JOURNAL OF RENEWABLE ENERGY AND SMART GRID TECHNOLOGY

Vol. 19, No. 1, January-June 2024

Grid-Connected Self-Consumption Photovoltaic Solar Energy Production Design and Simulation Evaluation in Type II Climate Areas of Southeastern Philippines

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Article info:

Received: 16 October 2023
Revised: 18 January 2024
Accepted: 22 March 2024
DOI: 10.69650/rast.2024.254448

Keywords:

Photovoltaic
Solar
Type II Climate
Cloudy Skies

ABSTRACT

Renewable energy production is urgently needed to sustain all sorts of life generations walking on this planet. This research designed an 18 kWh per day of grid-connected solar energy production with a backup system battery for self-consumption. The design is proposed in the Southeastern part of the Philippines (Eastern Mindanao), particularly a part with Type II Climate at a 10-degree tilt angle and zero degrees relative to the Azimuth. It is arranged in two strings of eight 360 Watts monocrystalline-silicon modules, two 3.6 kVA inverters, six parallel 54 Ampere-hour battery systems, and two 30 ampere capacity charge controllers. It was then simulated in the computer software PVSyst 7.2.12, resulting in a monthly average performance ratio of 0.811, which is relatively high relative to other designs and locations. Furthermore, 94.0 tons of carbon dioxide with a present value equal to Php 157,666.2 are prevented by the designed system for 252.074 megawatts-hours in its 30 years of power production. The designed system has an estimated 18.05% internal rate of return with a total social cost of carbon value of Php 236,501 of the 31m^2 panel area.

1. Introduction

Improved access to energy services is one of the primary stages toward achieving this Millennium Development Goals, according to literature, experience, and anecdotal evidence [1]. The capacity of a sustainable energy system to supply necessary services without depleting resources is vital for communities. Countries across the globe are now exploring all possible means for improvements in harnessing renewable energy. This is due to the Paris Agreement's climate objectives. The overall percentage of renewable energy must climb from roughly 15% of total primary energy output in 2015 to around two-thirds by 2050 [2].

The sun contributes significantly to our energy needs, and its availability greatly outweighs future energy demands [3]. Solar energy is widely considered a sustainable and readily available energy source in a region's rapid urbanization. Studies have found [4] that the advancement in power electronics technologies and the steadily declining costs of photovoltaic electricity generation make it more popular.

People in the southeastern part of the Philippines, particularly those areas with Type II climate,[*] aspire to contribute to the goal of 100% fossil-free energy through photovoltaic solar energy [1]. Though situated near the equator, its cloudy skies attributed to this type of climate are also expected to limit solar energy harvesting [5, 6]. Nonetheless, existing research on this field [7, 8] has not yet explored both the Panel Generation Factor (pgf) and the Peak Sun Hours (PSH) as the comparative basis in the designing process of a PV system, more particularly on this part of the country.

This research has simulated a grid-connected self-consumption photovoltaic solar power system in the context of a Climate 2 area in the country's southeastern part. It specifically provided the desired load for the PV system, selected specifications for a PV module, and designed its system configuration, including the number of modules appropriate for the load. The determination of the inverter size and the battery banks was also included. This technical evaluation was made through the system's performance ratio and the project's lifetime contribution to reducing carbon dioxide.

The usage of photovoltaic (PV) systems is well recognized for helping to conserve the environment, create lower levels of greenhouse gases (GHGs), and minimize global warming; yet, whether it is economically advantageous for consumers is a heated topic [9]. However, the Philippine government aimed to promote green energy sources through financial incentives with environmental goals like carbon levies, cap-and-trade schemes, and others [1]. Thus, this study also proposed the inclusion of environmental economics by determining prevented expenses caused by carbon footprints if this energy were to be produced by fossil fuel-based energy generation [10].

[*] When there is no dry season at all throughout the year, and a significant rainy season from November to February, the climate is classified as Type II.

2. Method detail

The methodology involves the combined analysis starting with theoretical calculation results, which became the basis of PV system sizing specifications. These specifications were then inputted in the trial version of computer software (PVSyst 7.2) simulation [11, 12, 13] where the system's performance ratio along with its contribution to carbon dioxide reduction was determined [14, 15].

2.1 Load Analysis

The first method employs quantitative methods composed of a series of calculations necessary to determine the specifications of the on-grid solar PV design. The process will have to start with the load analysis [16], which determines which load demand and profile are vital [17]. Along with other facilities, the kilowatt-hours per day of operational use Ш was given by

$$\text{Ш} = \sum_{i=1}^{n} P_i T_i \ [kWh] \tag{1}$$

where P_i are the specific individual load rating of every power-consuming equipment/appliance in watts, and T_i is the time that load is used per day in hours, from 1 to n, for different power-consuming devices [18].

