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Design of a Solar Photovoltaic System for an Engineering Building of a State College in the Philippines

Myrine Ysobelle Sioco *

Camarines Norte State College, Camarines Norte, Philippines

RESEARCH ARTICLE

Abstract

This study aims to design a solar photovoltaic power generation for the Engineering Building of Camarines Norte State College (CNSC). The present electrical system and consumption patterns were assessed to create a suitable system. The estimated daily energy consumption of the Engineering Building, taking a safety factor of 1.3, is 98.592 kWh and was used to size the solar photovoltaic (SPV) power system to meet this demand. A trial version of PVsyst v7.4.6 was used to determine the acceptability of two PV systems: off-grid and on-grid. Results show that on-grid has a higher performance ratio (82.3%) than off-grid (52.5%). This suggests that the on-grid converts more solar radiation into usable energy more efficiently than the off-grid system. The economic viability of the systems was determined; the net present value (NPV) of the on-grid over its life span of 25 years is ₱4,457,373.79, with a return on investment (ROI) of 268% and a payback period of 4.93 years. Also, on-grid had a positive net present value (NPV), revealing that it is economically feasible as it requires a lower cost, a higher ROI, and a shorter payback period—and is thus recommended for adoption by the Engineering Building of Camarines Norte State College.

Keywords: economic evaluation, engineering building, photovoltaic system, solar

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***Corresponding author**
myrineysobellesioco@yahoo.com

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1 INTRODUCTION

The electricity demand is rising due to population growth and urbanization. This creates a challenge for energy production while raising concerns about environmental impact. Fossil fuels, the traditional energy source, contribute significantly to greenhouse emissions [1]. The United Nations emphasizes that non-renewable sources account for over 75% of these emissions [2]. This reliance on fossil fuels created a need for clean and sustainable energy alternatives. Renewable energy sources, particularly solar and wind power, offer a promising solution. These clean and sustainable options generate electricity without releasing harmful greenhouse gases [3]. Maka and Alabis [4] highlight solar energy as an environmentally friendly technology that produces high-quality energy, contributing to energy independence and sustainable development. The public support for renewable energy is strong, with solar energy emerging as a favorable option due to its abundance and minimal environmental impact.

Educational institutions are significant energy consumers, accounting for an estimated 15% of global energy consumption [5]. This presents a unique opportunity for implementing renewable

energy solutions. Several studies have explored the potential of solar energy in educational settings. Studies by Hanus et al. [6] suggest that schools can meet up to 75% of their electricity needs with solar panels, similar to the findings of Dada and Popoola [7] and Dare et al. [8] who point out solar power's ability to reduce electricity cost. Al-Najideen and Alrwashdeh [9] further emphasize the advantage of solar power as a clean, renewable energy source that lessens dependency on fossil fuels and greenhouse gas emissions. Existing projects like Makati's public school solar initiative demonstrate the effectiveness of such implementations. The project achieved an impressive 88% reliance on solar power for electricity consumption, significantly reducing dependence on the traditional grid [10]. These initiatives demonstrate the potential for solar energy in educational settings.

The solar photovoltaic system can be designed in two primary configurations: grid-connected and off-grid. Grid-connected systems connect directly to the utility grid, while off-grid systems can operate independently. According to Chaar [11], off-grid PV system comprises solar charging, PV modules, storage batteries, and controls, while the on-grid PV system, according to Adfarati and Bansal [12], comprises a bi-directional inverter, PV panels, a smart meter, a DC bus system, and an AC bus. However, integrating solar energy with the existing grid can be challenging. Solar power is variable and unpredictable, potentially causing voltage and frequency fluctuation in the grid [13]. Adherence to specific technical and safety regulations is crucial for grid interconnection. These regulations may involve islanding prevention, reactive power management, and grid code compliance. The Energy Regulation Commission Resolution establishes specific requirements for this connection, guaranteeing safe and dependable operation to prevent damage to the grid and equipment and allowing solar PV systems in the Philippines. These requirements include the requirement that the system's voltage level at the connection point maintain the same level as the distribution utility's system, that the frequency operates at 60 Hz, and that the facility be adequately protected under all operating conditions, regardless of whether the interconnected generation is operating or not [14].

Camarines Norte State College (CNSC), a government-funded school in the Philippines, strives to become a premier higher education institution. Due to this, infrastructure expansion and investment in new equipment have increased electricity consumption. Efficient energy supply is essential for academic institutions to fulfill their core missions of teaching, research, and community service [15]. Additionally, monitoring and managing energy consumption patterns in university settings is crucial. Adopting a solar PV system offers CNSC significant long-term benefits. Solar energy presents a viable solution, especially considering the operational hours of educational buildings, coinciding with peak sunshine periods [16]. The system's ability to generate clean energy on-site can dramatically reduce reliance on grid electricity, leading to substantial cost savings over the system's lifespan (typically 25 years). This translates to a lighter financial burden on the college's operational budget. Furthermore, solar energy boasts a clean footprint, minimizing greenhouse gas emissions, particularly carbon dioxide, a major contributor to climate change. This aligns perfectly with CNSC's commitment to sustainability and the Renewable Energy Act 2008 (RA 9513).

