Hindawi
Journal of Engineering
Volume 2024, Article ID 3131377, 19 pages
https://doi.org/10.1155/2024/3131377

Research Article

Performance Evaluation of an Existing Renewable Energy System at Gilutongan Island, Cebu, Philippines

Khrisydel Rhea M. Supapo,[1,2] **Lorafe Lozano**,[3,4] **and Edward M. Querikiol**[1,3,5]

[1]*School of Engineering, University of San Carlos, Cebu 6000, Philippines*
[2]*Department of Electrical Engineering, Palawan State University, Puerto Princesa 5300, Philippines*
[3]*Center for Research in Energy Systems and Technologies (CREST), School of Engineering, University of San Carlos, Cebu 6000, Philippines*
[4]*Department of Industrial Engineering, School of Engineering, University of San Carlos, Cebu 6000, Philippines*
[5]*Department of Electrical and Electronics Engineering, School of Engineering, University of San Carlos, Cebu 6000, Philippines*

Correspondence should be addressed to Khrisydel Rhea M. Supapo; krmsupapo@psu.palawan.edu.ph

Received 20 February 2023; Revised 11 December 2023; Accepted 11 January 2024; Published 25 January 2024

Academic Editor: Assed Naked Haddad

Solar photovoltaics are considered the practical solution to energy access and climate change issues, especially in tropical countries that receive relatively more sunlight throughout the year. However, questions arise on the reliability of these systems in providing sufficient supply to meet the users' electricity needs. This paper looks at the reliability of a solar project installed on two rooftops on an off-grid island in Cebu, Philippines, that provides increased electricity access to 11 households. PVSyst and HOMER Pro software analyzed solar PV systems performance and techno-economics. The simulations yielded the annual mean values of reference yield, array yield, final yield, array capture loss, system loss, performance ratio, and capacity factor are 5.66 kWh/m^2/day, 3.51 kWh/kWp/day, 3.23 kWh/kWp/day, 2.15, 0.278, 57.10%, and 18.96%, respectively. The peak PV resource of 3.30 kWp/day can supply the 1.66 kWp/day of the consumer's electrical demand. It was concluded that the current installation could supply the electrical load demand of the residents; however, consideration for the potential increase in demand must be in place. While renewable energy sources are relevant in achieving 100% electrification in rural communities, their ability to address the energy demands of the users must be carefully considered in planning and design.

1. Introduction

Using renewable energy technologies (RETs) is a rational approach to address energy access in off-grid areas effectively and mitigate climate change, of which the energy sector is one of the highest contributors to carbon dioxide and greenhouse gas emissions [1, 2]. RETs have recently become a prevalent energy source, especially with the constant increase in fuel prices. According to the latest energy mix, renewable electricity generation is expected to grow by more than 8%, with hydropower providing the most significant contribution, and solar and wind are predicted to account for two-thirds of the increase [3]. The use of RE sources is perceived to (1) remove reliance on imported fossil fuels, (2) reduce greenhouse gas emissions, (3) slow the rate of environmental degradation, (4) increase green employment opportunities, and (5) provide for a solution to energy security issues [4–6]. Solar photovoltaics (PV) are gaining more popularity among renewable energy sources and are becoming the fastest-growing renewable as they have become more affordable over time [7]. It also requires less maintenance and is readily accessible, allowing anyone to customize the capacity of the PV system to meet their energy demand [8]. In off-grid communities with high solar radiation, this also proves to be the more practical choice [9], as stand-alone power systems can operate independently from the grid, provide energy security in the event of natural disasters and storms, and reduce transmission line losses

[10]. The sun continuously emits over 170,000 terawatts of solar energy onto the earth's surface—more than enough to meet the world's energy demand if appropriately collected [11]. Thus, solar PV generation systems are highly commended for their cheap operational costs, low maintenance requirements, and environmental friendliness. Despite the high initial cost of solar PV systems, there is still a growing market in many nations due to their potential economic and environmental benefits that could be realized over the medium and long term [12].

Through Republic Act No. 9136 or the Electric Power Industry Reform Act (EPIRA), the Philippines aims to promote renewable energy resources in the electrification of its rural communities, including its off-grid island communities [13]. The country has set the target to achieve 100% electrification of identified households as of the 2015 census by 2022 and 100% electrification of identified households as of the latest census by 2040, ideally using renewable energy for remote areas that are unviable to electrify through the primary grid [14]. However, adopting RETs has been relatively slow in the Philippines, despite renewable energy laws and policies enacted in the country [15]. Solar PV projects initiated in small island communities in the country typically fail after some years of operation due to financial constraints and the limited capacities of target beneficiaries [16]. Moreover, the complicated regulations and the country's growing population tend to hinder the country's expeditious adoption of RETs, especially solar renewables [17–19]. In general, poorer communities also tend to avoid RET implementations due to socio-technical barriers (lack of knowledge of adopters coupled with skepticism of the quality of technical components), economic barriers (questions on economies of scale considering high investment requirements of RETs and low-income of adopters), and policy barriers (perceived insufficiency of policy measures to support RET adoption) [20–22]. In rural areas of more progressive countries, the ecological issues brought about by RET installations (i.e., solar farms destroying nature and the problem of disposing of solar PV panels) are the main impediments to adopting RET in such communities [23].

Perhaps one of the more concerning problems of RET implementation is its ability to provide a reliable and continuous supply to meet the electricity needs in communities. Notably, a solar PV system alone is deemed insufficient and unreliable to continuously supply load demand due to its intermittent nature [24]. Thus, it is characteristic of solar PV systems to require energy storage to provide a more reliable energy source [25, 26]. However, such storage systems are still considered unreliable sources for meeting the base load demand [27]. Many have studied solar PV installation and conducted performance analyses to test the reliability and resiliency of such systems [28–32]. The performance analysis of solar PV generators is the best method to determine the potential of solar PV power production [33]. However, while most studies look at rooftop installations, no studies have considered island implementations, particularly those that serve poorer communities. Moreover, performance evaluations of renewable energy implementations, especially in the Philippines, are focused primarily on economic sustainability, policy issues, and social impacts [34–37]. To the researchers' knowledge, no substantial study has been conducted to assess the reliability of an actual RE installation on a Philippine island that ascertains the viability of RE sources to supply the electricity demand of household consumers.

This paper considers an off-grid rooftop solar PV installation serving selected households in an off-grid island community in the Philippines. The solar PV system has been operating since March 2020. Data has been gathered on the electricity demand of the households served by the system and system shutdowns over a year. Primarily, the paper aims to determine the ability of the installed solar PV energy system to supply the energy demand of the selected households on this island community. Postinstallation performance evaluation is done on the installed system, considering yield, performance, capacity, and losses. Then, a techno-economic analysis determines the optimum system size to sufficiently supply the selected households' load demand. The results of this paper provide an initial understanding of the ability of off-grid renewable energy systems to meet the household energy demand in an islandic community, which can help stakeholders to plan and design the optimal system size for such installations effectively. Moreover, the performance analysis results can offer preliminary evidence to support the country's policies on using renewable energy sources in its just energy transition policies.

2. Performance Evaluation of Renewable Energy Projects

Renewable energy, particularly solar photovoltaics, provides a clean energy source that can address energy needs, particularly in off-grid communities where sunlight is abundant and grid extensions are considered technically and economically infeasible. However, off-grid solar PV installations are usually challenged by intermittent supply due to weather conditions affecting sunlight availability [38, 39]. Solar PVs, along with other renewable energy sources, are seen to support the provision of 100% electrification. In achieving SDG 7, evaluating its capability to fully address the population's energy needs is imperative. Studies have been done in relation to its performance evaluation. Such evaluations are characteristically assessed against the International Electrotechnical Commission (IEC), where the IEC Standard 61724 serves as a basis for the technical analysis of a solar PV array. It evaluates various yield outcomes, losses, performance ratios (PR), and capacity factors (CF) [40].

A performance analysis of a 2 kW rooftop grid-connected solar PV system installed in an academic building in Serbia was conducted, where the annual specific yield factor, reference yield, performance ratio, capacity factor, and energy efficiency were determined to be 1161.704 kWh/kWp, 1390.9 h, 93.6%, 12.875%, and 11.35%, respectively. The results showed that the PV system works efficiently and that solar radiation in Serbia is enough to

generate electricity to supply a small load or to sell it to the utility grid [41]. A target-oriented performance assessment of a grid-connected solar PV system was done for a commercial building in Malaysia. It analyzed the reliability of the real-time performance of a 232.5 kWp grid-connected solar PV (GCPV) system. It achieved approximately 90% of the target yield. The annual PR, CF, system efficiency, and inverter efficiency of the system were 85.4%, 14.85%, 9.15%, and 98%, respectively. This means that the linear models of the two most important parameters (solar irradiation and PV module temperature) were statistically significant enough to predict the GCPV system's output [42].

Another real-time performance evaluation of a 7.8 kWp GCPV system was done on a rooftop solar PV installed for a residential house in Kuala Terengganu, Malaysia. The PV system's performance parameters were assessed considering a two-year energy production between 2018 and 2019. Results indicated that the PV system could generate sufficient electricity to supply the demand of the residential house and that system efficiency and PR are within the acceptable range. However, the fixed tilt angle and orientation of the installation affected the performance of the installed grid-connected rooftop PV system. Using PVSyst software, the best orientation and tilt angle were determined, and system performance was simulated. Results indicated that the annual energy production might increase by as much as 4.8%. It assumes a derating factor of 100%, which produces higher simulation-generated electricity, and found that HOMER Pro has high accuracy with an annual error of 1.7%. The discrepancy between simulation and actual performance is less if no external, uncontrollable factors occur in the existing system. The study further concluded that the GCPV system could be considered an excellent source of long-term profit for residential applications under the Feed-in-Tariff (FiT) scheme [43].

The solar potential assessment was done on the four islands of Lakshadweep in the Arabian Sea to estimate solar yield and performance parameters. The monthly average and annual average normalized performance parameters such as array yield, reference yield, final yield, array capture losses, and system losses of a 10 kWp PV system are calculated with the following results: 4.13 – 4.29 h/d, 5.78–5.88 h/d, 3.72–3.86 h/d, 1.58–1.66 h/d, and 0.41–0.43 h/d, respectively. Also, it is found that the obtained results for the annual average performance ratio and capacity factor vary in the range of 64.22–65.83% and 15.51–16.09%, respectively. The results suggest that in an islandic setting, the performance parameters of solar PV systems are well within the acceptable ranges per standards [44]. Similar performance analyses for grid-connected solar PV systems were done by [45–50], which are installed on the ground, and other site applications like rooftops of the building [51–54]. Further performance assessments compared different installed PV technologies [55–59]. Results showed that such a study significantly contributes to determining the efficiency of the PV system and is within the range of the standards of IEC 61724.

While previous studies have evaluated the performance of rooftop solar PV installations, these evaluations have primarily been conducted in urban and commercial settings. Few have been based on real-world examples of off-grid systems. This study seeks to address this gap by examining a solar PV system's technical and economic feasibility in an off-grid islandic setting. Unlike urban settings, off-grid island communities may have unique social factors, household electricity consumption patterns, weather conditions, and irradiation levels that must be considered.

