Comprehensive Assessment of Roof-Mounted Solar Photovoltaic Systems with Varying Tilt Angles: Case Study at the USTP Claveria Campus Gymnasium

Christopher S. Dolino, Clark Darwin M. Gozon*, Teodely Apple C. Tindoc-Morillo, Lyndy Mae V. Fajardo and James Federick N. Aguilar
Department of Electrical Engineering
University of Science and Technology of Southern Philippines
Cagayan de Oro City, 9000, Philippines
*clarkdarwin.gozon@ustp.edu.ph

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Abstract

Colleges and universities, including the USTP Claveria campus, face high electricity costs due to significant daily energy consumption for campus operations. This research addressed the gap in sustainable energy solutions by designing an optimal roof-mounted solar photovoltaic (PV) system to reduce reliance on utility electricity and mitigate carbon emissions. The study assessed the campus's energy consumption and roof space, evaluated solar energy potential using NASA POWER Project data, and designed a cost-effective and structurally viable PV system. Methodologies include site and building assessments, solar energy analysis, and system design utilizing Helioscope and AutoCAD software. Considering tilt angles of 6°, 9°, 11°, and 14°, the proposed 216 kW PV system, composed of 432 modules, is projected to generate 458,648.41 kWh annually. This energy output surpasses the campus's daily load requirements, offering scalability for future energy demands and potential distribution to the nearby community. Implementing this PV system will provide a sustainable, cost-effective solution to rising electricity costs and support USTP Claveria's sustainability goals while enhancing community energy resilience.

Keywords: cost effective design, energy efficiency, renewable energy resource, Solar Photovoltaic (PV) System, sustainability

1. Introduction

The Philippines' economic development and population growth have significantly strained its energy resources. To address this, Republic Act No. 9513, or the Renewable Energy Act of 2008, promotes renewable energy resources' development, utilization, and commercialization. Building on this, Republic Act No. 11285, or the Energy Efficiency and Conservation (E.E.C.) Act, establishes a framework for institutionalizing energy efficiency and conservation policies. These include promoting efficient energy use, increasing the adoption of energy-efficient and renewable technologies, and defining the roles of government agencies and private entities. In November 2019, the Department of Energy (D.O.E.) issued Department Circular DC2019-11-0014, establishing the implementing rules and regulations of the E.E.C. Act (Department of Energy, *n.d.*). Aligned with these policies, a regional-scale roof-mounted solar photovoltaic (PV) program serves as a clean and sustainable energy solution. By minimizing energy waste and supporting the transition to a low-carbon economy, it upholds the objectives of both the Renewable Energy Act and the E.E.C. Act.

Moreover, showcasing the benefits of renewable energy through rooftop solar PV installations in public buildings, such as State Universities and Colleges, creates value by improving service reliability and generating significant electricity savings. This, in turn, helps reduce operational costs and serves as an incentive for stakeholders. Additionally, these initiatives promote awareness of green energy in public schools and integrate sustainable energy practices into educational environments. This approach aligns with the Department of Energy’s (D.O.E.) strategy to encourage demand-side participation in energy production.

Maximizing the output of a PV Solar system is dictated by solar irradiation in the geographic location and the placement and orientation of the solar panels. A solar panel harnesses the most power when the Sun's rays hit its surface perpendicularly (Foster *et al.,* 2009). Ensuring that solar panels face the correct direction and have an appropriate tilt helps ensure maximum energy production, as they are exposed to the highest intensity of sunlight for the longest duration (Llorens *et al.,* 2015).

The angle or tilt of a solar panel is a crucial consideration for maximizing energy production. The geographical latitude of the location determines the optimal tilt angle for a solar panel. A general guideline for achieving the highest annual energy output is to set the solar panel's tilt angle equal to the geographical latitude (Gevorkian *et al.,* 2008). For example, if the location of the solar array is at 50° latitude, the optimal tilt angle is also 50°. Essentially, the closer a solar panel is to the equator, the more the panel should point straight up. The closer the panels are to the poles, the more they should tilt toward the equator (Llorens *et al.,* 2015).

A study by Sotto *et al.* (2023) investigated the effect of different module tilt angles on solar PV power production. The results show that the annual fixed optimum tilt angle is 10°, which produces a higher solar PV output compared to directly installing panels on rooftops.

Further, Chen *et al.* 2024, examined the power generation of PV panels at various inclination angles, using project-specific data to illustrate the impact of the tilt angle on PV power generation. Their findings reveal that secondary optimization of the tilt angle by PVsyst, combined with the geographic factors of Hainan, indicates that the optimal installation tilt angle for maximum power generation is 9°.

To further investigate studies related to the importance of tilt angles for different modules, Chen *et al*. 2005 used a genetic algorithm search technique to determine the optimum tilt angle for Chiayi, Taiwan, which has a latitude of 23.5°.