The benefits of this study extend beyond just cost savings and environmental impact. The solar PV system can be a valuable educational tool for engineering students. They can gain hands-on experience with solar energy principles, system components, data monitoring, and energy management practices. This will foster a deeper understanding of renewable energy technologies and prepare students for future careers in the clean energy sector. Additionally, a solar PV system on campus is a constant reminder of the importance of renewable energy and environmental responsibility. This can raise awareness among students, faculty, staff, the local community, and future researchers about embracing clean energy solutions. Moreover, a solar PV system offers CNSC a unique opportunity for cost savings, environmental benefits, and valuable educational experiences. However, a crucial aspect is that a single, generic solar power generation system design won't be optimal for all educational institutions. Building characteristics, energy consumption patterns, and local regulations are significant in designing the most suitable system [17]. Therefore, a site-specific assessment was essential to ensure the system is designed to meet the specific needs of each building.

This study focuses on designing and assessing the feasibility of an SPV power generation system for the Engineering Building of CNSC. The research will encompass site assessment, system design, and economic evaluation. This study utilized simulation software and CNSC's electricity bill data for design reference. At the same time, the study excludes system implementation and installation, environmental impact assessment, and carbon footprint reduction calculations. By designing an SPV system specifically for the Engineering Building of CNSC, this research will contribute to the college's commitment to sustainability and lessen its environmental impact. Additionally, the findings of this study can serve as a valuable resource for other educational institutions considering implementing an SPV power generation system. This research also aligns with the objectives of RA 9513, or the Renewable Energy Act of 2008 in the Philippines, which promotes the development and utilization of renewable energy sources like solar to lessen dependence on fossil fuels and foster sustainable development. The data utilized for this study is limited to CNSC's energy consumption for the year 2023.

2 METHODOLOGY

Camarines Norte State College, located at F. Pimentel Avenue, Daet, Camarines Norte, Philippines, has a coordinate position of 14°06'33" N latitude and 122°57'66" E longitude. It has a total area of 8.4213 hectares and comprises the CNSC Main Campus, which includes the Eco Athletic Field. The Main Building of the Engineering was considered in this study as a scope; it consists of two floors with 17 classrooms, two offices, and four comfort rooms. It has a total area of 1,728 m^2 and is a 5-year-old building.

2.1 Research Method

A descriptive research design was employed to design the solar SPV power generation system. This approach aimed to characterize the current state of the college's energy consumption and electrical system.

2.2 Research Procedure

The research procedure involved a step-by-step process for designing the SPV system.

2.2.1 Site Assessment

This initial phase assessed the suitability of the Engineering Building for solar power generation, considering factors like solar irradiance, shading analysis, and local climate conditions.

2.2.2 SPV Technology Selection

Following the site assessment, appropriate SPV equipment was selected based on efficiency, cost, and performance criteria. This included selecting panels, inverters, and mounting systems.

2.3 Data Collection

The Camarines Norte State College (CNSC) Engineering Building does not have individual metering devices. Hence, an alternate method was used to determine the building's energy usage profile. The data needed on the energy consumption of the Engineering Building heavily relies on the study of Afifa et al. [18]. Following approval from the CNSC president, the researcher collected data from various offices. This includes a formal letter requesting permission to collect data such as the electrical plan, roof plan, and electric bill. Unstructured interviews with concerned officials were conducted to gather data on electrical energy consumption, the electric bill structure, the roof structure, and the existing electrical system (including service entrance equipment).

2.4 Data Analysis

The data collected underwent the following analysis.

2.4.1 Evaluation of Existing Electrical System

This involved examining the CNSC's service entrance equipment and analyzing the electric bill to determine service connection details and monthly electrical consumption. These factors are crucial for designing a grid-interactive (on-grid) PV system.

2.4.2 Site Survey

A site survey was conducted to assess potential shading impediments and determine the usable roof space for the SPV system installation. This survey also examined temperature, sun irradiation, and roof area to assess the viability of SPV power generation and calculate the appropriate system size.

2.4.3 Energy Demand Assessment

This assessment was essential for designing the SPV system to meet the Engineering Building's energy requirements. To determine the building's load, the study by Afifa et al. [18] adopted that the energy consumption in a classroom without artificial lighting was 15.8 kWh/m^2. This assumption was used due to the building's absence of individual metering devices. The average daily load (A_{DL}) Energy consumption was then calculated, as seen in (1).

$$A_{DL} = \frac{\textit{Annual Energy Consumption}}{\textit{Number of Months} \times 30\ \textit{days}} \quad (1)$$

where,

- A_{DL} - average daily load energy consumption in kW/day
- *Annual Energy Consumption = Annual Consumption of CNSC x Area of the CNSC x 15.8 kW/m^2/year*.