The researchers selected an actual island community as a research location and conducted a single case study to evaluate the solar PV system's performance and techno-economic viability. It utilized established methods and software tools and did not propose a new approach or methodology. The findings of this paper can provide valuable insights into the potential of solar PV systems for similar remote island communities.

3. Materials and Methods

This section has four subsections: the research location, framework, performance analysis, and techno-economic analysis. The research location describes the study area, including its geographical location and the current electrification landscape. The research framework presents the study's conceptual framework, outlining the methodologies used in the analyses. The performance analysis describes the method used to assess the performance of the solar PV system, including the simulation software and the performance metrics employed. Finally, the techno-economic analysis details the methodology used to evaluate the solar PV system's technical feasibility and economic viability, including the software used, the technical specifications, and the economic indicators employed.

3.1. Research Location. The research was conducted on Gilutongan Island, Cebu, Philippines (10.2067°N, 123.9886°E), as shown in Figure 1. A 45-minute outrigger boat ride from mainland Cebu can reach it. It is an off-grid island, meaning it is not connected to the primary grid and only has four hours of electricity access provided by a 194 kVA diesel generator. The current electricity tariff is US$0.14 per bulb and US$0.16 per outlet, or approximately US$1.21 per kWh [61]. The solar PV installation on the island comprises a 7.92 kWp solar PV with a 38.4 kVA battery energy storage system and a 10 kW inverter, installed on two rooftops and serving a cluster of 11 households located in one of the subvillages on the island. The system was installed in March 2020, right before the lockdowns brought about by the COVID-19 pandemic, providing increased household electricity access. The tariff is set at US$0.40 per kWh of electricity consumed.

3.2. Research Framework. The research framework follows the input-process-output model (Figure 2). The inputs for the analysis are the hourly load data from April 2020 to March 2021, solar resource data, technical data of the existing solar PV arrays, battery storage and inverters, and economic data, i.e., the cost of the components. The input data will be used in the performance and techno-economic

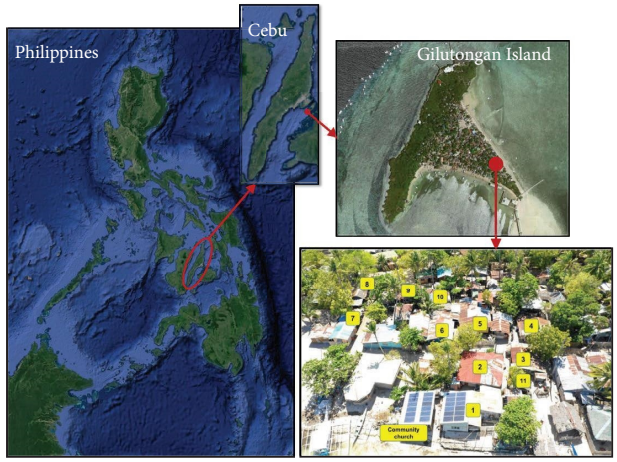

Figure 1: Research location (satellite imagery from Google Earth) [60].

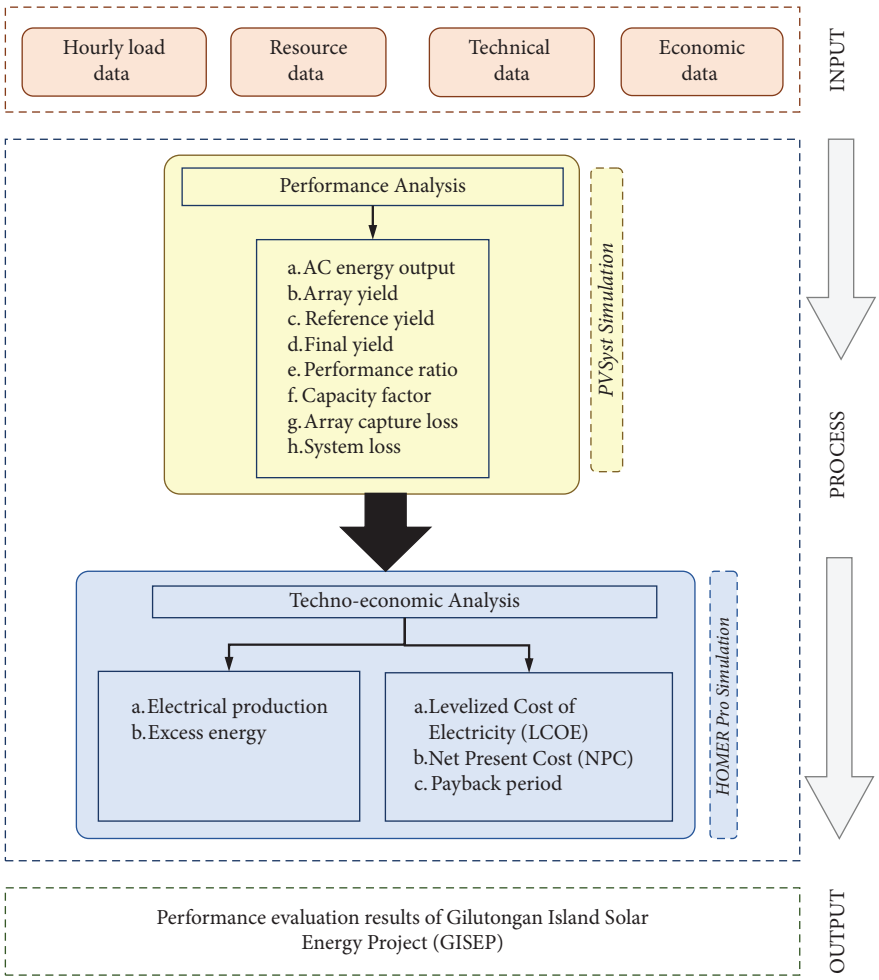

Figure 2: Research framework.

analysis of the system. The performance analysis will calculate the AC energy output, array yield, reference yield, final yield, performance ratio, capacity factor, array capture loss, and system loss. The techno-economic analysis will compute the electrical production, excess energy, levelized cost of electricity (LCOE), net present cost (NPC), and payback period. The result will be the Gilutongan island solar energy project (GISEP) performance evaluation with a battery storage system. While the approach is similar to most performance evaluation studies conducted, the

addition of the optimization of design through the techno-economic analysis becomes a relevant tool for stakeholders to create effective plans and designs for energy projects in off-grid island communities. Moreover, the performance analysis is conducted on a live solar PV installation that continuously provides electricity to selected households, thus providing real-time data on energy consumption and interruptions in an islandic setting.

3.3. Performance Analysis. The energy analysis of the PV system is an essential process that aims to evaluate the effectiveness of the Gilutongan island solar energy project (GISEP). It will help identify areas for improvement and optimize the system's design and operation. This involves assessing the system's output in terms of energy production, efficiency, and reliability over a specific period.

While the IEC 61724 standards provide helpful guidance for PV system monitoring and performance evaluation, they may not address specific considerations of unique roof-mounted PV systems or PV systems deployed in island settings. Additionally, it may not provide specific parameters or indices for quantifying self-consumed power and energy. Therefore, to evaluate the performance of roof-mounted PV systems in islandic contexts, it is necessary to complement the guidance provided by the IEC 61724 standard with additional considerations specific to these scenarios. It includes factors like specific environmental conditions, wind patterns, interruptions, and losses, among others.

3.3.1. Input Data Collection. The solar PV system installed on the island has a capacity of 7.92 kWp, providing increased energy access to 11 household beneficiaries. It was placed on two rooftops that are positioned in close proximity to the 11 residences. The PV system comprises 24 polycrystalline PV panels, each of 33 W, connected to 2 units of a 5 kW inverter with a built-in charger, and 16 units of a 200 Ah battery connected in 4 parallel strings, with each string having four batteries in series. It is assumed that the orientation and tilt angle of the PV panels are tilted relative to the rooftop arrangement. With a latitude of 10° north of the equator, the installation of solar panels is well-situated to receive sunlight throughout the year.

The electricity production data from the installed system and the end-user's energy use were collected from April 2020 to March 2021. The effect of temperature was considered, and the resource data, i.e., solar radiation, monthly average daylight hour, and monthly average air temperature for the selected island, was accessed through PVSyst software.

3.3.2. Data Analysis. The data collected were used as input data for the solar PV array to obtain the energy produced and to assess the following indices: reference yield, array yield, final yield, performance ratio, capacity factor, array capture loss, and system loss (Figure 3) [58].

(a) AC energy output (E_{AC}): It is the total AC power produced by the solar PV system over a given period, as determined by

$$E_{AC} = \sum_{t=1}^{N} E_{DC} \times \mu \,(\text{kWh}), \tag{1}$$

where t is the time in hours, N is the number of observations in the dataset, E_{DC} is the DC energy output of the system in kWh, and μ is the inverter efficiency [49, 62].

(b) Reference yield (Y_r): It is the ratio of the total in-plane irradiance (G_T, kWh/m^2) to the array reference irradiance ($G_0 = 1\,\text{kW/m}^2$). It expresses an equivalent number of hours at the reference irradiance [53, 57].

$$Y_r = \frac{G_T}{G_0} \left(\text{kWh}/m^2/\text{day}\right). \tag{2}$$

(c) Array yield (Y_a): It is defined as the direct current (DC) energy output from the PV array over a given period normalized by the PV-rated power. It represents the number of hours the PV array performs to its rated capacity (P_{rated}, kWp) [40, 47, 52].

$$Y_a = \frac{E_{DC}}{P_{rated}} \ (\text{kWh/kWp/day}). \tag{3}$$

(d) Final yield (Y_f): It is the total AC energy generated (E_{AC}) from a PV array over a defined period (day, month, or year) divided by its rated power [50, 51, 59].

$$Y_f = \frac{E_{AC}}{P_{rated}} \ (\text{kWh/kWp/day}). \tag{4}$$

(e) Performance ratio (PR): It is the ratio of the final yield to the reference yield. It serves as an indicator of the energy fed to the grid by the received irradiance. It reflects the overall losses in the system, including thermal loss, optical loss, inverter conversion loss, wire transfer loss, environmental loss, design loss, system age, and other losses when converting from DC to AC power [43, 44, 46].

$$\text{PR} = \frac{Y_f}{Y_r} \times 100\% \ (\%). \tag{5}$$

(f) Capacity factor (CF): It is the actual energy output ratio to the amount of energy generated by the PV system if operated at full-rated power for 24 h per day for a year [41, 63, 64].

$$\text{CF} = \frac{E_{AC,annual}}{P_{rated} \times 8760} \times 100\% \text{ or } \text{CF} = \frac{Y_f}{8760} \times 100\% \ (\%). \tag{6}$$

(g) Array capture loss (L_C): It is the difference between the reference yield and the array yield. It occurs as a result of the temperature rise of the cells, dust accumulation, partial shading, and inhomogeneous irradiance [45, 52, 62].