A vast knowledge base is available in studies of the design of Solar PV systems. Different techniques have been used, such as optimization, simulation, and other mathematical modeling tools. It is also observed that the optimum tilt angle-based PV panel orientation significantly increases solar radiation on its tilted surface. The study used an algorithm-based simple calculation of the optimum tilt angle that is appropriate and easy for all the locations without cost (Masrur *et al.,* 2021). Outputs of some of the studies in the Philippines revealed that solar PV output is significantly influenced by tilt angle, time, and principal components derived from weather parameters. Among the three angles considered, the tilt angle configuration with a 10° tilt showed the highest mean solar PV production (Benitez *et al.,* 2024).

Different methodologies and approaches can lead to varying outcomes of the analysis for a technical assessment of a roof-mounted solar PV, such as the area of the roof and load demand design basis. All the studies in the literature address the problem of selecting the optimal tilt angle without considering the specific concerns of maximizing the structural design for the location of the PV system and minimizing design costs. Therefore, a straightforward algorithmic analysis that explores its core aspects in real-world applications and is capable of addressing all these concerns is necessary to determine the optimal tilt angle for an installation

The primary objective of this project is to promote the development of roof-mounted solar photovoltaic systems for the University of Science and Technology of Southern Philippines (USTP)-Claveria Campus Gymnasium. To achieve this objective, a comprehensive assessment has been carried out to determine the suitability of the USTP-Claveria Campus Gymnasium for installing a solar photovoltaic system. Factors such as the available space, structural integrity, and sun exposure have been evaluated.

Evaluation of the system has included determining the potential amount of solar energy available at the USTP-Claveria Campus Gymnasium. This assessment has involved studying the historical weather data, sun orientation, tilt angle of the panels, and shading analysis to estimate the maximum solar energy potential of the site. A roof-mounted solar photovoltaic system design has been developed based on the site and energy assessments. The tilt angle of solar panels is a significant consideration for this study to determine the maximum annual energy production of the solar photovoltaic system at the USTP-Claveria Campus Gymnasium, calculated using the design specifications. This estimation would later help determine the system's potential contribution to the campus's energy needs.

2. Methodology

It has been perceived as a case study to assess the technical feasibility of installing a rooftop solar photovoltaic (PV) system on the Claveria Campus. Obtaining primary data is essential for projecting technical assessments of any system. For this study, field visits were conducted at the Claveria campus. The visits were necessary to confirm the roof type and structure and to confirm roof obstructions. The monthly electricity bill was acquired to determine the demand for electrical energy, and the as-built plan of the building was acquired.

Understanding how solar energy is transformed into electricity is crucial for designing a PV system. The process of converting energy can be better understood using the model below. The estimated maximum annual energy production of the Rooftop PV system to be installed has been calculated considering the parameters shown in Figure 1.

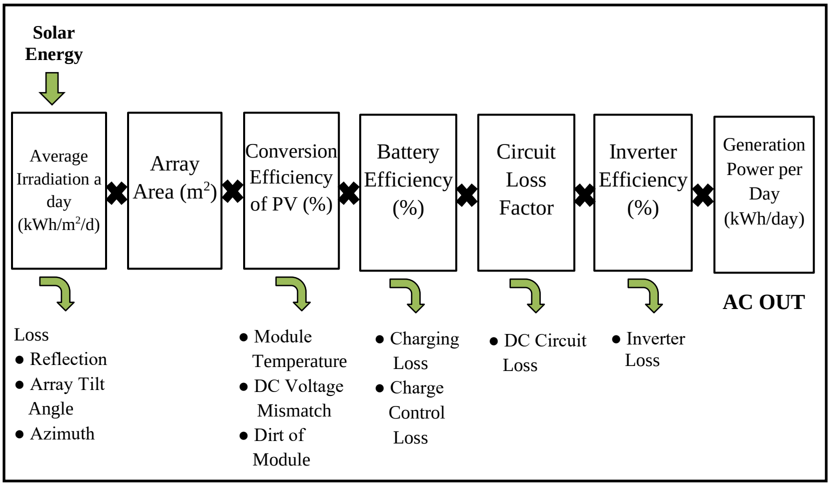

Figure 1. Energy Production Calculation

System efficiency parameters were derived from the most efficient PV module available on the market.

2.1 Irradiance Calculation

Solar radiation varies according to location, time of day, season, local landscape, and weather. To collect the maximum output power of a PV System, solar panels must be oriented to the sun so that solar radiation hits the surface of the panels. Solar radiation on an arbitrarily tilted surface with a tilt angle β from the horizontal and an azimuth angle of γ (assumed + west of south), as shown in Figure 2.