A formula incorporating a 1.3 system loss factor [19] was then used to determine the total energy required by the system, shown in (2).

$$\textit{Total Energy Required} = A_{DL} \times 1.3 \quad (2)$$

2.4.4 Designing the SPV Power Generation System

The solar panel system's design was based on the total energy required for the Engineering Building. The researcher considered various types of solar panels, including monocrystalline, polycrystalline, PERC, and thin-film.

2.4.5 Panel Sizing

To determine the number of PV modules needed based on factors like system losses, market availability, and the month with the lowest solar irradiance, the equation (3) was used,

$$\textit{Total Number of PV Modules} = \frac{\textit{Total Energy Required}}{\textit{Energy Output of One SPV Panel per Day}} \quad (3)$$

where,

Energy Output of One SPV Panel per Day Is the month with the lowest solar irradiance (kWH/m^2) per day times the solar array area (m^2) times the cell efficiency.

The effective roof area for solar module installation was calculated using the appropriate formula for the specific roof area shape (rectangular or trapezoidal). The number of panel assembly rows for the single-pitch roof was determined using (4) considering row spacing of 0.6m and setback requirements of 0.254m [20], [21].

$$\textit{No.of Rows per Panel Assembly} = \frac{\textit{Effective Roof Width} - \textit{Setback}}{\textit{Module Length} + \textit{Row Spacing}} \quad (4)$$

The number of modules per row was calculated with a module spacing of 0.03 m. Finally, the total number of modules was obtained by summing the modules per row.

2.4.6 Inverter Sizing

Inverter selection considered all appliances' maximum electrical load consumption when operating simultaneously. A safety factor of 1.2 was incorporated [22]. According to the Department of Energy [14], the grid-tie inverter is the type of inverter used in net metering, and the following parameters should be considered in selecting a grid-tie inverter: output voltage, phase, and frequency, efficiency, inverter strength, and resistance. The study emphasizes avoiding single-phase inverters in grid-tied systems, citing Khan [23]. The size and number of inverters were calculated [24] as seen in (5), with an additional formula for finding the optimal PV array combination.

$$No.of\ Inverters = \frac{Size\ of\ the\ PV\ System \times 1.2}{Rated\ Power\ of\ Inverter\ (kW) \times Inverter\ efficiency} \quad (5)$$

To find the optimal combination for the PV array, equations (6), (7), and (8) were used.

$$Min.no.of\ panels\ in\ series\ in\ each\ string = \frac{Min.MPP\ voltage\ of\ inverter\ (V)}{MPP\ voltage\ of\ PV\ panel\ (V)} \quad (6)$$

$$Max.no.of\ panels\ in\ series\ in\ each\ string = \frac{Max.MPP\ voltage\ of\ inverter\ (V)}{O.C.voltage\ of\ panel\ (V)} \quad (7)$$

$$Max.no.of\ string\ per\ inverter = \frac{Max.dc\ input\ of\ inverter\ (A)}{S.C.current\ of\ PV\ panel\ (A)} \quad (8)$$

2.4.7 Cable Sizing and Safety Disconnects

The importance of appropriate cable sizing for safety and system efficiency was stressed, referencing Alejo [25]. The inclusion of two safety disconnecting switches (DC and AC) was also emphasized by Greentech Renewables [26]. A DC isolator selection consideration based on the maximum voltage and current of the panel string was explained by referencing Zhu [27]. Each module's interconnection conductor's ampacity must not be less than the total of the single fuse's rating, 125 percent of the short-circuit current from the other parallel-connected modules, and 115 percent of the open circuit voltage (NEC 690.80). To comply with NEC 690.10, the circuit conductors between the inverter output and the building or structure disconnecting mechanism must also be developed depending on the output rating of the inverter [26]. To prevent electrical plants inside fire compartments or buildings from becoming activated during an emergency, all DC conductors of a PV system must be able to be disconnected from all other conductors in a structure building, as stated in Article 690 of the NEC [28].

2.5 Acceptability Evaluation

The design's acceptability was evaluated using the performance ratio to ascertain whether the solar PV power generation system was feasible. PVsyst v7.4.6 simulation software was used to test the design's performance ratio. The software's built-in weather data was employed for the simulations for the specific location (CNSC). This data is sourced from Meteonorm 8.1 and encompasses a timeframe from 2016-2021. While this historical data provides a valuable representation of weather patterns, it's important to acknowledge that it might not perfectly capture potential variations in future weather conditions. The solar panel's specific tilt angle and orientation were 12 degrees, and the azimuth used was 174.9 degrees. The possible shading analysis was determined using PVsyst. While specific solar panel and inverter models might be chosen for final implementation, the initial design phase utilized the software's built-in generic models for these components. This approach allows for a preliminary assessment without introducing bias

towards specific manufacturers. The generic models were selected based on their specifications aligning with the component requirements.

2.6 Economic Viability Evaluation

The economic viability evaluation of the solar PV power generation system was assessed through a life cycle cost (LCC) analysis considering the initial purchase cost, operation, and maintenance expenses. This evaluation determined factors like return on investment (ROI) and payback period.

