. With 24-h electricity access, residents in Cobrador are encouraged to use more electrical appliances and power tools. Figure 5 presents a one-day sample power consumption in Gilutongan and Cobrador recorded over a 24-h period in April and May 2018, respectively. It can be observed that there is higher electricity consumption during the daytime than in the night time for Cobrador, where 24-h electricity is available.

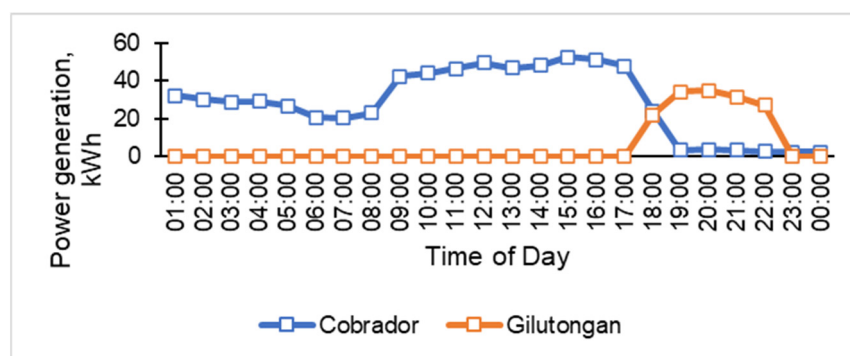


Figure 5. Sample 24-h power consumption for all households in Gilutongan and Cobrador Islands.

The electrification systems in the two case islands are fairly reliable with majority of the respondents experiencing less than three power disruptions per week. There are, however, a few respondents in Gilutongan (5%) and Cobrador (13%) who indicated that they have power disruptions for over a month. These are mostly residents who are located conspicuously far from the power supply and are the ones most affected with voltage drops or power losses when there are technical issues with the power generation system. In terms of duration, 99% of the respondents in Gilutongan indicated that they have less than 8 h

of electricity access, with most of them connected only to the communal diesel generator that provides only 4 h of electricity access every night. However, one of the households surveyed on the island has 12 h of electricity access, operating their own solar photovoltaic system when electricity from the diesel generator is no longer available. In Cobrador, 92% of the respondents have 24-h electricity access. Although majority of the residents in Gilutongan (68%) indicate that they have a fairly safe and secure electrification system, 32% report damages to electrical appliances, particularly to television sets and sound systems, due to voltage drops and sudden power interruptions. In Cobrador, residents reported a fatal accident due to electrocution while fixing the electrical distribution system.

The main source of livelihood in the two case islands is fishing (Gilutongan at 57% and Cobrador at 57%). Other sources of income are provision of manual labor or services, vending (including live seafood), souvenir selling, and shell gleaning. On average, residents in Gilutongan earn US \$4.15 per day and in Cobrador US \$5.20 per day. Interviews with residents in Gilutongan indicated that residents find the daily collection of electricity payment to be reasonable and economical considering that they earn income on a daily basis as well. In Cobrador, residents expressed that electricity tariff per kWh has significantly decreased since the installation of their hybrid microgrid, although they felt that the tariff could still be lowered such that it is comparable to the tariffs being enjoyed in the mainland. Majority of the residents in both islands pay between 5% to 10% of their gross monthly income for electricity with Gilutongan at 55% and Cobrador at 47%.

In Gilutongan, where electricity is available for only 4 h every night, majority of the respondents find that electricity has not helped in their economic activities. Only 28% for Gilutongan use electricity to generate income, albeit these uses are mostly for lighting up small vending stores at night or powering up video karaoke machines. In Cobrador, where electricity is available for 24 h a day, 79% of the residents engage in productive activities using electricity while only 21% of them do not use electricity for economic means. Upon the provision of 24-h electricity on the island, majority of the residents purchased and used refrigerators and freezers to preserve their catch or to improve small vending businesses. Other residents who engage in carpentry also made use of power tools to increase productivity. Other households ventured into selling food and beverages where they used domestic appliances such as blenders.

According to interviews with the respondents in Gilutongan, the limited availability of electricity supply has prompted 82% of them to still use conventional fuels like kerosene for lighting. In Cobrador, only 27% of the residents continue to use kerosene for lighting and most of them only use it during times when there are power interruptions. Moreover, 86% of the residents in Cobrador source their electricity only from conventional means (i.e., diesel generators) while 95% of the residents in Cobrador have a mix of renewable energy and conventional fossil fuels as sources of electricity.