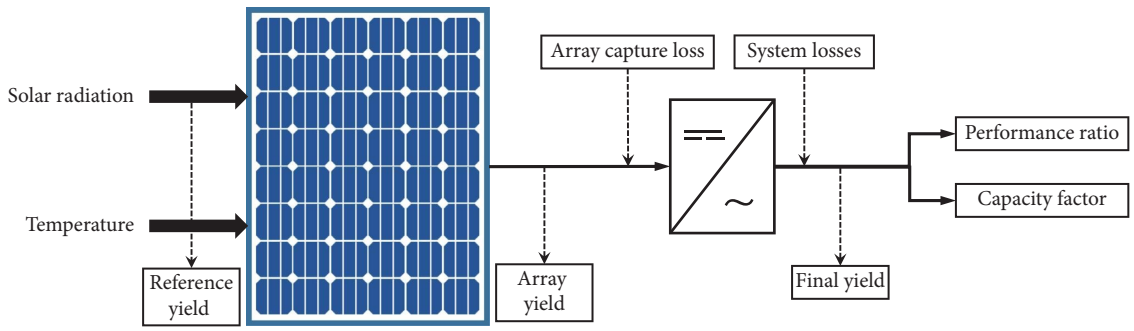

Figure 3: Solar photovoltaic system.

$$L_C = Y_r - Y_a. \quad (7)$$

(h) System loss (L_s): The difference between the array and final yields. It is due to losses in the system components, such as wiring losses, diode losses, and system aging [50, 53].

$$L_s = Y_a - Y_f. \quad (8)$$

3.4. Techno-Economic Analysis. A comprehensive evaluation of the technical and economic aspects of renewable energy projects through techno-economic analysis is crucial in assessing their feasibility and profitability. The analysis takes into account various factors, including the location of the study area, system design, equipment costs, installation and maintenance costs, electricity generation capacity, and more. Through this process, the technical design of the Gilutongan island solar energy project (GISEP) will be assessed for its reliability as a source of electricity and potential financial viability.

3.4.1. Technical Analysis. The PVSyst simulation output was utilized for further analysis using HOMER Pro software. The system architecture comprises a solar PV array with a capacity of 2–3.96 kWp, two 5 kW inverters, and a bank of 16 units of 200 Ah batteries connected in four parallel strings. Each string contains four batteries connected in series, as illustrated in Figure 4.

Table 1 presents the technical specifications and installation cost of the system under consideration. The technical specifications show the solar module's size and type of material, the number and capacity of the batteries used, the type of inverters used, and other related system components. The installation cost includes all necessary expenses during the installation and commissioning of the solar PV system, such as capital, replacement, operation, and maintenance costs. All data were then fed into the HOMER Pro software for further analysis.

3.4.2. Economic Analysis. Economic analysis is another fundamental approach to determining the financial feasibility of the PV system. Table 2 presents a detailed overview of the metric indicators used to measure the installation investment cost if it is a power-generating asset. These indicators help assess the overall economic viability by considering capital cost, net present cost, levelized cost of energy (LCOE), and payback period. Carefully evaluating these indicators will help determine the system's development, financing, and operation, ensuring that the system delivers the greatest possible value to all stakeholders.

4. Results and Discussion

This section presents a comprehensive analysis of the performance and techno-economic feasibility of the existing Gilutongan Island Solar Energy Project (GISEP). It also provides a detailed discussion of the simulation results obtained from PVSyst and HOMER Pro software. The findings of this study are expected to provide valuable insights into the feasibility and economic viability of the solar PV system, as well as its potential impact on the standard of living of island residents.

4.1. Weather Data Analysis. Weather-related parameters significantly influence the efficiency and performance of solar photovoltaic systems. These weather-related factors are essential for designing reliable and resilient solar energy systems capable of adapting to the diverse conditions posed by the natural environment.

Solar irradiance, the amount of sunlight reaching the panels, is subject to variations due to factors like cloud cover, rain, and atmospheric conditions, leading to fluctuations in energy production. From Figure 5, the minimum solar irradiation is 5.68 kWh/m^2/day in May, and the maximum is 6.08 kWh/m^2/day in October. The values of the clearness index are all less than 1, which suggests that atmospheric elements such as clouds, haze, or pollution affect the amount of sunlight reaching the solar panels.

The temperature variations impact panel efficiency, with both high and low temperatures posing challenges that can affect overall output. Figure 6 shows that the temperatures range from 23°C to 34°C, and the required or optimal operating temperature for PV panels typically falls within the range of 25 to 35 degrees Celsius. Thus, the temperature range of the GISEP is considered ideal for maximizing the efficiency and output of solar panels. Severe weather events, such as storms and hurricanes, can also compromise the structural integrity of PV systems, necessitating robust design considerations.

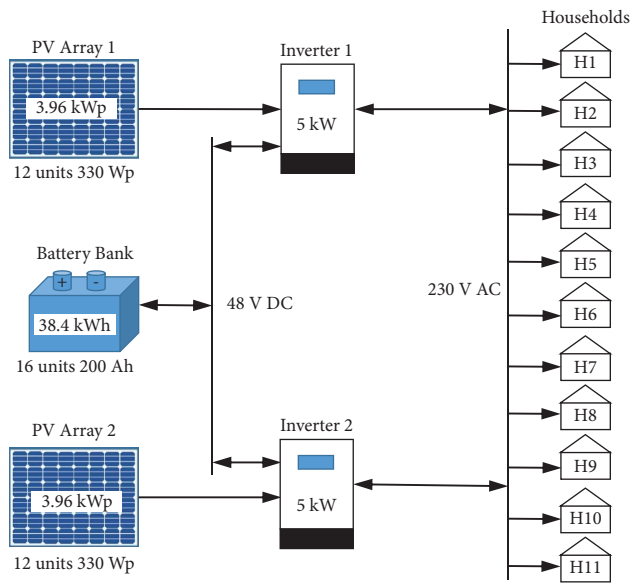

Figure 4: System architecture of Gilutongan island solar energy project (GISEP).

Table 1: Technical specifications and cost of the installed solar PV system [65].

Unit	Description	Value	Cost (US$)*		
			Capital	Replacement	O&M
Solar module	Material	Polycrystalline	$430/kW	$430/kW	$21.50/kW
	Rated maximum power (P_{max})	330 Wp			
	Open circuit voltage (V_{oc})	46.40 V			
	Maximum power voltage (V_{mp})	37.65 V			
	Short circuit current (I_{sc})	9.28 A			
	Maximum power current (I_{mp})	8.77 A			
	Temperature coefficient of I_{sc}	5.60 mA/°C			
	Operating temperature, °C	25°C			
	Lifetime	25 years			
Converter	Inverter efficiency	96%	$184/kW	$184/kW	$9.20/kW
	Rectifier efficiency	100%			
	Lifetime	15 years			
Battery	Material	Lead acid	$310	$310	$15.50
	Nominal capacity	200 Ah			
	Nominal voltage	12 V			
	Nominal energy capacity	38.40 kWh			
	Lifetime	10 years			

*Currency conversion rate during the installation is US$1.00 to PhP50.00.

Another factor included in the analysis is examining wind data to discern prevailing wind patterns. The highest average wind speed is 5.08 m/s, with minimum and maximum wind speeds of 0.59 m/s and 9.08 m/s, as shown in Figure 7, which indicates a diverse range of wind conditions. It contributes to a range of effects on solar PV systems, encompassing cooling benefits, cleaning advantages, structural considerations, and implications for energy production.

The wind direction values cover a wide spectrum of degrees, signifying varying prevailing wind directions. However, as seen in Figure 8, a wind rose displays a predominantly northeast (NE) wind direction, impacting solar PV systems with both advantages and challenges. The advantages include consistent energy capture, as solar panels are strategically positioned to maximize energy from the prevailing NE wind, ensuring stable and predictable energy output. Additionally, a consistent wind direction optimizes aerodynamic design, minimizing stress and enhancing system longevity. However, challenges may arise, such as the potential for uniform stress on solar panels due to the predominant NE wind, posing risks to their long-term durability.

Furthermore, systems optimized for an NE wind pattern face limitations in adaptability to changes in wind direction, impacting overall efficiency. Uneven cleaning, caused by the unidirectional wind pattern, may also affect panel efficiency. In summary, while an NE-dominated wind rose offers

Table 2: Economic metric indicators.

Economic indicator	Definition	Expression	Equation no	References
Net present cost (NPC)	It shows the loss or profit during the project's lifetime. It is the difference between the project's overall cost (i.e., capital, replacement, operation, and maintenance costs) and expected revenue throughout its lifetime. The positive value indicates loss, while the negative value shows a profit. The higher the value, the higher the profit or loss	$\mathrm{NPC} = (\mathrm{CTA}/\mathrm{CRF})$	(9)	[40, 43]
Total annual cost (CTA)	It is the sum of the annual capital cost of the system components, the annual cost for the replacements of the system components, and the annual operating and maintenance cost	$\mathrm{CTA} = \mathrm{CC} + \mathrm{CR} + \mathrm{COM}$	(10)	[43, 49]
Capital recovery factor (CRF)	The capital recovery factor (CRF) converts the initial investment cost to the annual capital cost	$\mathrm{CRF} = (r(1+r)^n)/((1+r)^n - 1)$	(11)	[43, 49]
Levelized cost of energy (LCOE)	It is the total cost of the generated electrical energy from the PV system in \$/kWh over its lifetime	$\mathrm{LCOE} = (\mathrm{CTA}/\sum_{h=1}^{h=8760} P_{\mathrm{load}})$ $\mathrm{LCOE} = (\mathrm{NPC}/\sum_{h=1}^{h=8760} P_{\mathrm{load}}) \times \mathrm{CRF}$	(12)	[42, 43, 49]
Simple payback period (PB)	The number of years it takes to recover the initial investment cost by earnings after interests and taxes	$\mathrm{PB} = (\mathrm{CC}/\mathrm{CES})$	(13)	[43, 57]

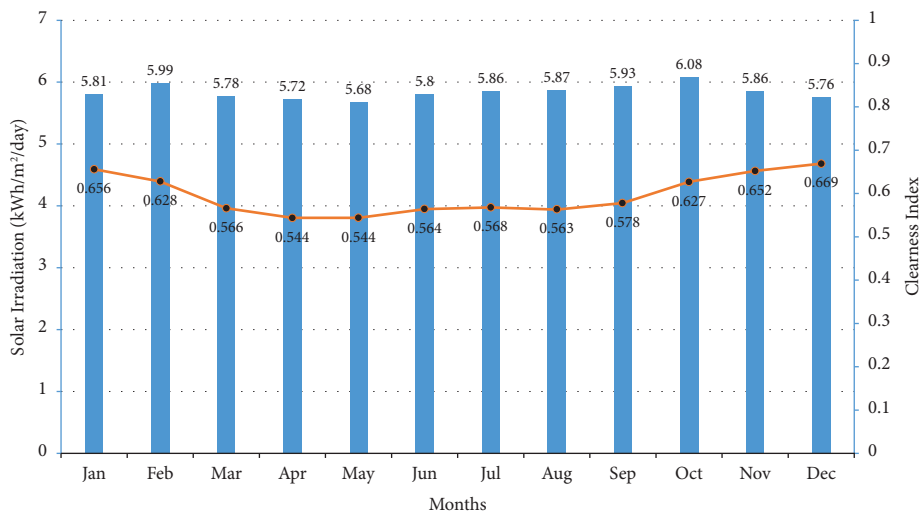

Figure 5: Monthly solar irradiation and clearness index in GISEP.