2.2 Solar Irradiance and Related Parameters

The calculation of solar panel size relies upon details of the solar path[†], PV tilt angle, Azimuth[‡], solar irradiance[§], peak hours per day[**] through the Global Solar Atlas website [19], clearness index[††], and other associated parameters [17]. The source of these data was determined through a paid Android mobile app called SolarCalc Pro and was compared from a free online resource [19] and a computer desktop application, PVSyst. Location coordinates (see Fig. 1) and historical meteorological data using the NASA SSE Satelite 1983-2005 database from PVSyst 7.2.12 [15] are important initial data in the process of the design. The location was selected in North Eastern Mindanao State University – Bislig City Campus, which is an area within type II climate.

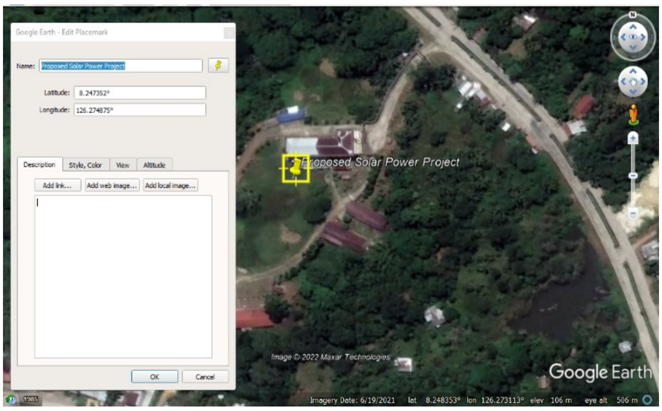

Fig. 1 Location of the proposed solar power project [53].

The sun chart was initially used to analyze shading obstructions that may hinder optimal energy production [20, 21]. The solar generator area of most PV systems employs not just direct solar energy but the entire global radiation (the sum of direct and diffuse solar radiation) [5, 6, 20]. Furthermore, it should be noted that the ambient temperature adversely affects the open-circuit voltage of a solar PV system [11, 14, 22].

2.3 Orientation

Nonetheless, the tilt angle and the azimuth orientation of the PV would affect the Transposition Factor (FT) and loss concerning optimum (loss/opt), thus affecting the system's overall performance [15, 23]. Initial simulation was made using the fixed-titled plane to determine the maximum Transposition Factor (FT)[‡‡] with the least loss/opt.

2.4 PV Module Sizing

The initial step in determining the sizes of PV modules is to find the total power of the PV panels (initially PV_{power}), which hinged on two contending equations. The first method is to determine the site's irradiance character through the panel generation factor (*pgf*). However, there are also competing equations about what *pgf* should be [24-26]. In this research, it was given by the equation [13]

$$\boldsymbol{pgf} = \frac{\textbf{Daily Solar Irradiance of the Location}}{\textbf{Irradiance at STC}} \tag{2}$$

Thus, the desired total power of the PV panels required was found through

$$PV_{power} = \frac{\text{Ш}}{pgf} * SLCF \quad [kWp] \tag{3}$$

where *SLCF* is the system loss compensation factor equal to 1.2 (range: 1.1 – 1.3) [27, 28].

The other way of finding the total power of the PV panels (PV_{power}) was done through the use of Peak-Sun-Hours (*PSH*)[§§] $\left[\frac{\frac{\text{kWh}}{\text{kWp}}}{\text{day}}\right]$ [6, 19, 23] which was found in data repositories like the SolarGIS Map of the World Bank Group [5, 16] and others. The PV_{power} equation was given by

$$PV_{power} = \frac{\text{Ш}}{PSH} * SLC\text{F} \ [kWp] \tag{4}$$

Through comparison, taking the lower value between *pgf* and *PSH* was reasonable considering the Type II Climate due to frequent cloudy skies, which affect energy harvesting [5, 6]. The higher values on equations 3 and 4 were considered in the design.

Suppliers' catalog or from PVSyst 7.2.12 database was used to determine the desired PV module specifications accounting for its

[†] The daily and seasonal arc-like route that the Sun seems to follow across the sky as the Earth rotates and circles the Sun. The Sun's path influences the duration of daytime and amount of daylight received along a particular latitude during a given season.

[‡] The angular distance of an object from the local North, measured along the horizon.

[§] The energy per unit area received by the earth from the Sun's electromagnetic radiation.

[**] It is when the sun is at its highest point in the sky with which provides direct angle to the panels.

[††] Clearness index is higher value when the sky and atmosphere are clear while it is lower with cloudy skies or bad weather which is a function of meteorological data pattern.

[‡‡] The ratio of horizontal irradiation (GlobInc) over incidence irradiation (GlobInc) on the plane (GlobHor). This is the amount of gain or loss that occurs when the collector plane is tilted, and it can be expressed in hourly, daily, monthly, or annual values.

[§§] The period when the solar system received the maximum amount of solar irradiation at 1 kW/m² [6].

peak power output Pnom*** in Wp, open-circuit voltage (Pvoc) in volts, short circuit current (Isc) in amperes, and voltage at peak power output (Vmpp) in volts.

Thus, the number of modules required (*NMR*) is given by the equation

$$NMR = \frac{PV_{power}}{P_{nom}} \quad (5)$$

Any fractional element of the *NMR* result is leveled up to the next largest whole number, thus becoming the actual number of modules required (NMR_{actual})) [20].