3.2. Factor Analysis Results

Figure 6 presents the scree plot for both Gilutongan and Cobrador, showing that three distinct factors are extracted for Gilutongan and four distinct factors are extracted for Cobrador, with all factors having eigenvalues of greater than 1.0.

Table 4 presents the component matrix for each of the identified factors for Gilutongan with their corresponding factor loadings. Factor 1 is composed of I_3 , I_8 , and I_4 ; factor 2 includes I_7 and I_6 ; and factor 3 includes I_1 , I_2 , and I_5 .

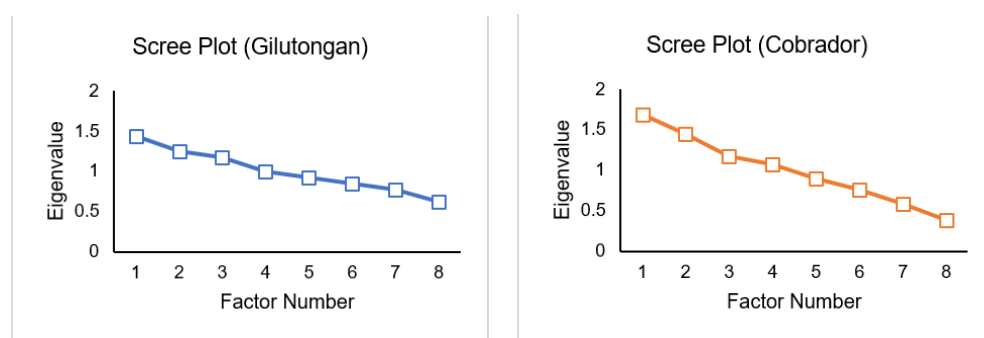


Figure 6. Scree plots for Gilutongan and Cobrador.

Table 4. Component Matrix for Gilutongan.

Indicator		Factor		
		1	2	3
I ₃	Duration of supply	0.682		
I ₈	Electricity source	0.644		
I ₄	Safety and security of electrical system	−0.471		
I ₇	Displacement of conventional fuels for lighting		0.800	
I ₆	Support for household income		0.646	
I ₁	Adequacy of supply			0.747
I ₂	Reliability of service			0.549
I ₅	Affordability of tariff			−0.525

Table 5 presents the component matrix for Cobrador for each of the identified four factors and their corresponding factor loadings. Factor 1 is composed of I₈ and I₃; factor 2 with I₁ and I₅; factor 3 with I₆ and I₇; and factor 4 with I₄ and I₂. This shows that the factors extracted for each island do not necessarily match with the typical categorization of technical, social, economic, and environmental dimensions that was previously presented in Table 1. It can be observed that duration of supply and electricity source are typically grouped together, indicating that there is an underlying correlation as manifested in the households (i.e., electricity sourced solely from diesel generators provide lesser hours of availability). It can also be observed that adequacy of supply and affordability of tariff are conventionally clustered together for both islands suggesting that there is a causal relationship between the ability to use electrical appliance with respect to supply and the electricity tariff paid by the consumers.

Table 5. Component Matrix for Cobrador.

Indicator		Factor			
		1	2	3	4
I ₈	Electricity source	0.885			
I ₃	Duration of supply	0.840			
I ₁	Adequacy of supply		0.757		
I ₅	Affordability of tariff		−0.716		
I ₆	Support for household income			0.828	
I ₇	Displacement of conventional fuels for lighting			−0.573	
I ₄	Safety and security of electrical system				−0.830
I ₂	Reliability of service				0.585

The descriptives of both islands are presented simultaneously in Table 6. Means are taken as the sustainability score for each of the factor and an average is computed for all factors to denote the overall sustainability index (OSI) of the community. Results for Gilutongan Island suggests that their current electrification system effects a low impact to sustainable development in terms of factor 1 and factor 2 and for indicators on duration,

electricity source, safety and security, displacement of conventional fuels for lighting, and support for household income. This result corroborates the findings in the survey, where majority of the households suffer from low scores in these indicators. Factor 3 scores at moderate level with 2.200 mean suggesting that electrification in the island has a moderate impact in terms of adequacy of supply, reliability, and affordability of tariffs. The overall sustainability index for the island, at 1.735, is below moderate.

Table 6. Descriptive statistics for Gilutongan and Cobrador.