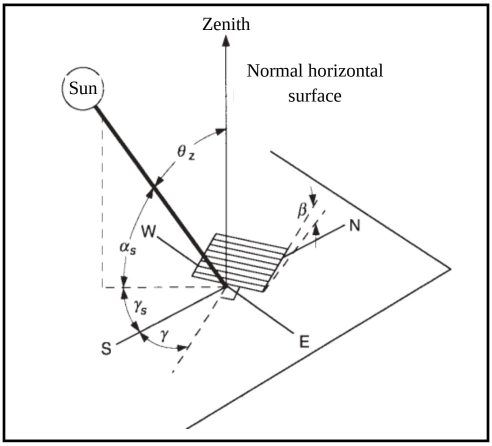

Figure 2. Definitions of Solar Angles (Duffie and Beckman 2006)

where:

α_s = Solar Altitude Angle
γ_s = Solar Azimuth Angle
β = Panel Tilt Angle
θ_z = Zenith Angle

The geographical latitude determines the angle a solar panel should set to produce the most energy in a year. A general rule for optimal annual energy production is to set the solar panel tilt angle equal to the geographical latitude (Foster *et al.*, 2009). Therefore, to achieve continuous sun tracking, which yields the maximum solar irradiation, this study propose the following algorithm:

1. Determine the declination δ. Declination is the angular position of the sun at solar noon for the plane of the equator. Cooper's equation gives its value in degrees using Equation 1:

$$\delta = 23.45\, sin\left(2\pi\, \frac{284+n}{365}\right) \tag{1}$$

where:

$-23.45^o < \delta < 23.45^o$ and n is the day of year, n=1 for January 1, $n=32$ for February 1, etc.

2. Determine the solar hour angle (ω). It is the angular displacement of the sun east or west of the local meridian; morning is negative, and afternoon is positive. It equals zero at solar noon and varies by 15° per hour from solar noon.

3. Determine the sunset hour angle ω_s. It is the solar hour angle corresponding to the time when the sun sets. The following equation yields the following using Equation 2:

$$cos\ \omega_s = -tan\, \psi tan\, \delta \tag{2}$$

where:

δ is the declination, calculated through Equation 1, and ψ is the site's latitude. The solar hour angle is crucial for calculating extraterrestrial radiation, as it determines the hours of solar exposure

4. Determine the Extra-terrestrial radiation. Solar radiation outside the Earth's atmosphere is called extraterrestrial radiation and is used to calculate the amount of solar radiation that reaches the Earth's surface. Daily extraterrestrial radiation on a horizontal surface, H_0, can be computed for the day using Equation 3:

$$Ho = \frac{86400Gsc}{\pi}\left(1 + 0.033\cos\left(2\pi\frac{n}{365}\right)\right)(\cos\psi\cos\delta\sin\omega_s + \omega_s\sin\psi\sin\delta) \quad (3)$$

5. Determine the clearness index. It is the ratio of solar radiation at the Earth's surface to extraterrestrial radiation. Thus, the monthly average clearness index, $\underline{K}_T$, is defined as shown in Equation 4:

$$\underline{K}_T = \frac{\underline{H}}{\underline{H}_0} \quad (4)$$

where:

$\underline{H}$ is the monthly average *daily solar radiation* on a horizontal surface, and

$\underline{H}_0$ is the monthly average *extraterrestrial daily solar radiation* on a horizontal surface.

6. Calculate Diffuse Radiation. Solar radiation is divided into two components: beam radiation, which emanates from the solar disk, and diffuse radiation, which emanates from the rest of the sky and contributes to the overall solar energy and is essential for determining the total solar energy received by the PV array. First, the monthly average daily diffuse radiation $\underline{H}_d$ is calculated from the monthly average daily global radiation $\underline{H}$ using the Erbs *et al*. (1982) correlation using Equation 5.

$$\frac{\underline{H}_d}{\underline{H}} = 1.391 - 3.560\underline{K}_T + 4.189\underline{K}_T^2 - 2.137\,\underline{K}_T^3 \quad (5)$$

7. Hourly Breakdown of Radiation. The average daily radiation is then broken down into hourly values to track solar energy over the course of a day and calculated using Equation 6, 7, and 8.

$$r_t = \frac{\pi}{24}(a + b\cos\omega)\frac{\cos\omega - \cos\omega_s}{\sin\omega_s - \omega_s\cos\omega_s} \quad (6)$$

where:

$$a = 0.409 + 0.5016\, sin\left(\omega_s - \frac{\pi}{3}\right) \quad (7)$$

$$b = 0.6609 - 0.4767\, sin\left(\omega_s - \frac{\pi}{3}\right) \quad (8)$$

r_t is the ratio of hourly total to daily total *global radiation*, where ω_s is the sunset hour angle, expressed in radians, and ω the solar hour angle for the midpoint of the hour for which the calculation is made using Equation 9.

$$r_d = \frac{\pi}{24} \frac{cos\omega - cos\, \omega_S}{sin\, \omega_S - \omega_S cos\, \omega_S} \quad (9)$$

where:

r_d is the ratio of hourly total to daily total *diffuse radiation*. For each hour of the "average day," the global horizontal irradiance H and its diffuse and beam components H_d and H_b, respectively, are given by Equation 10, 11, and 12:

$$H = r_t \underline{H} \quad (10)$$

$$H_d = r_d \underline{H}_d \quad (11)$$

$$H_b = H - H_d \quad (12)$$

8. Calculation of Hourly Irradiance in the Plane of PV Array

Calculating hourly irradiance in the plane of the PV array helps determine the electrical output of the PV system, H_t. Once the tilted irradiances for all hours are computed, the daily total H_t is obtained by summing the individual hours using Equation 13.

$$H_t = H_b R_b + H_d\left(\frac{1+cos\, \beta}{2}\right) + H_\rho\left(\frac{1-cos\, \beta}{2}\right) \quad (13)$$

where:

ρ represents the diffuse reflectance of the ground (also called ground albedo), and β represents the slope of the PV array. The tilt angle (β) varies between *0*° to 90°. Ground albedo is set to 0.2 if the average monthly temperature is more significant than *0°C* and ranges up to 0.7 based on the surrounding situation (Kacira *et al.*, 2004). R_b is the ratio of the beam radiation on the PV array to that on the horizontal, which can be expressed using Equation 14:

$$R_b = \frac{\cos\theta}{\cos\theta_z} \tag{14}$$

where:

θ is the incidence angle of the beam irradiance on the array and θ_z is the sun's zenith angle.