2.5 Inverter Sizing

The process may be iterative, starting with an initial selection, appropriate conformity, and compatibility with the one-phase 220 V 60-hz frequency††††‡‡ [29]. The size of the grid-tied inverter§§§ was determined with an input rating of 30% from the range between 0% to 30% [13, 27] larger than the total wattage peak requirement of the total load. The inverter size was determined through

$$\eta_{inv} = \frac{1.3\ PV_{power}}{\eta_{inv}}\ [kW] \quad (6)$$

where η_{inv} is the efficiency of the inverter (range: 90% - 98%) [27] from selections in catalogs. The nominal voltage of the inverter and the battery must be the same.

In a PV connection, the capacity provided to withstand surge current**** [24] is expressed in

$$Isc_{PV} < Iinv_{max} \quad (7)$$

where $Iinv_{max}$ is the rated maximum current input in the inverter.

Also,

$$Vout_{PV\ Array\ Series} = Pvoc * NMR\ [Volts] \quad (8)$$

where $Vout_{PV\ Array\ Series}$ is the total voltage output to be supplied by the PV array in series configuration. This must satisfy the condition

$$Vout_{PV\ Array\ Series} < Vinv_{maxmpp} \quad (9)$$

where $Vinv_{maxmpp}$ is the rated maximum power point voltage of the inverter.

2.6 Battery Sizing

The classification of short-term storage for a few hours or days to cover times of bad weather is the most appropriate type batteries in the system. Parameters in deciding battery size that must be accounted for [30, 31] are the battery efficiency (β) (range: 83 to 97%) [17, 20, 28], depth of discharge (ф) equal to 70% (range between 30% to 80%) [20, 22, 28, 32,], nominal battery voltage (ɣ), and the designed number of days of autonomy (*П*) which is equal to 1 day (24 hours). Thus, Battery Capacity (χ) is given by the equation:

$$\chi = \frac{ШП}{ф\beta ɣ}\ [Ah] \quad (10)$$

It was noted that the system would work better, and the battery life would be extended if additional PV modules were installed [30].

The Number of Batteries, *NB* is given by

$$NB = \frac{\chi}{BCap} \quad (11)$$

where *BCap* is the Battery Capacity of the selected unit to be used in the assembly.

2.7 Charge Controller Sizing

The capacity of a solar charge controller†††† [23, 31, 33] is generally rated in Amperage and Voltage. Though this device is mostly part of the inverter nowadays, the solar charge controller must be best suited to the design from catalogs that match the voltage of your PV array and batteries. Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) are the two available technologies. The researcher chooses the latter because it is more efficient than the first [21, 32, 34]. It is vital to ascertain that the solar charge controller has sufficient capacity to manage the current generated by the PV array [23, 31, 33]. The controller size for a series charge controller is determined by the total PV input current given to the controller and the PV panel layout (series or parallel configuration).

As part of standard practice in sizing solar charge controllers, the short circuit current (Isc) of the PV array was multiplied by 1.3 (range: 1.25 – 1.3) [24, 27]. Thus, have to satisfy the equation

$$I_{cc} = 1.3 * I_{sc}\ [Amperes] \quad (12)$$

2.8 Simulation

A professional simulation program was then run with theoretical calculations inputs to get an accurate yield forecast at the specified location. This applied the PVSyst (7.2.12), which was reliable with real-time studies to analyze on-grid and off-grid systems. Additionally, it provides comprehensive meteorological information and other tools for investigating PV systems [13, 14, 35]. The simulation started by defining the project, particularly selecting a geographic location and meteorology, followed by defining plane orientation (important shading and tilt are important). Next is the entry of the theoretically calculated system specifications, particularly the inverters, PV modules, load power, and others.

The system is grid-tied PV with backup battery storage [36], and self-consumption energy management has been initiated in the simulation analysis since it is an attractive potential worth driver for rooftop PV in the future [37-39]. The main aim was to consume its PV-produced energy while minimizing the grid power in the system.

*** The rated power (or nominal power) of the solar module, expressed in Watt-Peak (Wp), is its capability under Standard Test Condition (STC)*** to generate module's peak output under ideal conditions [20, 28].

††† Much of the rest of the globe uses 220-240 VAC, with the Philippines using 60 hertz rather than 50.

‡‡‡ Single-phase electricity is often used in residential houses, whereas three-phase power is typically used in commercial and industrial establishments.

§§§ Converts the DC output of PV panels into a clean AC current that may be used in AC equipment or returned to the grid.

**** The currents that raise or fall from the normal rated value in the short duration of time when first turned on.

†††† Regulates the voltage and current going to the battery from the PV panels, prevents battery discharge at night through the solar modules, and preventing battery overcharging and extending battery life.

The output includes system production (kWh/yr), specific production (kWh/kWp/yr)[‡‡‡‡], performance ratio[§§§§], normalized production (kWh/kWp/yr)[*****], array losses (kWh/kWp/yr), system losses (kWh/kWp/yr)[†††††], and carbon footprint[‡‡‡‡‡] [11, 14, 15, 35, 40]. Adjustments to the number of PV arrays were made for optimization.