The formula for the payback period is the total system cost minus the value of incentives, which is all over the cost of electricity and annual electricity usage. The total system cost is the cost of the material and the system installation. The net present value is divided by the total system cost to find the ROI. The specific formula used for LCC is provided in (9).

$$LCC = \textit{Initial Cost} + \textit{Operation and Maintenance Cost} \quad (9)$$

3 RESULTS AND DISCUSSIONS

3.1 The Present Electrical System of Camarines Norte State College

The Camarines Norte Electric Cooperative (CANORECO) provides energy to the Main Campus of CNSC. The college's distribution line is a 230 V, 60Hz, three ∅ wye-delta utility supply supplied by CANORECO [29] from the 13.2 kV utility grid. The entry point of the CNSC features a single major metering system that measures the institution's overall electricity usage. The main service entrance equipment is crucial for maintaining functionality and safety. The primary shutdown point for the CNSC is a load break switch, which enables safe disconnection in the event of an emergency or maintenance. When an unanticipated voltage spike from lightning or another transient threatens to harm delicate equipment, a surge arrester protects it. As the final line of defense, the power fuse is ready to cut off excessive current and avoid potential hazards.

The voltage is stepped down using a 2 MVA wye-delta transformer, and to ensure critical loads remain operational during power outages, an automatic transfer switch (ATS) transitions power from the grid to a 1 MVA generator. However, the generator may not always meet peak demand. The low voltage switchgear (LVSG) supplies several feeders and branch circuits. The Engineering Building is connected to a 200 AT three-phase circuit breaker, part of a larger 2000 AT branch of the LVSG, providing an additional layer of security.

Implementing an on-grid SPV system within a single metering presents several challenges. According to Rammell Law [30], these challenges include inconsistent policies, complex permitting processes, grid integration issues, and inadequate incentives. This can delay the project and increase costs, as institutions must navigate varying regulations that govern renewable energy installation. The existing infrastructure can also limit the amount of power produced and integrated from the installed SPV system [31]. In CNSC's case, the single metering system poses an additional challenge compared to institutions with dedicated solar meters, allowing net metering benefits.

3.2 Energy Consumption

Figure 1 is the monthly electrical energy consumption and electric bill of CNSC. As shown, there is a big gap between the electric bills in the last quarter for 2022 and 2023, while their electrical energy consumption is not that far apart. These appear to be some rate fluctuation.

Table 1 shows the monthly electricity rate for low voltage for 2022 and 2023, averaging Php 13.5059 per kWh and Php 11.9067 per kWh, respectively. The computation of the feed-in-tariff price depends on the distribution utility's generation charge, which is determined by the monthly blended generation cost [14], [24].

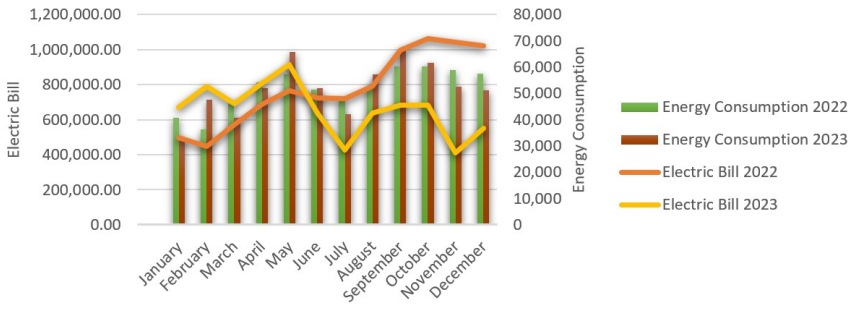


Figure 1. Energy Consumption and Electric Bill of CNSC

Table 1. Monthly Electricity Rate for Low Voltage (CANORECO)

Month	Rate (Php/kWh)	
	2022	2023
January	10.4393	16.0135
February	10.4942	15.4116
March	10.8083	14.6226
April	11.8160	14.2390
May	12.3125	13.5671
June	12.7705	11.7603
July	13.9429	9.9053
August	13.8896	10.6698
September	15.7691	9.7802
October	16.3856	10.3348
November	16.9690	6.9685
December	16.4734	9.6081
Average	**13.5059**	**11.9067**

According to CANORECO [29], the sudden rise in electricity rates during the last quarter of 2022 was brought on by an increase in the blended generation charge, which is a pass-through expense paid to power suppliers such as Therma Luzon, Inc. due to the ongoing increase in fuel costs.

Managing energy consumption to align with the solar generation profile can be challenging, as solar energy production is variable and unpredictable. While the long-term savings from reduced electricity bills can be substantial, the upfront investment for solar PV systems can pose a barrier, necessitating exploring financing options and potential incentives.

3.3 Design of Solar PV Power Generation System in the Engineering Building of CNSC

3.3.1 Site Survey

The monthly average solar global horizontal irradiance (GHI) of CNSC, located at 14°06′33″ latitude and 122°57′66” longitude, was collected from NASA's Prediction of Worldwide Energy Resource Power using the HomerPro (21-day free trial). As shown in Figure 2, there has been a change throughout the year. The month with the highest irradiance is April, with 6.970 kWh/m^2/day, while the month with the lowest irradiance is December, with 3.770 kWh/m^2/day. It shows that the average annual irradiance is 5.38 kWh/m^2/day. This data aligns with the findings of Sybauco et al. [24], who highlight the importance of considering local resource availability when designing

SPV systems.