Factor	Gilutongan					Cobrador				
	N	Min	Max	Mean	Std Dev	N	Min	Max	Mean	Std Dev
Factor 1	173	1.00	2.33	1.549	0.373	140	1.00	3.00	2.897	0.382
Factor 2	173	1.00	3.00	1.457	0.642	140	1.00	3.00	2.047	0.367
Factor 3	173	1.33	2.67	2.200	0.285	140	1.00	3.00	2.526	0.567
Factor 4	-	-	-	-	-	140	2.00	3.00	2.750	0.435
Average (OSI)				1.735					2.49	

Cobrador, on the other hand, demonstrates stronger sustainability indices except for factor 2 with a mean of 2.047 indicating moderate impact for the indicators adequacy of supply and affordability of tariff. This is in accordance with survey results where more than 70% of the respondents from Cobrador pay between 5% to more than 10% of their income for electricity. The island scores highest for factor 1 or for indicators on duration and electricity source since most of the residents are already connected to the hybrid diesel and solar facility and are already provided with 24-h electricity. Overall, the sustainability index for the island is moderate at 2.49, indicating that the current island electrification has comparatively contributed to the improvement in the island community's sustainable development.

4. Implications to Philippine Rural Electrification

The Philippine Department of Energy has targeted 100% household electrification by 2020 [95]. However, the goal does not explicitly state how sustainable development is factored in to the electrification of Philippine households. Providing electricity access to poor, rural communities where they are required to pay is not entirely advantageous if electrification does not uphold the socio-economic growth of these communities. A framework developed to assess how electrification systems influence sustainable development from a grassroots perspective offers a tool for policy-makers to determine how electrification policies can be crafted to support local communities and help them achieve more balanced and holistic progress.

The results of the case islands clearly indicate that communities with lower electricity access hours and with electrification systems reliant on diesel generator sets such as Gilutongan tend to fall behind in socioeconomic growth and that despite the availability of electricity supply, households still find no improvement in their socioeconomic activities. Moreover, the limited access discourages households to use more sophisticated electrical appliances and to use electricity in lieu of conventional fossil fuels. As electrification progresses to cleaner energy sources and as access increases, sustainability is also seen to improve. The case of Cobrador supports this inference, whereby residents are seen to engage in more income-generating activities through electricity consumption and move to lessen conventional fuels consumption.

Policies should then be targeted towards increasing electricity access in isolated island communities through renewable energy technologies, while also considering affordability of electricity tariff and productive uses of electricity to improve household income, thereby encouraging households to consume more electricity and to become involved in more consequential uses of electricity. The overarching nature of sustainability and electrification makes it necessary for policy makers to look at the holistic picture of electrification—not just on the mere provision of electricity access but also in making sure that the increased access brings forth social, economic, and environmental growth for the communities.

5. Conclusions

Electrification is a crucial element in achieving the global sustainable development goals. Providing electricity access to the rural, isolated communities is seen to support socioeconomic growth and development—helping to alleviate poverty, provide better education, and foster economic advancement. The sustainability of several electrification projects for rural communities has been a challenge and several projects have already failed due to a number of factors, including issues on capacity, affordability, and reliability. Sustainability assessments have already been proposed with various indicators for sustainability considered. However, there seems to be a lack of an assessment framework that addresses the sustainable development impacts of rural, off-grid electrification systems drawing from the perspective of the end users.

This paper developed a simple and pragmatic framework that could evaluate how electrification systems in small isolated islands impact sustainable development and could be a useful tool to assess how electrification systems in rural communities support the socioeconomic growth and sustainable development of the end-users. The framework is based on the three pillars of the Energy Trilemma. Eight indicators were established in the technical, social, economic, and environmental dimensions. The framework was applied in two case islands in the Philippines with different electrification systems. Results suggest that communities with limited electricity availability and sourcing electricity from conventional diesel generator sets exhibit low sustainable development scores while communities with 24-h access and sourcing electricity from cleaner energy sources tend to show higher sustainable development scores. Moreover, finding productive uses of electricity and high system capacity that sustains higher electricity consumption have direct impacts to the sustainable development of the communities. However, reliability, affordability, and environmental attributes also play crucial roles in ensuring that these two factors are achieved. In electrifying rural, isolated communities, provision of electricity is no longer enough to ensure that communities progress sustainably. Policies must be in place to support sustainable development while electrifying these communities through the increased reliable and affordable electricity supply, the use of cleaner energy sources, and the advancement of productive uses of electricity.

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