The angle of incidence (θ) on an inclined surface can be calculated using Equation 15:

$$\cos\theta = \sin\delta\ \sin\psi\ \cos\beta - \sin\delta\ \cos\psi\ \sin\beta\ \cos\gamma\ \cos\delta\ \cos\psi\ \cos\beta\ \cos\omega + \cos\delta\ \sin\psi\ \sin\beta\ \cos\omega\ \cos\gamma \cos\delta\ \sin\beta\ \sin\omega\ \sin\gamma \tag{15}$$

The zenith angle θ_z for a horizontal surface (where $\beta = 0$) using Equation 16:

$$\cos\theta_z = \sin\psi \sin\delta + \cos\psi \cos\delta\ \cos \tag{16}$$

Each step builds on the previous one to progressively model how solar radiation changes over time and across various angles. This is critical for optimizing PV system performance through sun tracking.

2.3 Array Area Calculation

For maximum PV array power generation, this study used a roof plan to determine the quantity of roof space available for the PV power rooftop system. The plan should include information on location (including longitude and latitude), height, slope, and any additional construction on the roof. Available rooftop areas for solar PV installation, shade from neighboring trees, building vicinity, and shade from adjacent solar panels, the edge zone should be accounted for. The available system capacity is based on the solar installation area and the selected panel sizes. This study used the Helioscope (Aurora Inc., 2022) to calculate the number of modules that could fit on the roof of the USTP-Claveria Gymnasium, It performs sophisticated shading simulations using both the roof's geometry and surrounding objects. This helps determine the optimal module placement to minimize shading and maximize energy output, making it easier to decide how many modules can be installed effectively.

To compute the total number of modules, divide the total roof space area by the area of our selected PV module using Equation 17.

$$Number\ of\ Module = \frac{Total\ Roof\ Space}{Solar\ Module\ Dimensions} \qquad (17)$$

While the total number of modules that can be mounted on an available roof space is important, other factors must be accounted for. The final number will depend on the choice of inverter and the number of modules that can be connected in series and parallels that are connected to it.

Equation 18 can be used to calculate the number of inverters.

$$Number\ of\ Inverter = \frac{Capacity\ of\ the\ System}{Rated\ Inverter\ Size} \qquad (18)$$

Modules connected in series must be computed using the inverter's D.C. voltage capacity and the stated modules' maximum power voltage, following Equation 19.

$$N_S = \frac{V_{DC}(inverter)}{V_{mp}(module)} \qquad (19)$$

The system will include modules connected in parallel; the number of modules and modules in series must be calculated (Equation 20).

$$N_P = \frac{N_O}{N_S} \qquad (20)$$

The total current produced by the array is equal to the module current rating multiplied by the number of parallel array modules (Equation 21).

$$I_A = I_{MO} * N_P \qquad (21)$$

Each module has a particular area. $(L \times W \times H)$ is multiplied by the total number of modules. Consequently, the total area of an array must be computed to determine the extent to which this project will consume space (Equation 22).

$$Total\ Array\ Area = (L \times W)(Number\ of\ Modules) \qquad (22)$$

3. Results and Discussion

The PV modules were installed on the roof of the USTP – Claveria Campus Gymnasium. The Gymnasium is located at latitude 8.612194 and longitude 124.887813, as established in the as-built plan, the building has a roof area of 2,280 sq. m. As shown in Figure 3, there were no obstructions in installing the solar PV modules in the USTP-Claveria Gymnasium that could cause shading of modules. Based on the preliminary field visit, the building had an adequate structure to carry heavier loads and could carry a ballasted PV-based system.

Figure 3. Roof Space Perspective View of USTP-Claveria Gymnasium

To determine theoretical energy potential and predict the actual performance of the system under realistic conditions, Solar Energy assessment using NASA (NASA, 2023) where the clear sky, and all-sky irradiance are considered. The monthly and annual irradiance at the USTP-Claveria Campus Gymnasium are shown.