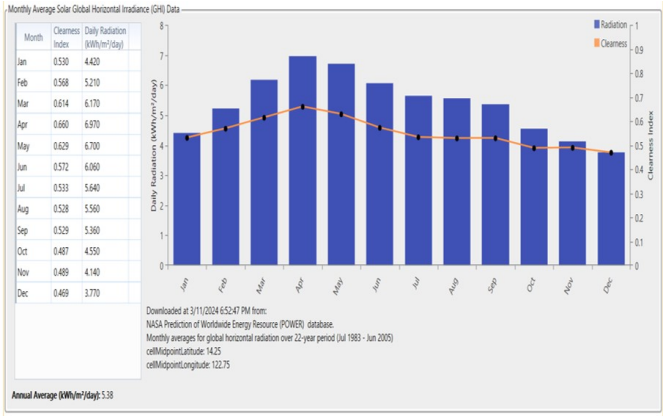


Figure 2. Monthly Average Solar Global Horizontal Irradiance of CNSC

Figure 3 shows the monthly average temperature of CNSC; it shows that the hottest month is May, with an average temperature of 28.66°C, while the coolest month is January, with an average temperature of 25.48°C. The annual average temperature of CNSC is 27.21°C.

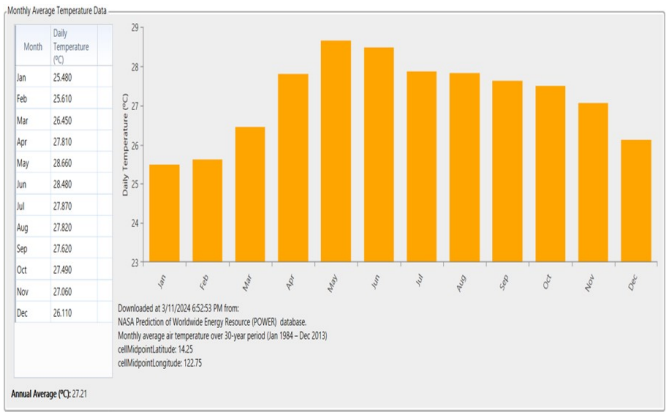


Figure 3. Monthly Average Temperature of CNSC

The data demonstrates a direct relationship between temperature and solar irradiance. Furthermore, Shrestha et al. [32] report that increasing solar radiation raises air temperatures, while Guerra Vega [33] notes that temperature and irradiance have a major impact on PV module efficiency. Additionally, a module's ability to generate more power grows with irradiance since it produces a larger current, according to Commercial Solar Electric Systems [34] . Al-Najideen and Alrwashdeh [9] also stated that solar radiation can affect the design of solar PV and energy consumption, according to Buni et al. [35].

The Engineering Building's roof was made up of a galvanized iron (G.I.) sheet with a steel truss structure and parapets, as shown in Figure 4, which presents a favorable configuration for solar panel installation, as confirmed by Si [36]. Flat roofs like G.I. sheets are generally considered ideal for solar panel mounting due to their ease of installation.

The entire amount of shortwave terrestrial irradiance a surface receives that is horizontal to the ground is known as Global Horizontal Irradiance (GHI) [24]. According to Global Solar Atlas v2.9, the average yearly GHI of Camarines Norte State College (14°06′33″ latitude and 122°57′66″ longitude) is 1818.2 kWh/m^2 with an average air temperature of 27.4°C. The ideal tilt for PV modules is 12/180°, the global tilted irradiation at the ideal angle is 1847.5 kWh/m^2, and the specific photovoltaic power output is 1466.3 kWh/kWp.



Source: Google Earth

Figure 4. Roof Area of Engineering Building

3.3.2 Energy Demand Assessment

Based on studies by Afifa et al. [18], the researcher estimates that a classroom in a tropical nation without artificial lighting uses 15.8 kWh/m^2. The researcher developed this assumption because the Engineering Building lacks individual metering devices to measure its electrical consumption and is primarily used during the day. The building was also well-ventilated, with large windows allowing natural ventilation to flow freely, an efficient energy-saving measure.

With a total area of 1, 728 m^2, the two-story Engineering Building's annual electrical energy usage is 27, 302.40 kWh based on the 15.8 kWh/m^2/year assumption. Consequently, considering the 1.3 safety factor, the average daily energy consumption based on the assumptions of 12 months and 30 days is 75.84 kWh/day; therefore, the total energy needed is 98.592 kWh. The energy needed determines the equipment selection for the solar PV power-producing system and the system building design.

3.3.3 Design of Solar Photovoltaic Power Generation

The design considers the lowest solar radiation month (December) for system capacity. It shows that seventy-seven monocrystalline 340 Wp solar panels are required to generate the power the Engineering Building needs.