One very important consideration in the findings is the system's performance ratio (PR), which is defined as the relationship between the system's energy production and radiation incidents in the specified area. From the perspective of the region or country, a statistical energy production and performance ratio (*PR*) comparison is the most reliable option to compare the quality of the mounted PV systems [40, 41]. This permits the discovery of operational problems and facilitates system evaluation. The simulation was run by equation

$$PR = \frac{Final\ System\ Yield}{Reference\ Yield} \tag{13}$$

Releases of green-house gases such as carbon dioxide, sulfur oxide, and nitrogen oxide resulting from the combustion of conventional power generating facilities are the major causes of climate change. PVSyst 7.2.12 highlighted only the reduction of carbon dioxide in its simulation. The calculation of Carbon Dioxide reduction of the PV system in the simulation was based on the standard of the International Energy Agency[§§§§§], of which the Philippines is a member. It has 480 grams of CO_2 per kilowatt-hour of energy production [42].

2.9 Economics

An economic assessment of the system was carried out based on the established parameters, system specifications, and simulation output. The computer calculation of the internal rate of return (IRR), payback period, and return on investment (ROI) was derived from starting expenses, annual operating and maintenance costs, tariffs, and levelized cost of electricity. This was cautiously made because of the increased rate of technology innovation resulting in the increasing availability of load control devices and high variability of technology costs [17, 36], and others which could produce untimely pricing results due to increased price dynamics [43]. The present price of electricity delivered by the local electric cooperative service provider is approximately Php 12.35 per kWh. The feed-in tariff of solar energy production in the Philippines is Php 9.69 per kWh while for net metering ranges from Php 4 to Php 10 per kWh [1]. Moreover, an environmental economic procedure of valuing the project's lifetime reduced carbon dioxide emission was made by initially multiplying it by the prevailing median social cost of carbon, $30 per ton [44], at a discounting rate of 2.5% [45] and summing these values.

3. Results and Discussion

For illustration purposes, part of the PV application in this research is to provide an AC pump that conveys water into the upper-level tank equal to 1.2 kilowatts. The design was also to provide energy that could be part of the power supply of a building, thus allowing it to produce 3 kW. On the day of operation, with conservative consideration of other uses, it was decided that the alternative energy source supplement at least 18 kWh per day.

3.1 Solar Irradiance and Related Parameters

The PVSyst initial simulation results depict the typical Sun Paths in a tropical region like the Philippines (see Fig. 2[******]). The graph explained the various positions of the sun in azimuth and height positions (both in degrees) with respect to specific dates of different months and legal times. The maximum sun height would register on April 20 and August 23, approaching between 85° and 87° around 11:30 AM. On the flip side, the lowest sun height would register on December 22 at around 55°, around 11:30 AM. This also shows the sun orientation shifts of an observer facing North (azimuth=0°) that sun is in fronting their eyes half span of the year (azimuth values ranging from +67° to +113°) while the other half will be at hindsight (azimuth values ranging from -67° to -113°).

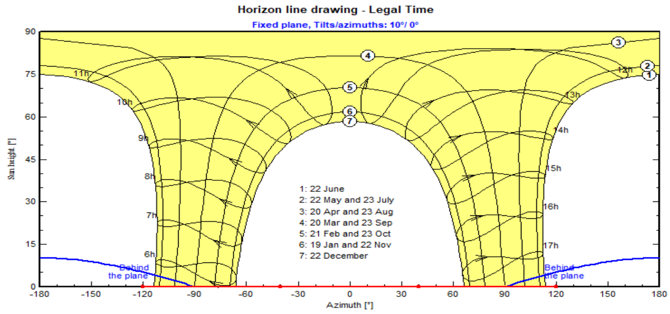

Fig. 2 Sun path.

Based on NASA -SSE data 1983-2005, Fig. 3[††††††] shows the clearness index (y-axis) with respect to the sun height (x-axis), which stabilizes at 30° and in reference to Figure 2 is at 7:30 AM to 4:30 PM. The minimum and maximum clearness indices (the portion of radiation at the top of the atmosphere that makes it to Earth's surface available for energy conversion) ranged from 0.03 to 0.9, respectively. Solar irradiance was based on the time series extrapolation, which integrates the weather analysis.

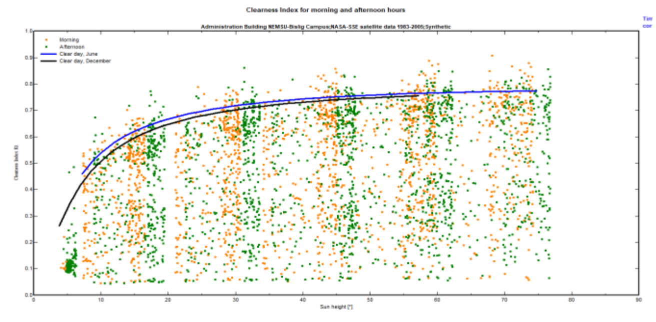

Fig. 3 Clearness index.