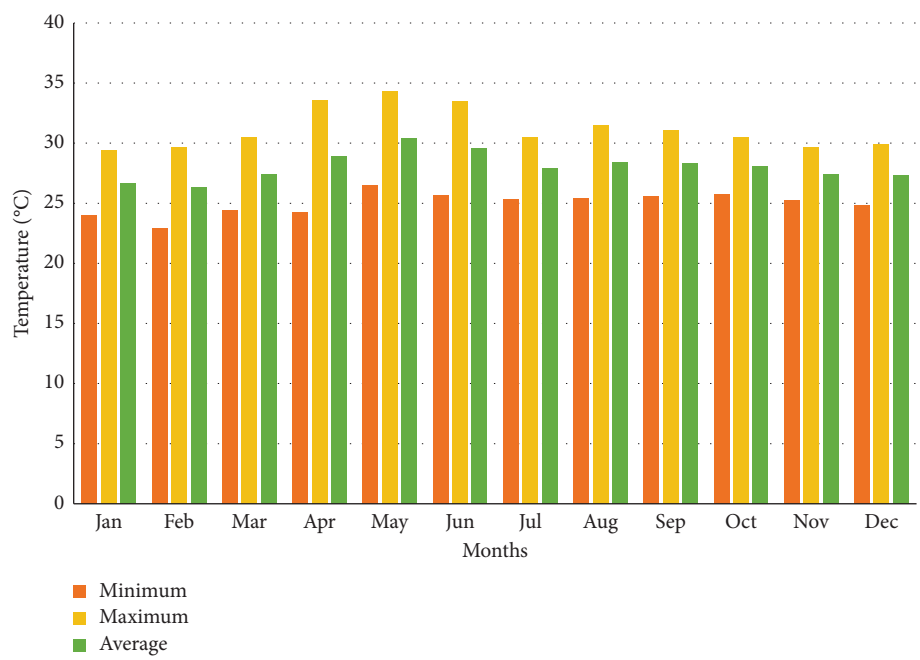

Figure 6: Monthly minimum, maximum, and average temperature variations.

energy capture consistency and design advantages, careful consideration is necessary to address challenges related to stress uniformity and system adaptability to varying wind patterns.

4.2. Performance Analysis. There are two 3.96 kWp installed solar PV panels, each having the same number of modules and strings. Still, for the simulation of the GISEP system through PVSyst software, only one system was used to represent the whole. Another input parameter used in the simulation was a 38.4 kWh battery storage. The software automatically defined the maximum power point tracking (MPPT) solar charge controllers corresponding to the PV array and battery ratings.

Table 3 shows data related to the performance of a solar PV system for each month of the year and the overall yearly performance. The data includes the amount of global horizontal and incident irradiation received and various energy outputs and demands.

The GlobHor and GlobInc columns describe the amount of global horizontal and global incident solar radiation at the collector plane in kilowatt-hours per square meter, respectively. The E_Avail represents the potential annual

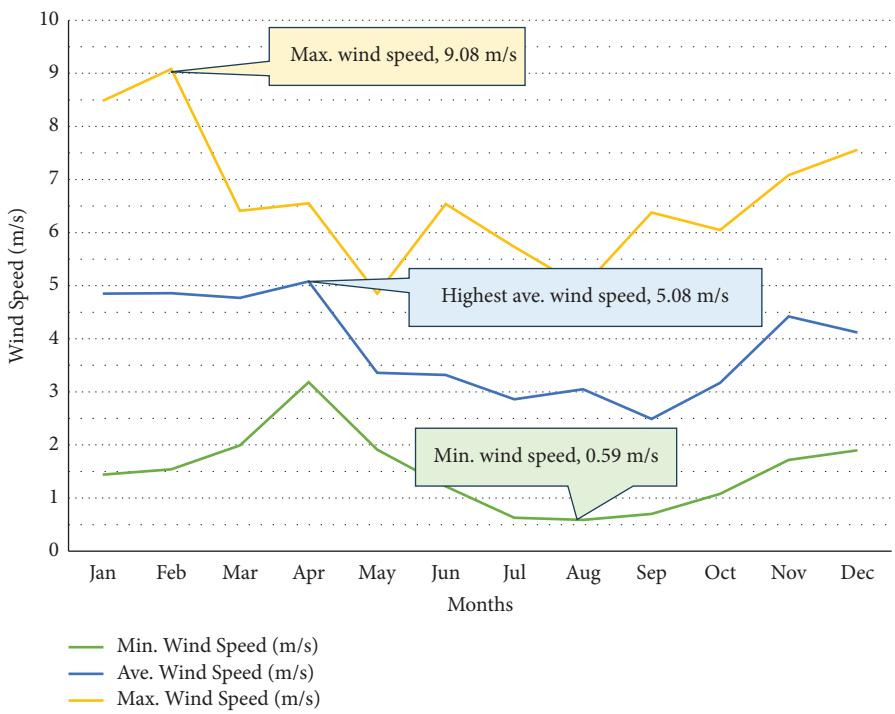

Figure 7: Monthly minimum, maximum, and average wind speed in Gilutungan island.

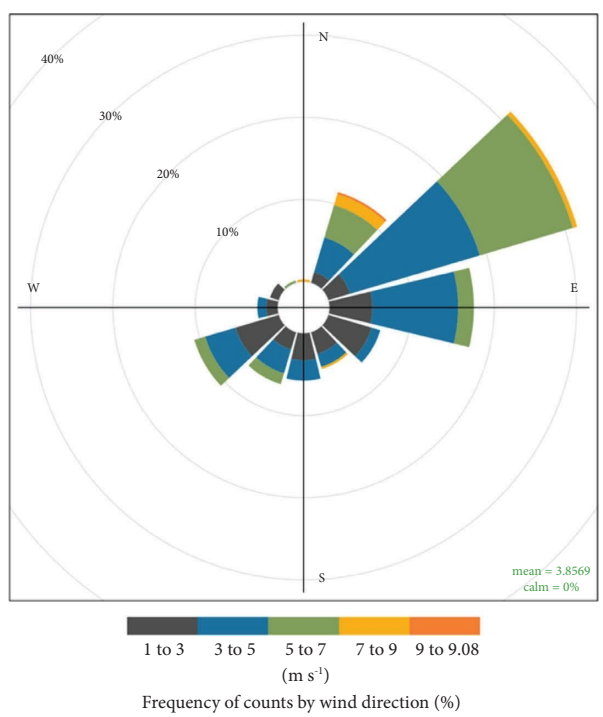

Figure 8: Wind rose in Gilutungan island.

available energy from the PV system, while the EArray represents the effective output energy of system. E_Load is the amount of energy the user needs, while E_User is the energy supplied to the user.

The EUnused is the amount of unused energy the system generates when the battery is full. The E_Miss column indicates the amount of missing energy, which is the difference between the energy demand and the supplied energy. The

Table 3: Energy production by solar PV array.

Month	GlobHor (kWh/m^2)	GlobInc (kWh/m^2)	E_Avail (kWh)	EArray (kWh)	E_Load (kWh)	E_User (kWh)	EUnused (kWh)	E_Miss (kWh)	SolFrac (ratio)
January	160.1	174.8	552.9	486.3	447.9	441.4	86.60	6.50	0.985
February	151.3	159.9	504.7	433.6	401.0	401.0	89.20	0.00	1.000
March	196.4	201.1	625.3	532.3	490.3	490.3	114.80	0.00	1.000
April	198.3	195.6	615.3	341.7	310.3	310.3	287.10	0.00	1.000
May	176.4	169.1	532.7	365.5	335.7	335.7	182.30	0.00	1.000
June	177.9	167.2	529.0	327.8	299.1	299.1	214.90	0.00	1.000
July	175.8	166.8	529.5	332.7	304.8	304.8	211.00	0.00	1.000
August	170.4	166.1	528.9	341.2	312.1	312.1	201.70	0.00	1.000
September	169.0	170.4	536.7	384.5	370.0	370.0	168.40	0.00	1.000
October	180.9	189.8	593.5	555.5	507.0	507.0	59.70	0.00	1.000
November	143.2	154.1	482.6	502.3	497.6	474.6	1.20	22.99	0.954
December	139.0	151.6	478.9	472.7	467.6	428.2	26.30	39.39	0.916
Year	**2,038.6**	**2,066.7**	**6,510.0**	**5,076.1**	**4,743.4**	**4,674.5**	**1,643.20**	**68.89**	**0.985**

The bold values in Table 3 indicate the total figures.

SolFrac shows the solar fraction ratio of the energy supplied to the user (E_User) to the energy needed by the user (E_Load).

The simulation results show that each solar PV system's potential annual available energy is 6,510 kWh, with an effective output energy of 5,076.1 kWh. However, it is important to note that various factors, such as shading, dust and dirt, reflection, spectral losses, irradiation, thermal losses, array mismatch, DC cable losses, etc., can cause a considerable decrease in energy output, as outlined in [66]. The annual energy demand of the user is 4,743.4 kWh, which is slightly higher than the supplied energy of 4,674.5 kWh, resulting in a deficit of 68.9 kWh. This deficit may be attributable to the inverter and AC cable losses, etc.

Despite the energy deficit, the solar PV system can provide the needed energy demand of the user for most months of the year. However, there are three months (November, December, and January) during which the solar PV system may not be able to meet the user's energy demands. These months are typically described as cool and dry and are associated with frequent power interruptions.

Table 4 presents the performance indices of the GISEP system. These indices evaluate the system's overall performance in terms of energy output and losses throughout the year. The reference yield (Y_r), which represents the available solar radiation on the PV module, has an annual mean value of 5.66 kWh/m^2/day. Meanwhile, the array yield (Y_a), which represents the energy output of the PV system, has an annual mean value of 3.51 kWh/kWp/day. The final yield (Y_f), which takes into account the losses in the PV system, has an annual mean value of 3.23 kWh/kWp/day.

The results show that the minimum yield outcome is in July, while the maximum yield outcome is in October. This could be due to the variations in solar radiation throughout the year. Moreover, the yearly mean array capture loss (L_c) and system loss (L_s) are 2.15 and 0.28, respectively, with November showing the highest array capture loss. These losses are attributed to several factors, such as shading, dust and dirt, reflection, spectral losses, irradiation, thermal losses, array mismatch, DC cable losses, etc.