The effective roof area for installing solar PV modules for the Phase 1 roof of the Engineering Building was 482 m^2. Hence, there are four rows per panel assembly; the number of panels per row is 26, 29, 32, and 34 modules. Taking into account the number of modules from the first to the third row with a potential number of 87 modules, there are three rows required, and if additional solar PV is needed, there are 44 more solar PV that can be installed in the Phase 1 roof of the Engineering Building as reference to Figure 4. The dimensions and distances on the roof are shown in Figure 5, which includes a 0.8 m setback to the array from the roof edge for the working space, allowing the technician to operate efficiently during maintenance.

The inverter chosen and used in this study was a three-phase string inverter, 15 kW. The minimum number of PV arrays in the series is six to 18 to be connected to each inverter string, and the maximum number of strings to be connected to each inverter is 4. Five (5) – thirteen (13) PV arrays are interconnected in series, and one (1) twelve (12) PV array. The 13 PV array in series gives a total PV voltage output V_{oc} of 600.6 V, total voltage at maximum power V_{mp} of 492.7 V, total PV output current I_{mp} of 8.97 A and the short circuit current I_{sc} of 9.48 A. The 12 PV array in series had a total V_{oc} of 554.4 V, total V_{mp} of 454.8 V, total PV output current I_{mp} of 8.97 A, and a short circuit current I_{sc} of 9.48 A, which means the inverter can the handle the output per array.

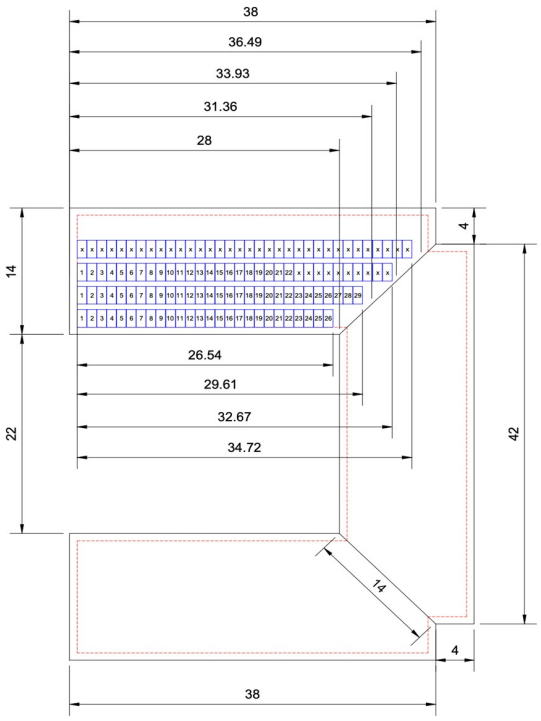


Figure 5. Roof Assembly Layout of Solar Panel for the Phase 1 of the Engineering Building

The two 15 kW inverters are paralleled to each other, each with three strings connected. 20 AT, 1000 V, 2P, DC isolators (each) were used to safely isolate the PV system during maintenance and to safeguard the premises, and a 100 AT, 230 V, 3P, AC isolator.

Gor [37] states that government laws require DC cables to have a minimum area of 4 sq mm. Consequently, the researcher DC cables with a minimum area of 4 sq. mm from the PV array to the DC isolator and 38 sq. mm from the inverter to the AC load.

Additional factors for the on-grid setup should include installing a bi-directional meter, a renewable energy certificate (REC) meter, a rapid shutdown switch, and anti-islanding equipment. At the same time, a REC meter calculates the energy produced by solar PV, and a bi-directional meter records both incoming and leaving electricity, same with the study of Santos [38], which employs a bi-directional meter. In an emergency, such as a fire or downed power line, a rapid shutdown required by the PEC was necessary to add safety. In contrast, anti-islanding protection automatically turns off to prevent accidentally restoring a disconnected grid section and posing a safety risk. These features are required to guarantee that the on-grid solar PV system operates safely, effectively, and compatible.

3.4 Acceptability of the PV Design

PVsyst v7.4.6 simulator software was used to determine the acceptability of the design. The simulation runs under the azimuth parameters of 174.9°; the tilt angle is set at 3.6° considering the slope of the roof of the building and the coordinates of 14.11°N and 122.96°E.

3.4.1 On-Grid

The monthly normalized production of the simulated on-grid solar PV system is shown in Figure 6, which shows that April and May result in high normalized energy production. Despite high production, a significant collection loss is also attributed to high temperatures. Solar panels are less efficient at converting sunlight into electricity when they get too hot. However, the produced

useful energy and system loss were low in November and December, most likely because those months are significantly shorter than summer days.