[‡‡‡‡] The array's nominal power divided by the generated energy (Pnom at STC). This is a measure of the system's potential, taking into consideration irradiance circumstances (orientation, site location, meteorological conditions).
[§§§§] It is the ratio of the system's energy production to the radiation incident on a specific region. It gives you information about the solar system's energy efficiency and dependability.
[*****] The nominal power is to be divided on the energy output values – thus, the energy production of a 1 kW_p unit. This shows losses including collection loss, and system loss on top of produced useful energy in a graph.
[†††††] This loss happens in the inverter system and among other electrical elements utilized for grid integration.
[‡‡‡‡‡] It is the total of all CO_2 (carbon dioxide) emissions caused by energy production over a certain time period (typically one year).
[§§§§§] The International Energy Agency designs policies to help the world accomplish climate, energy access, and air quality goals while focusing on energy dependability and affordability for all.
[******] Source: PVSyst 7.2
[††††††] Source: Ibid.

3.2 Orientation

There is no shading, and at a tilt angle of 10°, the sun will only have an unfavorable spot to generate power at 5:30 AM and pm in the months of April, May, June, July, and August. Also, optimization occurs at this chosen tilt angle, giving TF equal to 1.01, with no losses with respect to optimum, and indicates global on collector plane equal to 1996 kWh/m² (see Fig. 4‡‡‡‡‡‡).

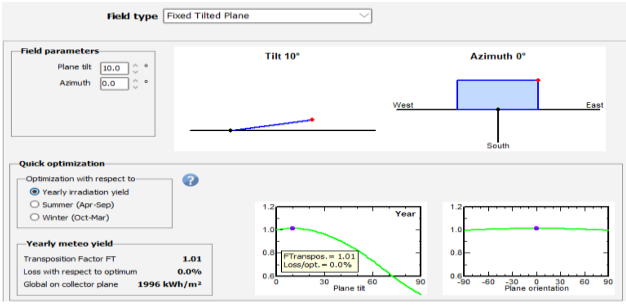

Fig. 4 PV orientation.

3.3 Location and Irradiation

Fig. 5§§§§§§ provides the Global Horizontal Irradiation (GHI), in which December has the least while August has the maximum. The average GHI is equal to 4.84 kWh/m²/day and, based on equation (1), gives a PGF equal to 4.84, which could be used in equation 2.

Site: NEMSU - Bislig City (Philippines)
Data source: NASA-SSE satellite data 1983-2005

	Global horizontal irradiation (kWh/m²/day)	Horizontal diffuse irradiation (kWh/m²/day)	Temperature (°C)
January	3.83	1.87	25.0
February	4.30	2.06	25.0
March	4.95	2.22	25.3
April	5.59	2.23	25.9
May	5.52	2.12	26.2
June	5.01	2.14	26.1
July	5.13	2.15	25.9
August	5.34	2.21	26.1
September	5.40	2.17	26.1
October	4.91	2.06	25.9
November	4.27	1.91	25.5
December	3.84	1.81	25.2
Year	4.84	2.08	25.7

Fig. 5 Global Horizontal Irradiation (GHI).

However, Fig. 6 shows that the proposed location ranged from 3.8 to 4.2 Peak Sun Hours*******. With our initial consideration that using a lesser value would provide a more reliable system, Peak Sun Hours equal to 4.0 was implemented.

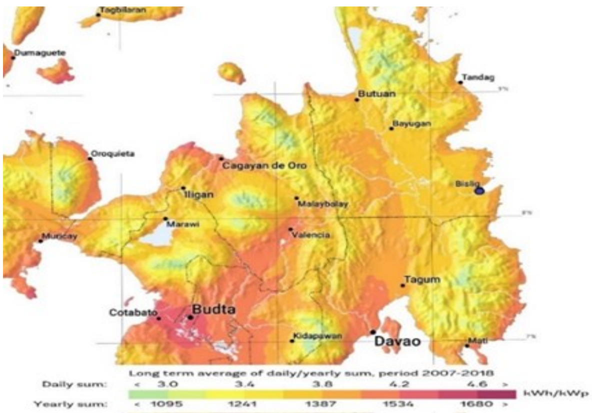

Fig. 6 Peak sun hours of Bislig city.†††††††

3.4 PV Module Sizing

Calculations through equation 4 led to a Watt-peak rating equal to 5.4 kWp. Selecting the PV Module AE 350M6-72 as the desired PV Panel, which provided details presented below in Fig. 7‡‡‡‡‡‡‡. Calculations in the Number of Modules Required (*NMR*) from equation 5 give us 15 modules. An additional one (1) module was made, thus doing 16 modules in anticipation of the area's fluctuating weather system. These arrays would occupy an area of 31 m2.