In clear sky irradiance, for the past 12 years, April had the most considerable amount of irradiance, with an average of 7.42 kWh/m^2/day. On the other hand, December had the lowest average amount of irradiance, 6.11 kWh/m^2/day. The annual average clear sky irradiance for the past 12 years was 6.88 kWh/m^2/day

For all-sky irradiance (accounts for actual weather conditions), April had the most significant average amount, 5.88 kWh/m^2/day, for the past 12 years. On the other hand, December had the lowest average, 4.44 kWh/m^2/day. The annual average all-sky irradiance for the past 12 years was 5.05 kWh/m^2/day. The potential generation of the project first depends on the capacity of the available roof spaces, also known as the Roof Area method, when designing a PV system. Given that the roof is curved, the researchers had to modify their project design to accommodate the available spaces. The solar panels were not positioned at the center of the roof because they did not have an optimum tilt angle at which a module when installed almost flat could accumulate a large amount of dirt and be difficult to wash away, in addition taking into account the easy access on installing of the PV modules, able to facilitate future of the component inspection, cleaning and other routine maintenance. The solar panels were positioned on the curved side of the roof with approximate tilt angles of 6°, 9°, 11°, and 14° as shown in Figure 4, which typically mounted just the same orientation and tilt angle as the roof; this is versatile, easy to install and relatively inexpensive avoiding additional support structure that corresponds to wind loading forces. The solar panels were aesthetically arranged and designed to accommodate available spaces to achieve high-energy production. With such a design, the system's total installed capacity was 216 kW, derived from the 18 modules connected in series and a maximum of 24 parallel connections, as shown in Figure 4-6, using AutoCAD (Autodesk, 2022). Hence, the system consisted of 432 modules, each with a peak power of 500 W. The total Array Area for this proposed design was 1,041.15 m^2.