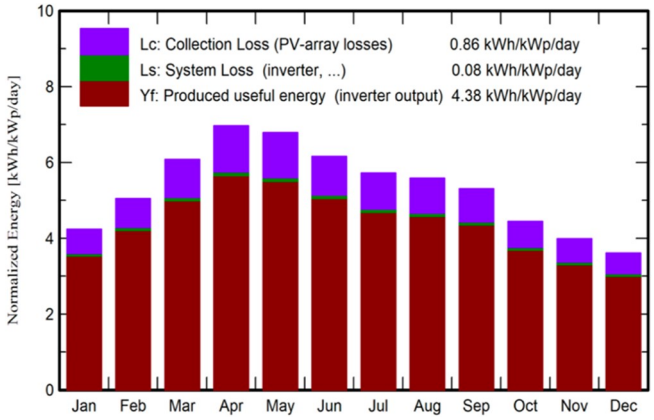


Figure 6. Normalized Production of On-Grid Solar PV System

As depicted in Figure 7, the simulated on-grid solar PV system's monthly performance ratio revealed that the average annual performance ratio is 0.823, indicating the system is efficient. Additionally, it shows the amount of energy generated by the off-grid solar PV power-producing system. According to Baqir [39], a power factor of 0.7 to 0.9 indicates that the system is operating in good condition. Additionally, as Solex Energy Limited [40] states, a high-performance ratio is necessary to maximize the return on investment of a solar PV system, as a higher PR result in more significant energy savings and financial benefits for the system owner.

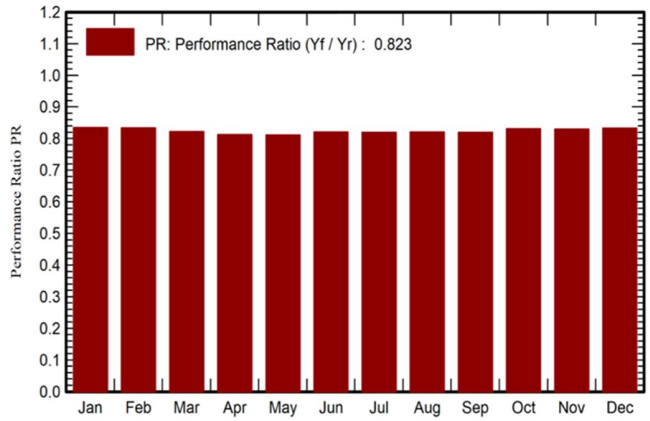


Figure 7. Monthly Performance Ratio of On-Grid Solar PV System

3.4.2 Off-Grid

Based on the computed system power of 26.52 kW of an off-grid solar PV system and a battery capacity of 1600 Ah, it shows that the useful energy from solar is 27, 257 kWh/year and the available solar energy is 41, 931 kWh/year and an excess or unused energy of 13, 973 kWh/year. Figure 8 shows the result of normalized production, and Figure 9 shows the performance ratio of the off-grid solar PV power generation system using the PVsyst software.

March, April, and May have the highest normalized energy production, according to Figure 8. This is probably because of longer sun hours throughout the summer. Therefore, solar panels have more time to capture sunlight and convert it into electricity. As a result, more solar energy was generated during those months. However, even though those months have more sunlight, the losses are also high; an increase in temperature can make the system work less efficiently, according to Dey [41].

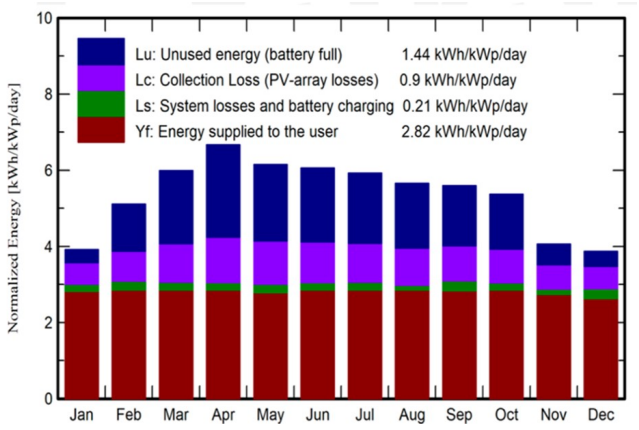


Figure 8. Normalized Production of Off-Grid Solar PV System

On the other hand, December and January have shorter days with less sunlight, leading to lower energy production; however, the energy loss in the system is also less. According to Supapo et al. [42], those months are described as cool and dry and are linked to frequent power outages; that's why the unused energy is low because the battery is being used during these months when the solar doesn't provide enough energy.

Figure 9 depicts the monthly performance ratio of the off-grid solar PV power generation system. The yearly solar fraction of the simulated system is 0.987, and the performance ratio is 0.525, according to Tsoutsos et al. [43]. This represents the entire effect of losses (due to inverter and cell temperature, etc.). The graph illustrates how the performance ratio varies throughout the year, with January (cold) showing the greatest PR and April (summer) showing the lowest PR. Dhimish [44] , on the other hand, claims that spring and summer are supposed to have higher monthly PR than winter. Furthermore, the PV panel performance ratio can drop by as much as 0.75 in the summer, according to Aktacir [45].