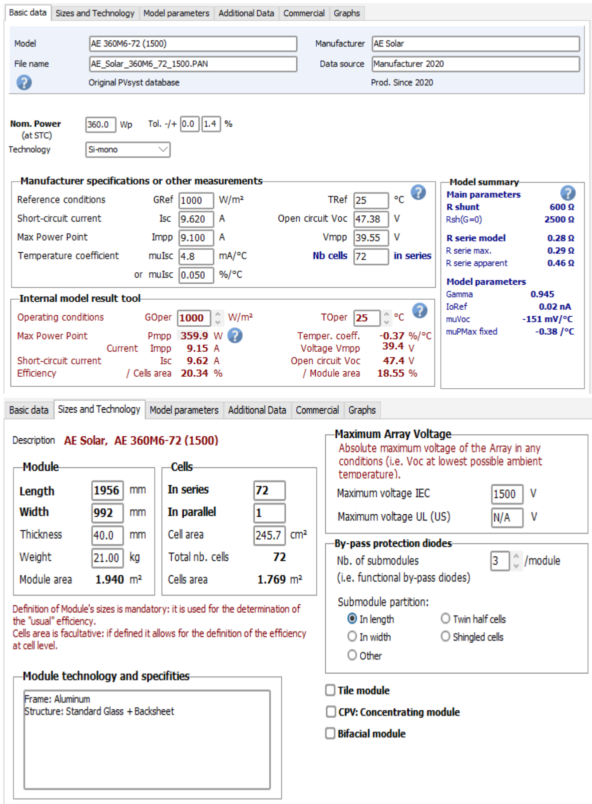

Fig. 7 PV Specifications.

3.5 Inverter Sizing

Initially, through equation 6 and using the maximum efficiency of approximately 98%, the inverter size was calculated to be 7.163 kWac. Through PVSyst 7.2.14 and selecting Senergytec SE 3K6TL S1 with specifications shown in Fig. 8, the design made the set-up of two (2) string inverters (3.6 kW capacity of each inverter) with eight (8) PV panels each.

In satisfaction with the condition expressed in equation 7, the Isc of the PV panel is 9.62 Amperes, which is lower compared to the 10.3 Amperes of the Maximum Input Current capacity of the inverters. Also, from equation 8, we have 379.04 Volts from the eight (8) modules connected in series. This is lower than the maximum MPP voltage capability of the selected inverter, which is equal to 580 V, thus satisfying equation 9.

‡‡‡‡‡‡ Source: Ibid.
§§§§§§ Source: Ibid.
******* The period when the solar system received the maximum amount of solar irradiation at 1kW/m² [6].

††††††† Source: [19]
‡‡‡‡‡‡‡ Source: PVSyst 7.2

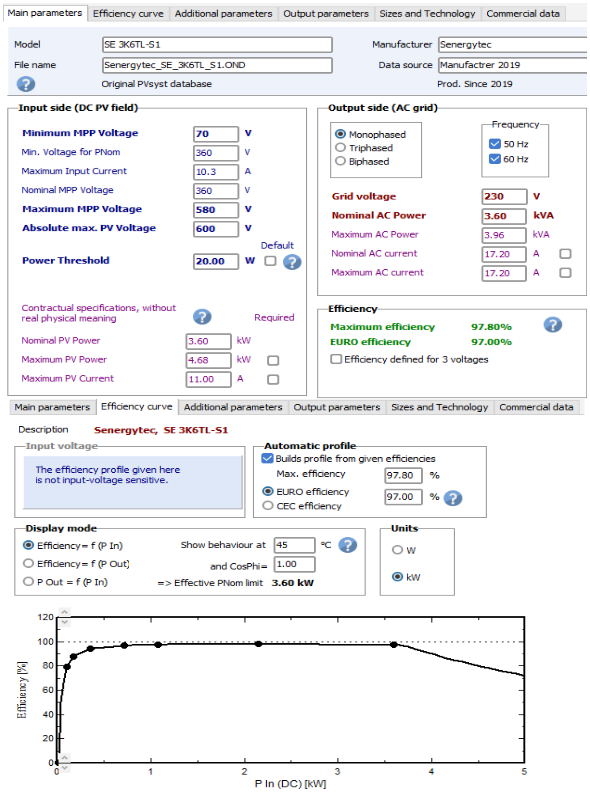

Fig. 8 Inverter specifications.

3.6 Battery Sizing

Battery specifications are provided in Fig. 9 with the help of PVSyst 7.2.12. Equation 10 provided the Battery Capacity (*χ*) set-up, which was initially found to be 278.44 Ampere-hours given the desired autonomy (*Π*) is about 12 hours or 0.5 days, 96% efficiency, and with the nominal battery voltage (*γ*) equal to 48.1 Volts. With Capacity at C10 equal to 54 Ah and with equation 11, the Number of Batteries (*NB*) equals 5.16 or 6 units.

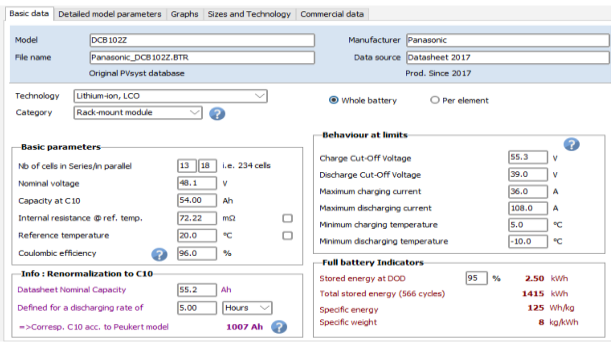

Fig. 9 Battery specifications.