The performance ratio (PR), which represents the ratio of the final yield to the reference yield, ranges from 40.10% to 77.80% throughout the year, with an average value of 57.10%. A high-performance ratio indicates that the PV system efficiently converts available solar radiation into electrical energy. On the other hand, the capacity factor (CF), which represents the ratio of the actual energy output to the maximum energy output, is 18.96%. This indicates that the system is generating energy at less than its maximum capacity due to the losses in the system.

The result of the simulation in PVSyst software is summarized in Figure 9 for more detailed representation and interpretation. The available solar radiation (Y_r) of two-3.96 kWp installed PV panels in Gilutongan Island has an annual average of 5.66 kWh/m^2/day. The system's potential annual available energy (E_Avail) is 6,510 kWh. However, factors such as shading, dust, and reflection can cause a considerable decrease in energy output (Y_a), which reached 3.51 kWh/kWp/day and an annual output energy (EArray) of 5,076.1 kWh.

With array capture and system losses equivalent to 2.15 and 0.28, respectively, the final yield (Y_f) becomes 3.23 kWh/kWp/day. The available annual energy supplied to the user (E_User) has decreased to 4,674.5 kWh. The performance ratio reflects the system's ability to convert solar energy into usable electricity. From the simulation, the average PR value is 57.10%, and the capacity factor is 18.96%.

4.2.1. Power Interruptions and Losses. The simulation results of the GISEP in the PVSyst software showed technical losses, as shown in Figure 10, which reveals why there is a missing energy of 1.45%, equivalent to 68.89 kWh.

A slight loss of 0.38% due to irradiance level fluctuations suggests a minor performance dip linked to variations in solar irradiance. A more substantial 12.58% loss attributed to elevated temperatures underscores the negative impact of high temperatures on PV module efficiency. Conversely, a modest positive value of 0.75% in module quality loss implies a potential improvement from using high-efficiency

Table 4: Normalized performance indices of GISEP.

Month	Y_r (kWh/m^2/day)	Y_a (kWh/kWp/day)	Y_f (kWh/kWp/day)	PR (%)	L_c (ratio)	L_s (ratio)
January	5.64	3.96	3.60	63.80	1.678	0.366
February	5.71	3.91	3.62	63.30	1.802	0.294
March	6.49	4.34	3.99	61.60	2.152	0.342
April	6.52	2.88	2.61	40.10	3.644	0.265
May	5.45	2.98	2.73	50.10	2.476	0.243
June	5.57	2.76	2.52	45.20	2.815	0.241
July	5.38	2.71	2.48	46.10	2.671	0.227
August	5.36	2.78	2.54	47.40	2.580	0.237
September	5.68	3.24	3.11	54.80	2.444	0.122
October	6.12	4.53	4.13	67.40	1.599	0.395
November	5.14	4.23	4.00	77.80	0.908	0.233
December	4.89	3.85	3.49	71.30	1.040	0.363
Year	**5.66**	**3.51**	**3.23**	**57.10**	**2.15**	**0.28**

The bold values in Table 4 indicate the average figures.

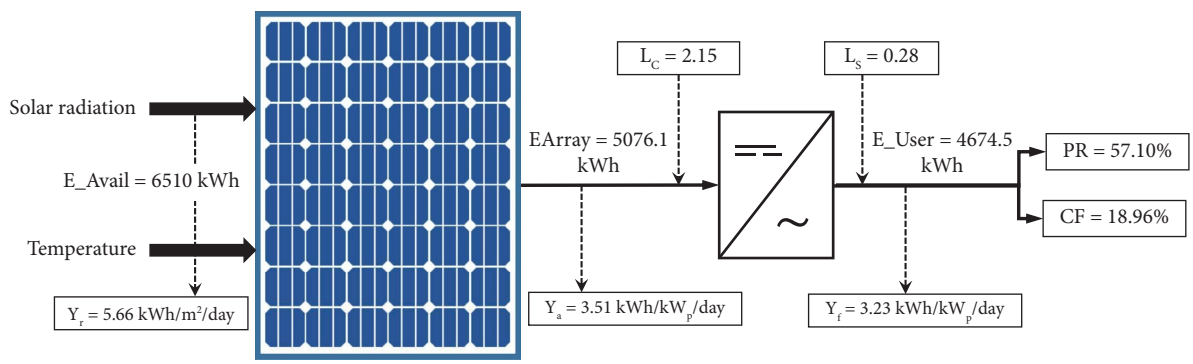

Figure 9: Solar photovoltaic system with simulation results.

or premium-quality solar panels. Mismatch losses of 2.10% point to reduced efficiency due to mismatched modules and strings, while ohmic wiring loss indicates energy output reduction from wiring resistance.

A significant 24.45% loss during battery full conditions highlights underutilized generated energy, possibly due to energy storage limitations. Converter efficiency losses during operation (4.11%) and minor losses related to power and voltage thresholds indicate areas for efficiency improvement. Energy storage efficiency loss of 2.91%, charge/discharge current efficiency loss of 2.05%, and other minor losses associated with gassing and self-discharge collectively contribute to the multifaceted nature of losses.

Addressing temperature, mismatch, and unused energy issues could enhance the overall efficiency of the solar PV system.

The actual historical records of power interruptions, detailing their frequency, duration, and causes, are documented in Table 5. In January, a short interruption of 20 minutes occurred due to cloudy conditions. Subsequent interruptions in May, June, and October were more extended, lasting 180, 300, and 300 minutes, respectively, and were attributed to inverter overheating. December stood out with 14 interruptions totaling 4500 minutes, attributed to both inverter overheating and maintenance downtime.

The analysis suggests that while cloudy conditions and inverter issues contributed to disruptions, a significant portion of interruptions in December were linked to maintenance activities. Addressing inverter-related challenges, especially overheating, and optimizing maintenance procedures are crucial to enhancing system reliability.

4.2.2. Performance Comparison of a Rooftop-Installed Solar PV System. Table 6 compares the performance of grid-tied solar PV systems in various locations that used polycrystalline silicon materials installed on rooftops. It is based on the average final yield, performance ratio, and capacity factor to determine if this study's result was on par with their results.

The average final yield represents the energy a solar PV system generates per day per kWp of its rated capacity. Based on the results, the present study on Gilutongan Island, Cebu, Philippines, has an average final yield of 3.23 kWh/kWp/day. This value is within the average final yield of other studies, which ranges from 2.55 kWh/kWp/day to 4.93 kWh/kWp/day. The highest average final yield is observed in Durban, South Africa, while the lowest is in Norway. The other locations, including Malaysia, Kiltan, Northern India, Bhubaneswar, Thailand, and Tangier, have average final yields within the range of the present study. The reason is that the amount of irradiation varies for every location, so if a country has a higher ambient temperature, the value of the final yield is much higher than that in cold countries.

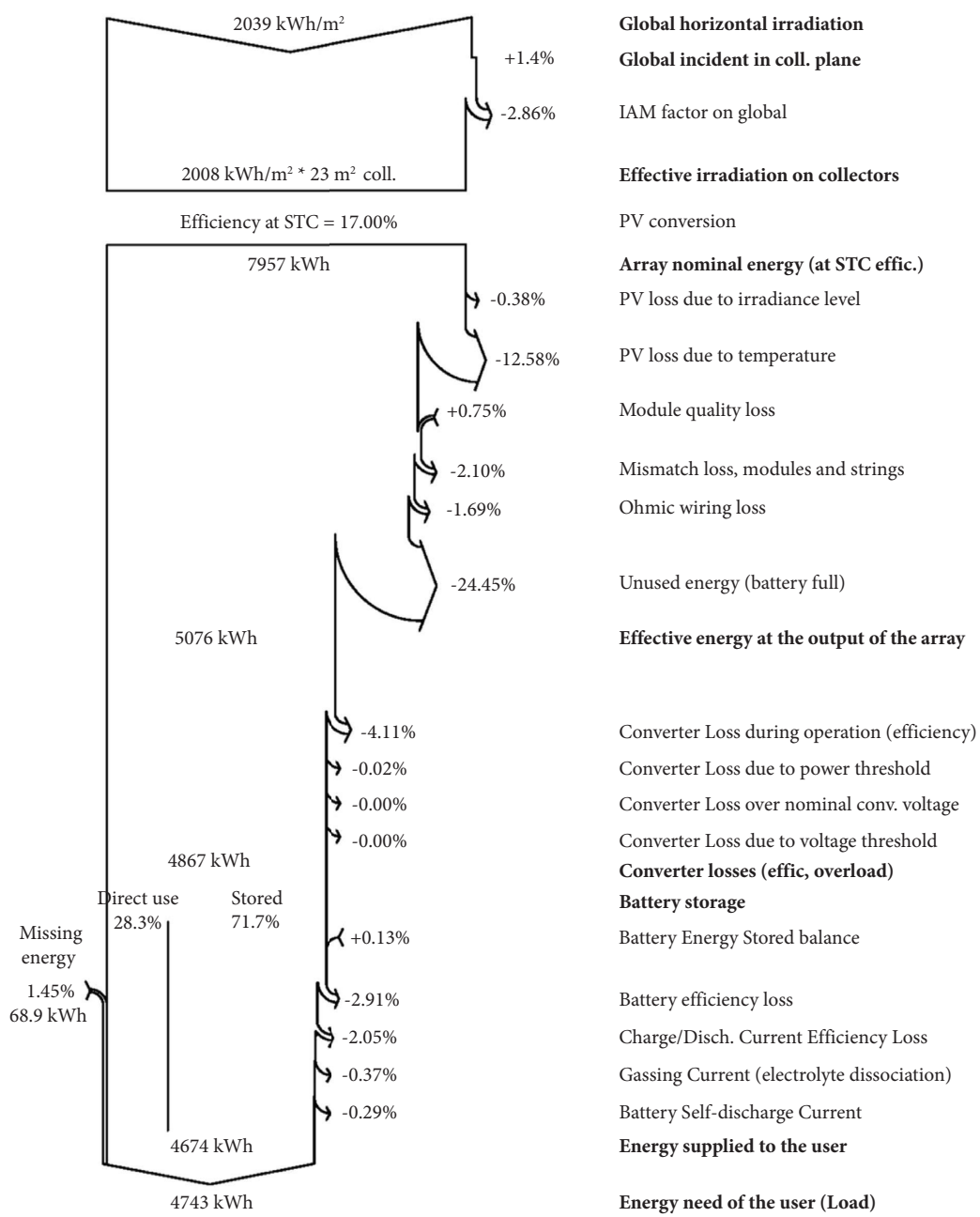

Figure 10: Simulation result of system losses.

Performance ratio (PR) is a measure of how efficiently a solar panel system converts sunlight into electricity. The table shows that the PR varies widely across the different locations, ranging from 46.08% in Malaysia to 83.03% in Norway. Durban, South Africa, has the highest performance ratio range (81.4%–93.7%) among all the locations.

The higher the performance ratio value, the more likely the solar PV system will work near its rated power. In contrast, a lower PR value implies production losses owing to technical or design issues [67]. The low PR of GISEP, 40.1%, can be attributed to the time when the project started in April 2020. Still, it can be seen that the system's performance is improving as it progresses. Typically, the PR value shifts between 0.6 and 0.8 due to the variable weather conditions, but it can go above 0.9 in colder regions [53, 67, 70]. Additionally, 60–80% PR is within the defined standard of IEC 61724 for daily irradiance of more than 2 kWh/m^2 [40].