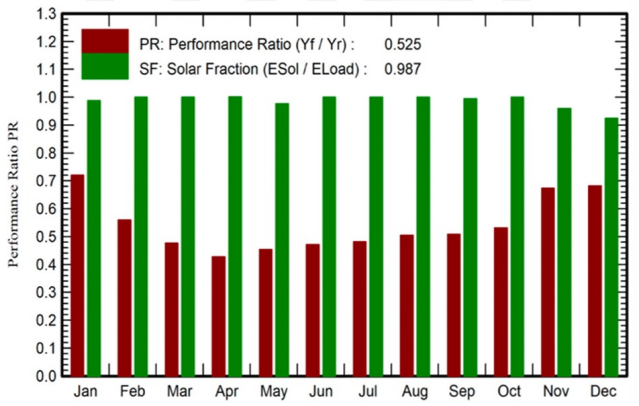


Figure 9. Performance Ratio of Off-Grid Solar PV System

Both systems see higher energy production during the summer months. However, off-grid systems experience higher losses during these months due to temperature effects. The on-grid system exhibits a significantly higher performance ratio, indicating better overall efficiency in converting solar energy to usable electricity.

3.5 Economic Viability of the System

The economic evaluation of the system requires the project's total cost, including the annual maintenance and financial parameters inputs such as inflation rate, discount rate, and tariff

charges. The researcher considered the consumption FIT obtained from CANORECO's official Facebook page that the electricity rate for low voltage for February 2024 was ₱9.109/kWh, and the feed-in tariff for solar power in the Philippines was ₱9.68/kWh [46] and was used in this study. The inflation rate in this study was 3.4% based on the Philippine Statistics Authority [47], the discount rate was 5.5%, and the income tax rate used was 15%. The annual degradation of solar panels was also considered in this study to be 0.5% [48].

The overall system cost of the on-grid solar PV power generation installation cost based on market availability is P1,660,361.93 considering the 5% VAT, 2% withholding tax, 10% profit, and 15% overhead cost (OCM), while the overall system installation cost was approximately 30% of the material cost. Therefore, the installation cost of the PV system was ₱381,160.45. The annual maintenance cost of the PV system was ₱10,504.087 annually for repairs and cleaning of solar panels, corresponding to 1% of the initial cost. According to Alejo [25], the system required proper module cleaning and preventive and corrective maintenance.

The economic evaluation of the on-grid solar PV was determined based on the annual energy generated from the annual GHI of CNSC, which is $1,818.2 \text{kWh/m}^2$, total cell area of 129m^2, 15% solar panel efficiency and a performance ratio of 0.823 and based on the result in the acceptability of the design the total energy generated was $28,954.93$ kWh annually. The NPV of the system after 25 years (end of life) is ₱4,457,373.79, with an ROI of 368% and a payback period of 4.93 years.

The economic evaluation of the on-grid reveals a positive net present value (NPV) similar to the study of Kavuma et al. [49], implying that having a positive NPV, the investment is feasible. Therefore, an on-grid solar PV system is economically viable; it requires a lower cost, a higher ROI, and a shorter payback period, and is thus recommended for adoption by the Camarines Norte State College Engineering Building.

However, the expense of PV panels and construction adaption is also identified as a significant hurdle, as is the general lack of knowledge about the advantages of renewable energy and passive architecture and how present construction practices fall short of addressing sustainability. Modern classrooms are packed with electrical equipment, another factor driving energy use [50].

4 CONCLUSION AND RECOMMENDATION

The existing electrical system of CNSC is suitable for implementing a solar power generation system. A metering system and transformer facilitate integration with the solar system. The seasonal variations in consumption highlight the potential benefits of solar power, particularly during peak demand periods. The fluctuating electricity rate further strengthens the case of exploring alternative energy sources like solar to achieve cost savings.

The Engineering Building of CNSC is suitable for solar PV power generation systems. The system considers the building's energy consumption, solar irradiance data, and safety factors.

Based on the performance ratio of the two PV systems, namely off-grid and on-grid, this suggests that the on-grid system converts more solar radiation into usable energy and is more efficient than the off-grid system. On-grid solar PV systems are economical. It also has a significantly lower overall cost, a shorter payback period, and higher NPV and ROI. Additionally, the economic viability depends on future electricity rates and feed-in tariffs.

This study examined whether the SPV system would be financially beneficial, with a positive NPV and a payback period of less than five years. An interesting finding is that while both on-grid and off-grid systems produced more energy during summer, the on-grid system has a significantly higher performance ratio overall. In addition to the financial benefits, the SPV system can serve as a valuable educational tool for engineering students. Students can learn about renewable energy technologies, data analysis related to system performance, and even economic considerations like costs and payback periods. This study highlights the potential of SPV systems to benefit educational institutions financially and educationally.

For further studies, forecast the electricity used over the next ten years to size the system with sufficient allowance for future growth or new loads. A smart grid management system can also be put in place by the CNSC to maximize energy utilization during peak hours. Also, the Engineering Building's electrical energy consumption patterns may be investigated in detail, and the peak hours may be determined so that the system can be sized to handle the demand. Compare the intended solar system's monthly generated capacity to the actual solar system's monthly consumption and determine the environmental impact and the possible reduction in carbon footprint in using a PV power generation system. Lastly, the college is suggested to purchase software such as PVSyst and HomerPro.

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