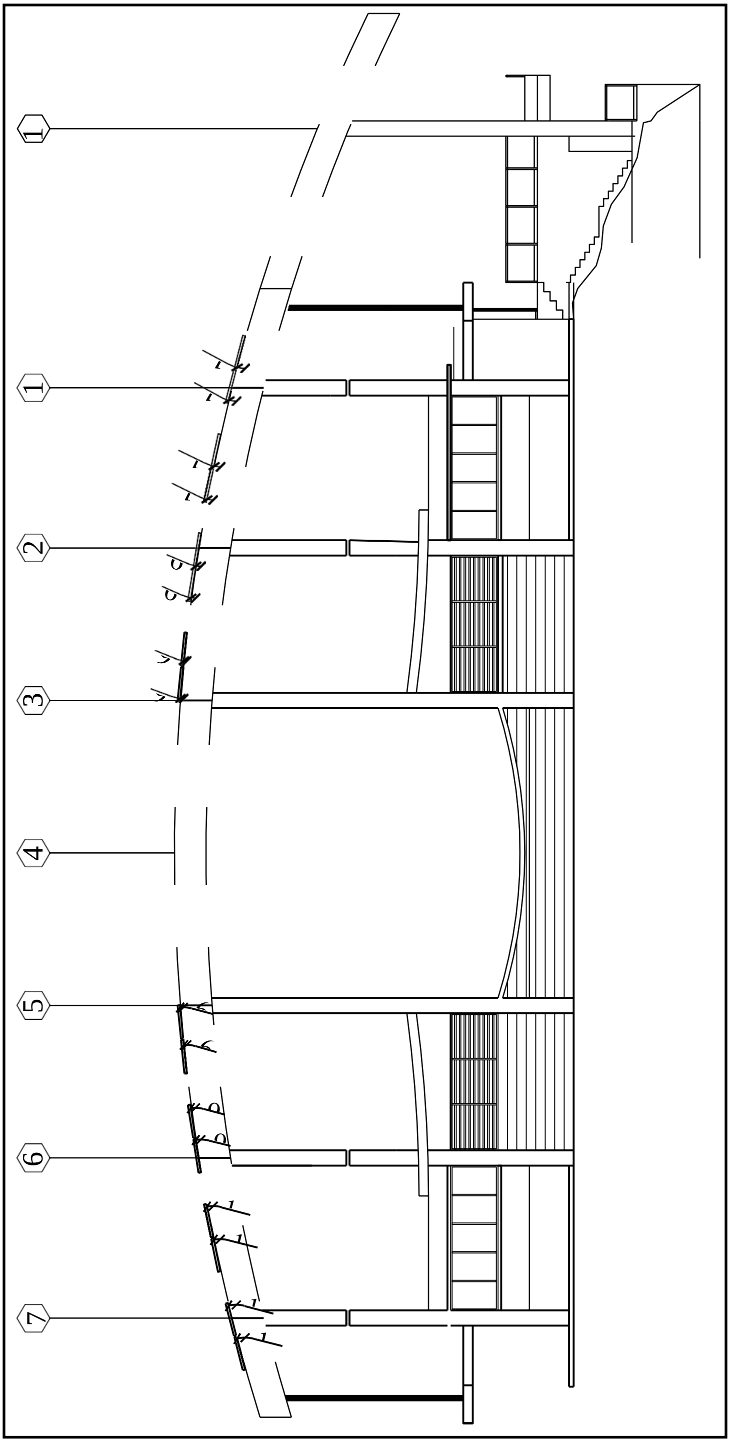

Figure 4. Solar PV Tilt Angle Position

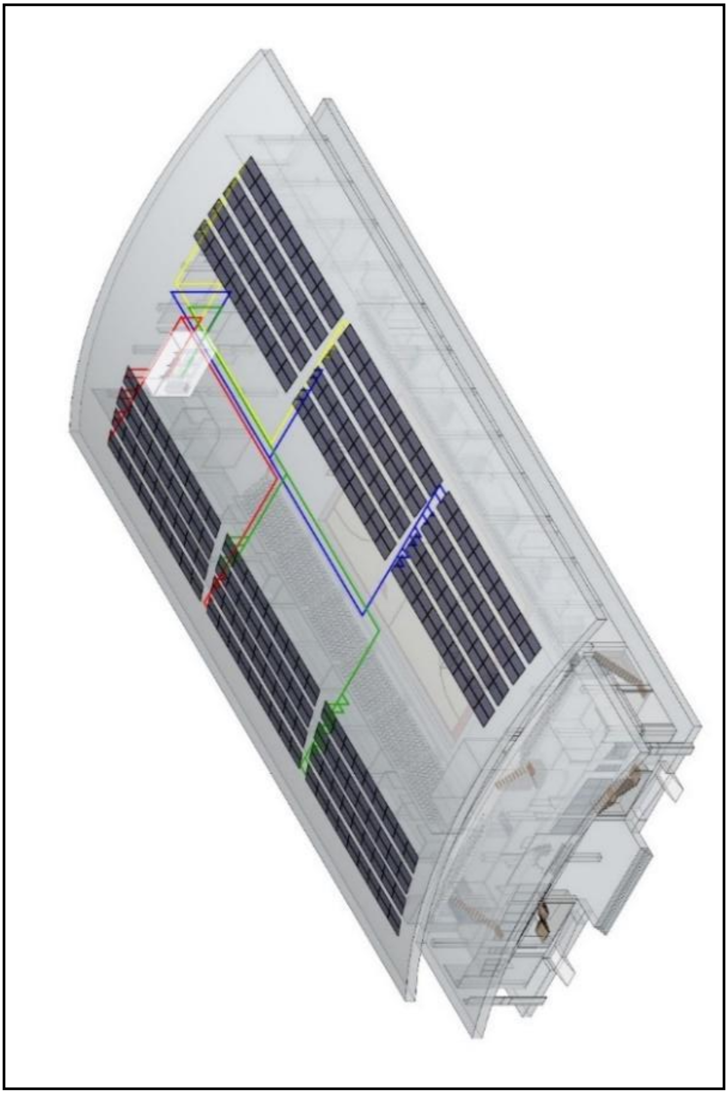

Figure 5. Proposed PV Layout Roof Design

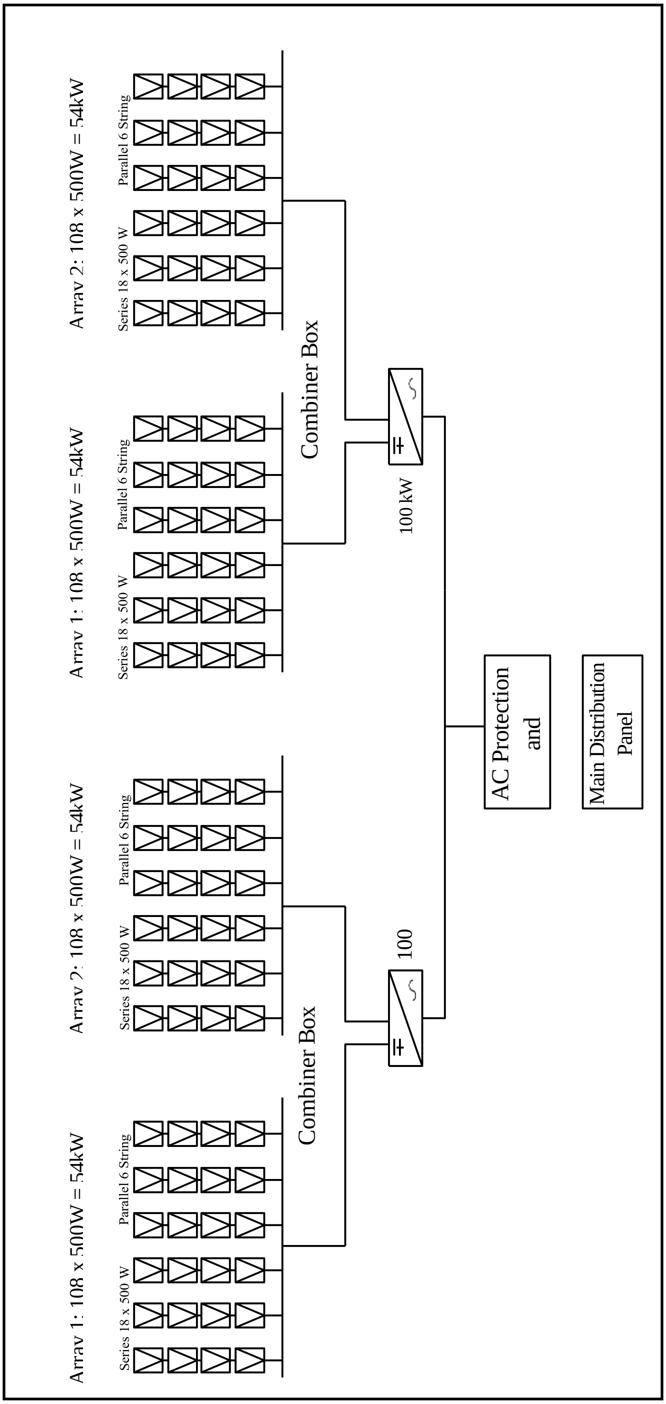

Figure 6. PV Grid System Line Diagram of 216 kW Peak Design of Grid-tie Solar System

The projected annual energy production of the PV system following the above PV layout and tilt angles following the diagram below as Figure 7.