The capacity factor (CF) is the ratio of actual energy output to the maximum possible output over a given period. It is an important metric that indicates that the system produces electricity efficiently and reliably. The CF of the different locations ranges from 10.1% to 18.96%, as the table shows. The highest capacity factor of 18.96% is observed in this study, which suggests that the solar PV system on Gilutongan Island utilizes a significant portion of its rated

Table 5: Power interruptions of GISEP.

Month	Frequency	Duration (minutes)	Cause (s)	Losses
January	1	20	Cloudy	Nontechnical
February	0	0	—	—
March	0	0	—	—
April	0	0	—	—
May	1	180	Thunderstorm with rain	Nontechnical
June	1	300	Inverter overheat	Technical
July	0	0	—	—
August	0	0	—	—
September	0	0	—	—
October	1	300	Inverter overheat	Technical
November	0	0	—	—
December	14	4500	Rain/cloudy, inverter overheat, maintenance downtime	Nontechnical, technical, nontechnical

Table 6: Comparison between this paper and other reviewed literature.

Location	Rated capacity (kWp)	Average final yield (kWh/kWp/day)	Performance ratio (%)	Capacity factor (%)	References
Malaysia (2018)	7.8	3.30	46.08–75.72	13.71	[43]
Kiltan, Lakshadweep Island, India	10	3.86	60.48–71.8	16.09	[44]
Durban, South Africa	8	4.93	81.4–93.7	10.1	[48]
Norway	2.07	2.55	83.03 (ave.)	10.58	[52]
Northern India	5	3.99	72.67–82.5	16.39	[53]
Bhubaneswar, Eastern India	11.2	3.67	56.0–87.0	15.27	[67]
Thailand	3.5	3.80	59.0–76.4	—	[68]
Tangier, Morocco	5	4.45	58.0–98.0	14.84	[69]
Gilutongan Island, Cebu, Philippines	7.92	3.23	40.1–77.8	18.96	Present study

capacity. However, it is important to note that the capacity factor can be influenced by various factors such as climate, shading, and maintenance practices. The capacity factor also depends on the location of the PV system and varies according to the received sunlight and the number of clear sunny days [71].

4.3. Techno-Economic Analysis. The PVSyst simulation was used to estimate the electrical production of the solar PV array based on the local weather conditions and other parameters. The simulation results were then used as inputs to the HOMER Pro software, which was used to analyze and compare two different system configurations for the solar PV system, as shown in Table 7.

The first system configuration is composed of a 3.96 kWp solar PV array, 5 kW inverter, and 16 units of 200 Ah battery connected in 4 parallel strings, with each string having four batteries in series. The second system configuration consists of a 2–3.96 kWp solar PV array, 2–5 kW inverter, and 16 units of 200 Ah battery with the same parallel strings.

The first system configuration can produce 6,510 kWh/yr of electrical energy, enough to supply the demand of 4,743.4 kWh/yr. Additionally, it has an excess energy of 1,570 kWh/yr. However, the likelihood of having service disruptions, which can be attributed to the intermittent availability of sunlight, should be considered to avoid power outages. Also, providing a reliable energy source to the residents could improve their standard of living, which may account for the increase in the number of electrical appliances used.

On the other hand, the second system configuration can produce 13,020 kWh/yr of electrical energy, which is more than enough to supply the demand. It also has an excess energy of 8,020 kWh/yr and a spinning reserve that can accommodate additional electrical loads, increasing the system's reliability and availability. Thus, the second system configuration is ideal because it has a spinning reserve in the event that the residents add more electrical loads or compensate for periods of low solar resources.

The techno-economic analysis also provided the net present cost (NPC), levelized cost of energy (LCOE), and payback period for each system configuration. The NPC determines the total cost of a power system over its lifetime. It takes into account all costs associated with the system, including initial installation costs, maintenance costs, replacement costs, and other expenses over the system's lifetime. In the simulation results, the second configuration has a higher NPC of US$21,223.73 compared to the first configuration, with an NPC of US$16,588.75. This means the second configuration is more expensive to install and operate over its lifetime.

The levelized cost of energy (LCOE) in the second configuration is also higher at US$0.346/kWh compared to US$0.271/kWh for the first configuration. LCOE measures the total cost of generating electricity from the system over its lifetime, including all operating and maintenance costs, discounted to their present value and divided by the total amount of electricity generated. A higher LCOE indicates higher costs per unit of electricity generated.

Table 7: Simulation results of the techno-economic analysis.

System Configurations	Electrical production (kWh/yr)	Excess energy (kWh/yr)	Net present cost (NPC) (US$)	Levelized cost of energy (LCOE) (US$/kWh)	Payback period (year)
	6,510	1,570	16,588.75	0.271	2.49
	13,020	8,020	21,223.73	0.346	3.60

Finally, the payback period, the time required for the system to generate enough savings to recover its initial costs, is 3.60 years for the second configuration compared to 2.49 years for the first configuration. This means the second configuration will take longer to break even on its initial investment.

Overall, the second configuration is more suitable despite its higher cost if additional loads are likely to be added in the future. In contrast, the first configuration may be more cost-effective in scenarios with less uncertainty regarding future loads.

4.4. Technical and Nontechnical Losses. The weather data analysis for the solar photovoltaic system on Gilutungan Island reveals crucial insights into its efficiency and performance. Solar irradiance variations, influenced by weather factors such as cloud cover and atmospheric conditions, directly impact energy production. The temperature range of 23°C to 34°C is considered optimal for panel efficiency, and the prevailing Northeast wind direction provides both advantages and challenges. While it ensures consistent energy capture and aerodynamic design benefits, challenges arise from potential stress uniformity and limited adaptability to changing wind directions.

The analysis of technical losses points to various factors affecting system performance. Addressing temperature, mismatch, and unused energy issues could enhance system efficiency. Historical records of power interruptions reveal a mix of technical and nontechnical causes, emphasizing the need to address inverter-related challenges, mainly overheating, and optimize maintenance procedures to improve system reliability.

While nontechnical losses can indeed impact the economic viability of a solar PV system, the implemented security and operational measures within the project offer a robust defense against potential financial losses. Firstly, security measures have been diligently implemented. The electrical room, housing critical components of the PV system, is situated within a fenced area and further secured in a locked room specifically designed for the project. Additionally, the PV modules are securely mounted on the rooftop within the confines of the fenced area, effectively deterring theft or unauthorized access.

Furthermore, in addressing concerns related to fraud, the installation of smart meters across all 11 houses ensures accurate measurement and consumption of electricity only by the connected households. This antifraud technology serves as a protective mechanism, minimizing the risk of fraudulent activities that could lead to nontechnical losses.

While there is no formal legal agreement in place with the households, the organization of the 11 households has been structured to facilitate internal agreements. The consensus among the households on aspects such as collection procedures and the distribution of responsibilities adds a layer of protection against legal disputes and potential financial inefficiencies.

Educational efforts have also been a focal point throughout the project's duration. Monthly meetings and capacity-building initiatives have been conducted, covering both technical and financial aspects. These educational endeavors contribute to raising awareness among stakeholders, reducing the likelihood of billing errors or disputes that could result in nontechnical losses. It is worth noting that, currently, there is no insurance coverage in place. However, the comprehensive security measures, antifraud technologies, and organizational structure implemented within the project serve as proactive measures to mitigate risks associated with nontechnical losses.

In summary, the project has taken significant steps to fortify itself against nontechnical losses through a combination of physical security measures, technological safeguards, organizational structuring, and educational initiatives. While insurance coverage may be considered for added protection, the existing measures collectively contribute to a resilient and economically sound photovoltaic system.

5. Conclusion

Renewable energy sources, particularly solar PV, are seen as pragmatic solutions to the electrification problem, especially in off-grid island communities in the Philippines. The abundance of sunlight and the ease of installation are the primary reasons why these are popular technologies in rural electrification initiatives. However, such solar PV installations suffer from intermittency due to weather conditions that affect the availability of sunlight. The problem of the ability of these systems to continuously supply the electricity demand then arises. The need to study the performance of solar PV installations in an islandic setting becomes necessary to support energy planning and design as communities strive to achieve SDG 7, Just Energy Transition, and 100% electrification.

The literature shows limited studies on the performance of solar PV plants after installation. Most studies are focused on commercial and household installations in urbanized communities. Hence, this paper conducted a performance evaluation and techno-economic analysis of an existing solar PV system installed in an off-grid island community in the Philippines. The solar PV project was launched in March 2020

as a pilot project that serves 11 households (out of 342). This paper aimed to determine if the installed system is viable in terms of reliability and resiliency. In addition, it answers whether a just energy transition using renewable energy resources can be achievable in off-grid island communities.

The performance analysis of the solar PV system, simulated using PVSyst software, indicates a potential annual available energy of 6,510 kWh. However, various factors contribute to a decrease in effective output energy, resulting in a deficit of 68.9 kWh compared to the user's annual energy demand. Despite this deficit, the system can meet the user's energy needs for most months, except for November, December, and January, which are characterized by cool and dry conditions and frequent power interruptions. Furthermore, the performance indices highlight the system's efficiency, with a performance ratio ranging from 40.1% to 77.8% throughout the year and a capacity factor of 18.96%, which is reliable and resilient to withstand various weather conditions. Hence, the analysis results were quite acceptable and within the range specified by the IEC 61724 standards.

The techno-economic analysis conducted on two different system configurations for the solar PV system on Gilutungan Island provides valuable insights into their electrical production, reliability, and cost-effectiveness. In conclusion, the second system configuration proves more suitable for the solar PV system on the island, offering greater electrical production and reliability despite higher costs. The first configuration may be more cost-effective in scenarios with less uncertainty regarding future loads. This analysis underscores the importance of considering both technical and economic factors in designing and implementing solar PV systems, ensuring optimal performance and long-term sustainability.

It is important to highlight that the study is crucially limited in its determination of electricity load, which is reliant on the current consumption of households. It fails to consider the potential increase in electricity demand, especially when households are encouraged to engage in productive uses of electricity to support the financial viability of rural electrification projects, as highlighted in several mini-grid studies in the rural setting [72–74]. While renewable energy sources, particularly solar PV, are relevant in achieving 100% electrification in rural communities and the Just Energy Transition, their ability to address the energy demands of the users must be carefully considered in planning and design. Further studies should consider the expected increase in electricity demand, particularly those that look into the productive uses of electricity. Socio-economic considerations are also significant, as rural electrification should not only address the simple lighting of households but must also improve the users' quality of life.