3.7 Charge Controller Sizing

Given the short-circuit current of the selected PV module specification is 9.62 Amperes, equation 12 gives 12.51 Amperes. The Tristar TS MPPT 30-48V model from the Morning Star Manufacturer was selected (see specifications in Fig. 10) since it can withstand up to 30 Amperes while noting that voltage conformity with the battery and the PV module equal to approximately 48 volts must be satisfied. Since there are two parallel series PV modules, there is also the need for two charge controllers.

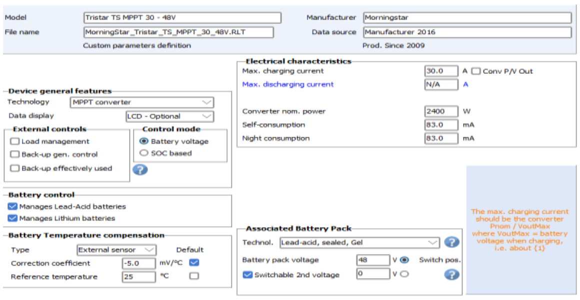

Fig. 10 Charge Controller Specifications.

3.8 Simulation Result

3.8.1 Production and Performance Ratio

The simulation study examined normalized productions based on IEC standards [14], such as collection and system losses. It produced useable energy per installed kWp/day (see Fig. 11). Respectively, these values averaged 0.72, 0.21, and 3.97, all in kWh/kWp/day. Energy supply depends on the weather pattern for a specific location and time of the year [46].

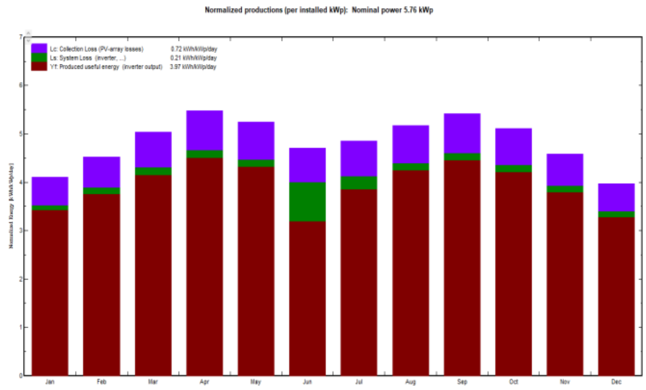

Fig. 11 Normalized production.

Thus, the Performance Ratio (*PR*) of the simulated system in Fig. 12 below has an average of 0.811, which is within the great values [47] and quite high innate to their locations [41, 48]. Only in April will the value of this *PR* visibly vary from the rest, but it will still fall within the normal values (range: 0.2 – 0.9) [47, 49]. This could be explained based on Table 1 that given the average value of 150.3 kWh/m2 of Global Horizontal Irradiance (GHI), which is relatively less compared to other months adjacent to it, its reference ambient temperature is high with respect to its GHI [49].

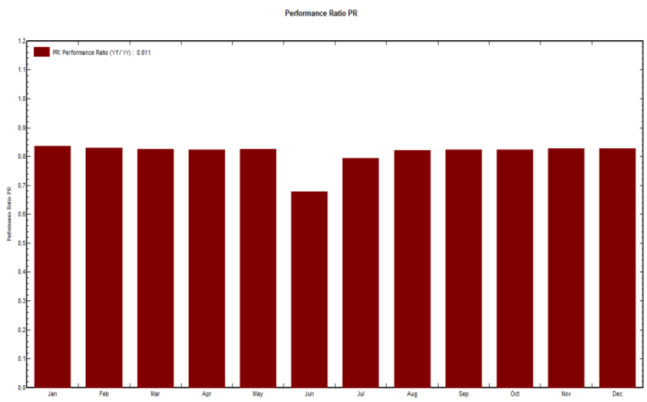

Fig. 12 Average monthly performance ratio.

3.8.2 Carbon Dioxide Reduction

Generally, carbon dioxide reduction measurements comprise CO_2 emissions related to the acquisition of electricity from the utility grid and the consummation of city gas for fuel cell and afterburner processes [50]. The designed system prevents 94.0 tons of carbon dioxide from generating 252.074 megawatts-hours (EGrid x Project Lifetime) in its 30 years of power production (see Fig. 13). Immediate use of photovoltaic solar energy production helps resolve the challenges of lessening carbon dioxide production [51].