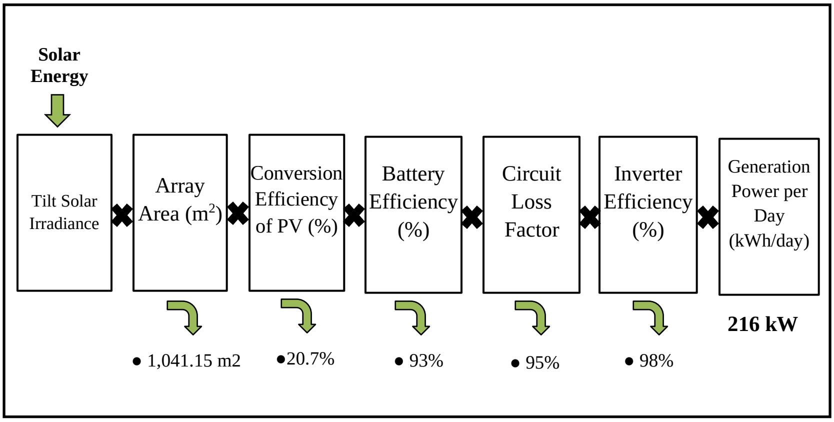

Figure 7. Daily Generation Flow

Table 1. Annual Energy Production on Tilt Angles

	East Facing					West Facing					Total Monthly Productiob (kWh)
	6˚	9˚	11˚	14˚		6˚	9˚	11˚	14˚		
Jan	4033.26	4002.46	3960.26	3904.49	15900.48	4005.46	3953.68	3911.17	3843.41	15713.72	31614.20
Feb	4412.79	4377.92	4331.64	4270.31	17392.67	4392.04	4338.92	4294.89	4224.49	17250.34	34643.00
Mar	5441.94	5397.17	5339.98	5264.08	21443.17	5432.95	5373.81	5324.01	5244.15	21374.90	42818.07
Apr	5601.18	5555.86	5498.22	5421.9	22077.16	5593.43	5534.34	5484.64	5405.08	22017.49	44094.65
May	5453.32	5412.46	5359.04	5288.85	21513.67	5434.69	5375.27	5326.07	5247.79	21383.82	42897.49
June	4833.40	4798.63	4752.55	4692.33	19076.91	4813.02	4760.03	4716.44	4647.32	18936.81	38013.73
July	4925.83	4889.93	4842.63	4780.76	19439.15	4907.35	4853.98	4809.94	4740.03	19311.30	38750.45
Aug	5177.33	5137.15	5085.43	5017.33	20417.24	5166.41	5111.82	5066.21	4993.45	20337.88	40755.13
Sept	4854.59	4814.91	4764.57	4697.97	19132.05	4850.46	4799.96	4757.30	4688.93	19096.65	38228.70
Oct	4855.00	4816.27	4765.55	4698.35	19135.17	4837.59	4781.48	4734.72	4659.92	19013.72	38148.89
Nov	4445.88	4411.46	4364.63	4302.56	17524.53	4416.13	4359.00	4312.01	4237.02	17324.16	34848.70
Dec	4321.80	4288.89	4243.19	4182.64	17036.52	4286.23	4227.96	4180.32	4104.37	16798.88	33835.40
		TOTAL			228,487.72					228,559.68	
								Annual Production			458,648.41

Table 1 shows that the 6° tilt produces more energy than the other tilt degrees, consistent throughout the year. At the same time, the 14° tilt angle produces the least energy. Also, the PV system project generates 458,648.41 kWh annually, with April producing the highest energy at 44,094.65 kWh, with a similar pattern shown in the annual irradiance assessment for clear sky and all-sky irradiance with NASA for the past 12 years.