Nomenclature

Abbreviations and Symbols

RET:	Renewable energy technology
PV:	Photovoltaic
EPIRA:	Electric Power Industry Reform Act
SDG 7:	Sustainable Development Goals 7
IEC 61724:	International Electrotechnical Commission 61724
GCPV:	Grid-connected solar PV
FiT:	Feed-in-Tariff
GISEP:	Gilutongan Island Solar Energy Project
E_{AC} (kWh):	AC energy output
E_{DC} (kWh):	DC energy output
μ (%):	Inverter efficiency
t (h):	Time
N:	Number of observations in the dataset
Y_r (kWh/m^2/day):	Reference yield
G_T (kWh/m^2):	Total in-plane irradiance
G_0 (1 kW/m^2):	Array reference irradiance
Y_a (kWh/kWp/day):	Array yield
P_{rated} (kWp):	Rated capacity of the array
Y_f (kWh/kWp/day):	Final yield
PR (%):	Performance ratio
CF (%):	Capacity factor
$E_{AC,annual}$ (kWh):	Annual AC energy output
L_c (Ratio):	Array capture loss
L_s (Ratio):	System loss
P_{max} (Wp):	Rated maximum power
V_{oc} (V):	Open circuit voltage
V_{mp} (V):	Maximum power voltage
I_{sc} (A):	Short circuit current
NPC (US$):	Net present cost
CTA (US$):	Total annual cost
CC (US$):	Capital cost
CR (US$):	Replacement cost
COM (US$):	Operation and maintenance cost
CRF (Ratio):	Capital recovery factor
r (%):	Interest rate
n (years):	Component lifetime
LCOE (US$/kWh):	Levelized cost of electricity
P_{load} (kWh):	Hourly load demand
PB (years):	Simple payback period
CES (US$/year):	Annual cost of energy savings
MPPT:	Maximum power point tracking
GlobHor (kWh/m^2):	Global horizontal irradiance
GlobInc (kWh/m^2):	Global incident (irradiation) in the collector plane
E_Avail (kWh):	Available solar energy
EArray (kWh):	Effective energy at the output of the array
E_Load (kWh):	Energy need of the user (load)
E_User (kWh):	Energy supplied to the user
EUnused (kWh):	Unused energy (battery full)
E_Miss (kWh):	Missing energy
SolFrac (Ratio):	Solar fraction (EUsed/ELoad).

Data Availability

Data are available upon request.

Disclosure

The funders had no role in the study design, data collection, analysis, interpretation, manuscript preparation, or in the decision to publish the results.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Khrisydel Rhea M. Supapo conceptualized the study, proposed the methodology, provided a software, performed validation, performed formal analysis, investigated the study, provided resources, curated the data, prepared the original draft preparation, wrote, reviewed, and edited the study, visualized the study, and was responsible for funding acquisition. Lorafe Lozano conceptualized the study, proposed the methodology, performed validation, provided resources, wrote, reviewed, and edited the study, supervised the study, and administrated the project. Edward M. Querikiol conceptualized the study, provided resources, wrote, reviewed, and edited the study, supervised the study, and administrated the project. All authors have read and agreed to the published version of the manuscript.

Acknowledgments

The authors would like to extend their profound gratitude to the following organizations and individuals: the Department of Science and Technology-Engineering Research and Development for Technology (DOST-ERDT) for the scholarship of KRM Supapo; the University of San Carlos (USC) School of Engineering and Palawan State University (PSU) for allowing having a professional growth; to the Visayas CELL project team, University of San Carlos Center for Research in Energy Systems and Technologies (USC-CREST), and the ASEP-CELLs Project Management Office during the data gathering process; the European Union-Access to Sustainable Energy Programme (EU-ASEP) for the funding of the solar PV installation on the island; and Elorde Pastera, Jr., and Michael Ernie F. Rodriguez who extends their help as a consultant during the data analysis and validation. The European Union funded the Solar PV installation project as part of the research component of the Access to Sustainable Energy Program—Clean Energy Living Laboratories (ASEP-CELLs) project, with Contract no. 2017/392-650 of the project. The researchers shoulder the article processing charge (APC) for the publication of this paper.

References

[1] International Energy Agency, "Global energy and CO2 status report 2018," https://webstore.iea.org/global-energy-co2-status-report-2018.

[2] P. Cabrera, H. Lund, and J. A. Carta, "Smart renewable energy penetration strategies on islands: the case of gran canaria," *Energy*, vol. 162, pp. 421–443, 2018/11/01/2018.

[3] International Energy Agency, "Global energy review 2021: assessing the effects of economic recoveries on global energy demand and CO2 emissions in 2021," https://iea.blob.core.windows.net/assets/d0031107-401d-4a2f-a48b-9eed19457335/GlobalEnergyReview2021.pdf.

[4] S. Wang, L. Sun, and S. Iqbal, "Green financing role on renewable energy dependence and energy transition in E7 economies," *Renewable Energy*, vol. 200, pp. 1561–1572, 2022.

[5] J. A. Dar and M. Asif, "Environmental feasibility of a gradual shift from fossil fuels to renewable energy in India: evidence from multiple structural breaks cointegration," *Renewable Energy*, vol. 202, 2022.

[6] S. Zhang, S. Luo, and S. Afshan, "Role of climate technologies, financial development, and renewable energy in the facilitation of social, economic, and environmental goals," *Renewable Energy*, vol. 199, pp. 169–178, 2022.

[7] S. Marais, K. Kusakana, and P. Koko, "Techno-economic feasibility analysis of A grid-interactive solar PV system for South African residential load," in *Proceedings of the presented at the International Conference on Domestic Use of Energy (DUE 2019)*, Wellington, South Africa, March 2019.

[8] S. M. Shaahid, L. M. Al-Hadhrami, and M. K. Rahman, "Review of economic assessment of hybrid photovoltaic-diesel-battery power systems for residential loads for different provinces of Saudi Arabia," *Renewable and Sustainable Energy Reviews*, vol. 31, pp. 174–181, 2014.

[9] G. Zubi, R. Dufo-López, G. Pasaoglu, and N. Pardo, "Techno-economic assessment of an off-grid PV system for developing regions to provide electricity for basic domestic needs: a 2020–2040 scenario," *Applied Energy*, vol. 176, pp. 309–319, 2016.

[10] C. Ghenai and M. Bettayeb, "Modelling and performance analysis of a stand-alone hybrid solar PV/fuel cell/diesel generator power system for university building," *Energy*, vol. 171, pp. 180–189, 2019.

[11] A. El Hammoumi, S. Chtita, S. Motahhir, and A. El Ghzizal, "Solar PV energy: from material to use, and the most commonly used techniques to maximize the power output of PV systems: a focus on solar trackers and floating solar panels," *Energy Reports*, vol. 8, pp. 11992–12010, 2022.

[12] P. Choudhary and R. K. Srivastava, "Sustainability perspectives- a review for solar photovoltaic trends and growth opportunities," *Journal of Cleaner Production*, vol. 227, pp. 589–612, 2019.

[13] Senate and House of Representatives of the Philippines, "Republic Act No. 9136: an Act ordaining reforms in the electric power Industry, amending for the purpose certain laws and for other purposes," 2001, https://www.napocor.gov.ph/images/about_us/EPIRA_RA9136.pdf.

[14] Department of Energy, "Philippine energy plan: towards a sustainable and clean energy future 2020-2040," https://www.doe.gov.ph/sites/default/files/pdf/pep/PEP_2020-2040_signed_01102022.pdf.

[15] S. Lloyd and T. Nakamura, "Public perceptions of renewable energy in the Philippines," *Sustainability*, vol. 14, no. 16, p. 9906, 2022.

[16] M. A. Quirapas-Franco and A. Taeihagh, "Renewable energy adoption in poor rural areas: why communities matter," 2021, https://www.ippapublicpolicy.org/file/paper/60c1da0a0de48.pdf.

[17] R. B. Dime and E. A. E. Eviota, "Philippines," in *The Renewable Energy Law Review*, M. Hassan, Ed., pp. 155–166, Law Business Research Ltd, London, UK, 5th edition, 2022.

[18] M. A. Quirapas-Franco, "Sustainable energy transition of the poor rural communities in the Philippines," https://www.stratforumph.com/post/sustainable-energy-transition-of-the-poor-rural-communities-in-the-philippines.

[19] GIZ BMWi, "IT'S MORE SUN IN THE Philippines: facts and Figures on Solar Energy in the Philippines Project Development Programme (PDP) Southeast-Asia," https://www.doe.gov.ph/sites/default/files/pdf/netmeter/policy-brief-its-more-sun-in-the-philippines-V3.pdf?withshield=2.

[20] E. Karakaya and P. Sriwannawit, "Barriers to the adoption of photovoltaic systems: the state of the art," *Renewable and Sustainable Energy Reviews*, vol. 49, pp. 60–66, 2015/09/01/ 2015.

[21] D. Asante, J. D. Ampah, S. Afrane et al., "Prioritizing strategies to eliminate barriers to renewable energy adoption and development in Ghana: a CRITIC-fuzzy topsis approach," *Renewable Energy*, vol. 195, pp. 47–65, 2022.

[22] E. L. Meyer and O. K. Overen, "Towards a sustainable rural electrification scheme in South Africa: analysis of the Status quo," *Energy Reports*, vol. 7, pp. 4273–4287, 2021.

[23] M. Angowski, T. Kijek, M. Lipowski, and I. Bondos, "Factors affecting the adoption of photovoltaic systems in rural areas of Poland," *Energies*, vol. 14, no. 17, p. 5272, 2021.

[24] S. Baurzhan and G. P. Jenkins, "Off-grid solar PV: is it an affordable or appropriate solution for rural electrification in sub-saharan african countries?" *Renewable and Sustainable Energy Reviews*, vol. 60, pp. 1405–1418, 2016.

[25] R. H. T. Djiela, P. T. Kapen, and G. Tchuen, "Techno-economic design and performance evaluation of photovoltaic/diesel/batteries system through simulation of the energy flow using generated solar radiation data," *Energy Conversion and Management*, vol. 248, Article ID 114772, 2021.

[26] A. B. Esan, A. F. Agbetuyi, O. Oghorada, K. Ogbeide, A. A. Awelewa, and A. E. Afolabi, "Reliability assessments of an islanded hybrid PV-diesel-battery system for a typical rural community in Nigeria," *Heliyon*, vol. 5, no. 5, Article ID e01632, 2019.

[27] W. Kuo and C. Pan, "A reliability look at energy development," *Joule*, vol. 2, no. 1, pp. 5–9, 2018.

[28] J. P. Torreglosa, P. García, L. M. Fernández, and F. Jurado, "Energy dispatching based on predictive controller of an off-grid wind turbine/photovoltaic/hydrogen/battery hybrid system," *Renewable Energy*, vol. 74, pp. 326–336, 2015.

[29] K. Murugaperumal and P. Ajay D Vimal Raj, "Feasibility design and techno-economic analysis of hybrid renewable energy system for rural electrification," *Solar Energy*, vol. 188, pp. 1068–1083, 2019.

[30] M. Ramesh and R. P. Saini, "Dispatch strategies based performance analysis of a hybrid renewable energy system for a remote rural area in India," *Journal of Cleaner Production*, vol. 259, Article ID 120697, 2020.