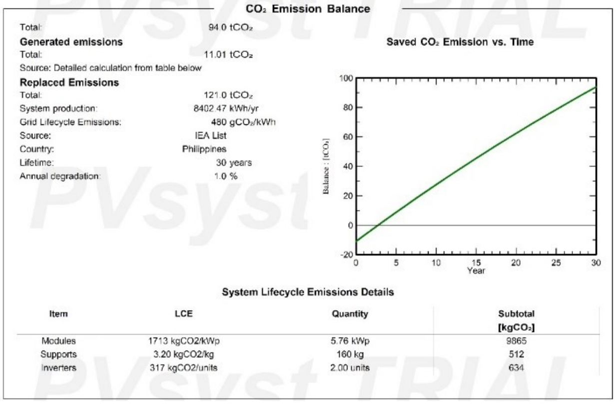

Fig. 13 Project's lifetime saved Carbon Dioxide emissions.

3.8.3 Solar PV Energy Production Economics

The financial analysis simulation result is presented in Fig. 14. It was computed that its return on investment (ROI) was 54.8%, its internal rate of return (IRR) was 18.05%, and it had a payback period of 10.5 years. The environmental economic value of carbon footprint reduction on the project's lifetime energy generation is 94.0 tCO_2 multiplied by \$30/tCO_2 and converted to Philippine Peso. This was itemized and plotted in Fig. 15 based on the system's yearly production of 8,402.47 kWh, at an emission rate of 480 gCO2/kWh, and a social discount rate of 2.5%, which summed to a value of Php 236,501 of the 31m^2 panel area. The net present value occupied is Php 7,541.54/m^2 with Php 7,629.06/m^2 social cost of carbon value saved. These results suggest that the area's solar energy production project and the procedures for finding specifications are financially appealing. A timely switch from non-renewable to renewable sources is necessary for energy security, especially in natural calamities and sustainable economic growth [52].

4. Conclusion

Renewable energy production is urgently needed to sustain all sorts of life's generations walking on this planet. This research designed a grid-connected photovoltaic solar energy production with a backup system battery for self-consumption. It is proposed that the system would be evaluated in a location with Type II Climate in the Southeastern part of the Philippines at 10 degrees tilt angle and zero degrees relative to the Azimuth. It was arranged in two strings of eight 360 Watts monocrystalline-silicon modules, two 3.6 kVA inverters, six parallel 54 Ampere-hour battery systems, and two 30 ampere capacity charge controllers. It was then simulated in the computer software PVSyst 7.2.12, resulting in a monthly average performance ratio of 0.811, which is quite high relative to other designs. Though frequent cloudy skies in the area hide away the sun, the location is beneficial for photovoltaic solar energy production.

Furthermore, 93.641 tons of carbon dioxide are prevented by the designed system for the generation of 251.28 megawatts-hours of power production in its 30-year lifetime. The designed system has an estimated 18.05% internal rate of return with a total social cost of carbon value of Php 236,501 of the 31m^2 panel area. As a viable alternative energy source that addresses climate change issues without compromising economic growth, renewable energy production and consumption may be promoted with the same simulated climate characteristics in South Asian countries.

Acknowledgements

I want to thank my wife, Hannah, and sons, Bezalel Anastacio and Abijah Alejandro, for the inspiration. Furthermore, I would like to thank everyone who encouraged me to conduct this research, especially our supportive North Eastern Mindanao State University officials.

Installation costs (CAPEX)	
Total installation cost	426,900.00 PHP
Depreciable asset	231,500.00 PHP
Financing	
Own funds	426,900.00 PHP
Subsidies	0.00 PHP
Loans	0.00 PHP
Total	**426,900.00 PHP**
Expenses	
Operating costs(OPEX)	64,026.45 PHP/year
Loan annuities	0.00 PHP/year
Total	**64,026.45 PHP/year**
LCOE	**11.4980 PHP/kWh**
Return on investment	
Net present value (NPV)	**233,787.75 PHP**
Internal rate of return (IRR)	**18.05 %**
Payback period	**10.5 years**
Return on investment (ROI)	**54.8 %**

Fig. 14 Financial analysis simulation result.

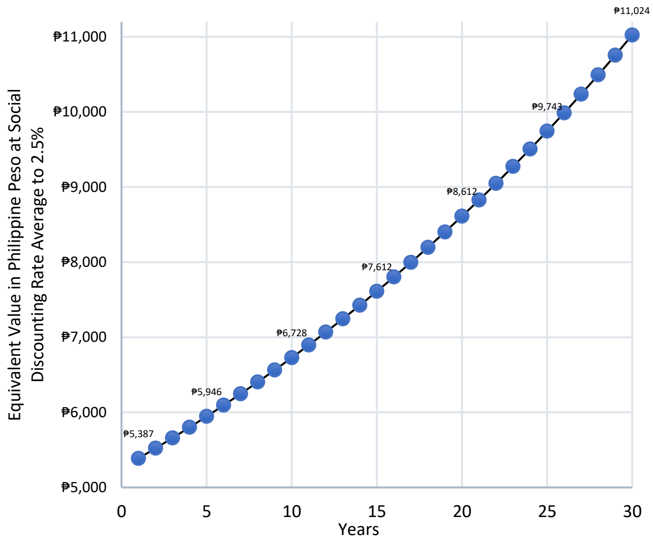

Fig. 15 Annual Social Cost of Carbon officials.

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