[31] K. V. Konneh, H. Masrur, M. L. Othman et al., "Optimal design and performance analysis of a hybrid off-grid renewable power system considering different component scheduling, PV modules, and solar tracking systems," *IEEE Access*, vol. 9, pp. 64393–64413, 2021.

[32] M. Fatin Ishraque, S. A. Shezan, M. M. Ali, and M. M. Rashid, "Optimization of load dispatch strategies for an islanded microgrid connected with renewable energy sources," *Applied Energy*, vol. 292, Article ID 116879, 2021.

[33] S. Seme, K. Sredenšek, B. Štumberger, and M. Hadžiselimović, "Analysis of the performance of photovoltaic systems in Slovenia," *Solar Energy*, vol. 180, pp. 550–558, 2019.

[34] G. W. Hong and N. Abe, "Sustainability assessment of renewable energy projects for off-grid rural electrification: the Pangan-an Island case in the Philippines," *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1, pp. 54–64, 2012.

[35] P. Bertheau, J. Dionisio, C. Jütte, and C. Aquino, "Challenges for implementing renewable energy in a cooperative-driven off-grid system in the Philippines," *Environmental Innovation and Societal Transitions*, vol. 35, pp. 333–345, 2020.

[36] M. T. Castro, J. D. A. Pascasio, L. L. Delina, P. H. M. Balite, and J. D. Ocon, "Techno-economic and financial analyses of hybrid renewable energy system microgrids in 634 Philippine off-grid islands: policy implications on public subsidies and private investments," *Energy*, vol. 257, Article ID 124599, 2022.

[37] T. Urmee, D. Harries, and A. Schlapfer, "Issues related to rural electrification using renewable energy in developing countries of Asia and Pacific," *Renewable Energy*, vol. 34, no. 2, pp. 354–357, 2009.

[38] B. Akbas, A. S. Kocaman, D. Nock, and P. A. Trotter, "Rural electrification: an overview of optimization methods," *Renewable and Sustainable Energy Reviews*, vol. 156, Article ID 111935, 2022.

[39] M. Shi, X. Lu, H. Jiang et al., "Opportunity of rooftop solar photovoltaic as a cost-effective and environment-friendly power source in megacities," *iScience*, vol. 25, no. 9, Article ID 104890, 2022.

[40] P. Kumar, N. Pal, and H. Sharma, "Performance analysis and evaluation of 10 kWp solar photovoltaic array for remote islands of andaman and nicobar," *Sustainable Energy Technologies and Assessments*, vol. 42, Article ID 100889, 2020.

[41] D. D. Milosavljević, T. M. Pavlović, and D. S. Piršl, "Performance analysis of a grid-connected solar PV plant in niš, republic of Serbia," *Renewable and Sustainable Energy Reviews*, vol. 44, pp. 423–435, 2015.

[42] M. Z. Saleheen, A. A. Salema, S. M. Mominul Islam, C. R. Sarimuthu, and M. Z. Hasan, "A target-oriented performance assessment and model development of a grid-connected solar PV (GCPV) system for a commercial building in Malaysia," *Renewable Energy*, vol. 171, pp. 371–382, 2021.

[43] N. Anang, S. N. A. Syd Nur Azman, W. M. W. Muda, A. N. Dagang, and M. Z. Daud, "Performance analysis of a grid-connected rooftop solar PV system in Kuala Terengganu, Malaysia," *Energy and Buildings*, vol. 248, Article ID 111182, 2021.

[44] S. Bhakta and V. Mukherjee, "Solar potential assessment and performance indices analysis of photovoltaic generator for isolated Lakshadweep island of India," *Sustainable Energy Technologies and Assessments*, vol. 17, pp. 1–10, 2016.

[45] K. Padmavathi and S. A. Daniel, "Performance analysis of a 3MWp grid connected solar photovoltaic power plant in India," *Energy for Sustainable Development*, vol. 17, no. 6, pp. 615–625, 2013.

[46] V. Sharma and S. S. Chandel, "Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India," *Energy*, vol. 55, pp. 476–485, 2013.

[47] K. P. Satsangi, D. B. Das, S. B. Gs, and S. Ak, "Performance analysis of grid interactive solar photovoltaic plant in India," *Energy for Sustainable Development*, vol. 47, pp. 9–16, 2018.

[48] A. A. Adebiyi, I. J. Lazarus, A. K. Saha, and E. E. Ojo, "Performance analysis of 8kW grid-tied solar photovoltaic power plant in durban, South Africa," *International Journal of Advanced Research in Engineering and Technology*, vol. 10, no. 4, pp. 140–153, 2019.

[49] L. D. Mensah, J. O. Yamoah, and M. S. Adaramola, "Performance evaluation of a utility-scale grid-tied solar photovoltaic (PV) installation in Ghana," *Energy for Sustainable Development*, vol. 48, pp. 82–87, 2019.

[50] A. Al-Badi, "Performance assessment of 20.4 kW eco-house grid-connected PV plant in Oman," *International Journal of Sustainable Engineering*, vol. 13, no. 3, pp. 230–241, 2020.

[51] L. M. Ayompe, A. Duffy, S. J. McCormack, and M. Conlon, "Measured performance of a 1.72kW rooftop grid connected photovoltaic system in Ireland," *Energy Conversion and Management*, vol. 52, no. 2, pp. 816–825, 2011.

[52] M. S. Adaramola and E. E. T. Vågnes, "Preliminary assessment of a small-scale rooftop PV-grid tied in Norwegian climatic conditions," *Energy Conversion and Management*, vol. 90, pp. 458–465, 2015.

[53] S. K. Yadav and U. Bajpai, "Performance evaluation of a rooftop solar photovoltaic power plant in northern India," *Energy for Sustainable Development*, vol. 43, pp. 130–138, 2018.

[54] S. Thotakura, S. Chandan Kondamudi, J. F. Xavier et al., "Operational performance of megawatt-scale grid integrated rooftop solar PV system in tropical wet and dry climates of India," *Case Studies in Thermal Engineering*, vol. 18, Article ID 100602, 2020.

[55] S. Edalati, M. Ameri, and M. Iranmanesh, "Comparative performance investigation of mono- and polycrystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates," *Applied Energy*, vol. 160, pp. 255–265, 2015.

[56] A. M. Humada, M. Hojabri, H. M. Hamada, F. B. Samsuri, and M. N. Ahmed, "Performance evaluation of two PV technologies (c-Si and CIS) for building integrated photovoltaic based on tropical climate condition: a case study in Malaysia," *Energy and Buildings*, vol. 119, pp. 233–241, 2016.

[57] A. Allouhi, R. Saadani, T. Kousksou, R. Saidur, A. Jamil, and M. Rahmoune, "Grid-connected PV systems installed on institutional buildings: technology comparison, energy analysis and economic performance," *Energy and Buildings*, vol. 130, pp. 188–201, 2016.

[58] P. Ramanan, K. K. Murugavel, and A. Karthick, "Performance analysis and energy metrics of grid-connected photovoltaic systems," *Energy for Sustainable Development*, vol. 52, pp. 104–115, 2019.

[59] D. A. Quansah, M. S. Adaramola, G. K. Appiah, and I. A. Edwin, "Performance analysis of different grid-connected solar photovoltaic (PV) system technologies with combined capacity of 20 kW located in humid tropical climate," *International Journal of Hydrogen Energy*, vol. 42, no. 7, pp. 4626–4635, 2017.

[60] Asep-Cells, "University of san Carlos Visayas CELL inaugurates first solar photovoltaic project at gilutongan island," https://asepcells.ph/2020/04/22/university-of-san-carlos-visayas-cell-inaugurates-first-solar-photovoltaic-project-at-gilutongan-island/.

[61] L. Lozano, E. M. Querikiol, M. L. S. Abundo, and L. M. Bellotindos, "Techno-economic analysis of a cost-effective power generation system for off-grid island communities: a case study of Gilutongan Island, Cordova, Cebu, Philippines," *Renewable Energy*, vol. 140, pp. 905–911, 2019.

[62] D. Atsu, I. Seres, and I. Farkas, "The state of solar PV and performance analysis of different PV technologies grid-connected installations in Hungary," *Renewable and Sustainable Energy Reviews*, vol. 141, Article ID 110808, 2021.

[63] B. Shiva Kumar and K. Sudhakar, "Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India," *Energy Reports*, vol. 1, pp. 184–192, 2015.

[64] E. Kymakis, S. Kalykakis, and T. M. Papazoglou, "Performance analysis of a grid connected photovoltaic park on the island of Crete," *Energy Conversion and Management*, vol. 50, no. 3, pp. 433–438, 2009.

[65] J. Lacea, E. Querikiol, and E. Taboada, "Balancing energy trilemma using hybrid distributed rooftop solar PV (DRSP)/Battery/Diesel microgrid: a case study in gilutongan island, cordova, Cebu, Philippines," *Energies*, vol. 14, no. 21, p. 7358, 2021.

[66] Jim Bruce, "10 solar PV system losses–how to calculate solar panel efficiency," https://diysolarshack.com/10-solar-pv-system-losses-their-impact-on-solar-panel-output/.

[67] R. Sharma and S. Goel, "Performance analysis of a 11.2 kWp roof top grid-connected PV system in Eastern India," *Energy Reports*, vol. 3, pp. 76–84, 2017.

[68] A. Chaita and J. Kluabwang, "Performance evaluation of 3.5 kWp rooftop solar PV plant in Thailand," in *Proceedings of the International MultiConference of Engineers and Computer Scientists 2016*, Hong Kong, March 2016.

[69] K. Attari, A. Elyaakoubi, and A. J. E. R. Asselman, "Performance analysis and investigation of a grid-connected photovoltaic installation in Morocco," *Energy Reports*, vol. 2, pp. 261–266, 2016.

[70] T. D. A. Growitz, S. Kurtz, J. L. B. Cruz, E. Riley, and C. Hansen, *Weather-Corrected Performance Ratio*, National Renewable Energy Laboratory (NREL), Golden, CO, USA, 2013.

[71] M. Shravanth Vasisht, J. Srinivasan, and S. K. J. S. E. Ramasesha, "Performance of solar photovoltaic installations: effect of seasonal variations," *Solar Energy*, vol. 131, pp. 39–46, 2016.

[72] E. Hartvigsson, J. Ehnberg, E. O. Ahlgren, and S. Molander, "Linking household and productive use of electricity with mini-grid dimensioning and operation," *Energy for Sustainable Development*, vol. 60, pp. 82–89, 2021.

[73] E. van Hove, N. G. Johnson, and P. Blechinger, "Evaluating the impact of productive uses of electricity on mini-grid bankability," *Energy for Sustainable Development*, vol. 71, pp. 238–250, 2022.

[74] T. van Gevelt, T. Zaman, F. George, M. M. Bennett, S. D. Fam, and J. E. Kim, "End-user perceptions of success and failure: narratives from a natural laboratory of rural electrification projects in Malaysian Borneo," *Energy for Sustainable Development*, vol. 59, pp. 189–198, 2020.