Table 2. Hourly Energy Generation for January 1

Tilt angle	Time of day										
	7	8	9	10	11	12	1	2	3	4	5
	54 PV Panel Facing East										
6°	10.18	10.85	11.93	13.39	14.52	14.92	14.44	13.19	11.41	9.31	5.85
9°	11.05	11.21	12.03	13.40	14.50	14.88	14.38	13.10	11.25	8.91	4.29
11°	11.01	11.44	12.08	13.40	14.48	14.84	14.33	13.03	11.13	8.63	3.25
14°	11.32	11.77	12.15	13.39	14.43	14.77	14.25	12.92	10.95	8.21	1.69
	54 PV Panel Facing West										
6°	5.53	9.22	11.37	13.16	14.42	14.90	14.50	13.36	11.88	10.75	9.88
9°	3.81	8.77	11.18	13.06	14.36	14.85	14.47	13.36	11.96	11.06	10.37
11°	2.66	8.46	11.05	12.99	14.30	14.81	14.44	13.35	12.00	11.25	10.52
14°	0.94	7.99	10.85	12.86	14.20	14.73	14.38	13.33	12.05	11.53	10.74
Total Hourly Energy Generation (kW-hr)	56.49	79.71	92.65	105.65	115.21	118.71	115.20	105.64	92.63	79.65	56.60
Total Daily Energy Generation (kW-hr)											1,018.14

Table 2 shows an hourly generation for a day. This is to understand the energy yield potential across different panel configurations of solar modules oriented towards the east and west and further specify the effective daily energy harvest hours at various tilt angles for these orientation.

The researchers gathered the average energy consumption of the University of Science and Technology of Southern Philippines (USTP)-Claveria. Figure 8 shows how much energy is consumed.

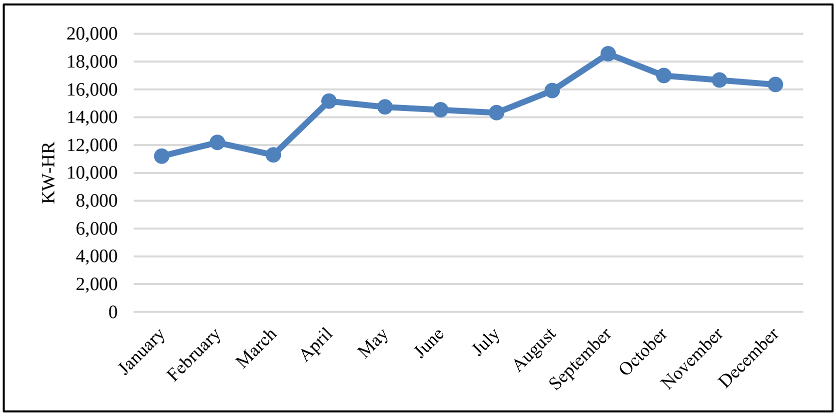

Figure 8. Energy Consumption of Claveria Campus

September has the largest kW-hr consumed, 18,560 kW-hr; the lowest kW-hr consumed is 11,201 kW-hr in January. Furthermore, the average kW-hr consumed by the USTP-Claveria Campus was 14,823.75 kW-hr.

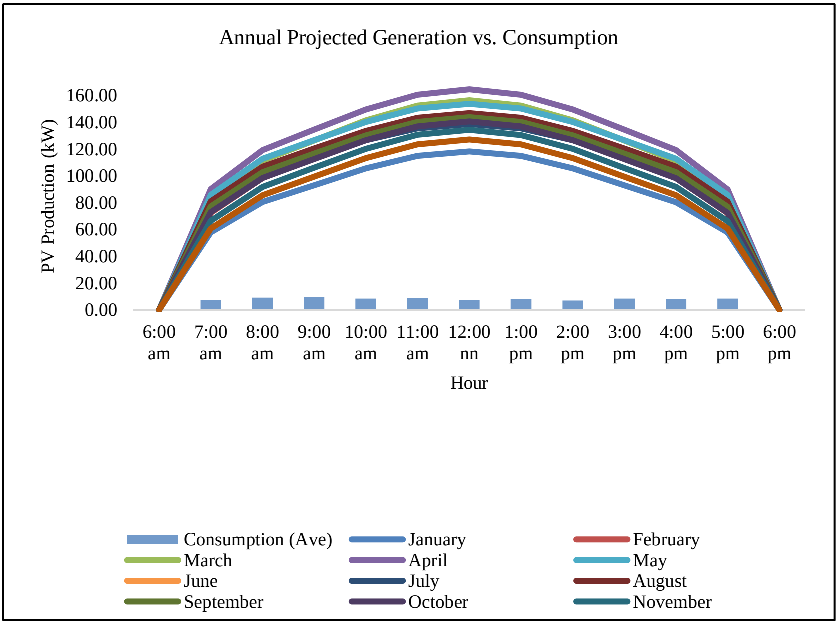

Figure 9. Projected PV Generation vs. Average Consumption

Figure 9 shows that the estimated load demand for the entire USTP Claveria campus was much lower, comprising only 10% of the total energy production of the Rooftop PV system. Hence, it can be shared with the nearby community through possible adaptation Distributed Energy Resources (DER) Rules wherein on-grid or off-grid DER End-users, utilizing renewable energy, with a maximum nameplate capacity of 1 MW, can export a maximum of 30% of its excess capacity to the distribution system and be compensated for it (Energy Regulatory Commission n.d.). Additionally, this is an excellent alternative to the Net Metering scheme in which the Department of Energy has a maximum installed capacity of 100 kW to be exported to the grid if there is excess power generation. Another scheme was also considered, such as putting up a storage system for excess production from the PV System, which can be explored and exported to the nearby community at night.

4. Conclusion and Recommendation

The site assessment confirms that the proposed PV system at USTP Claveria will not be affected by shading from nearby structures or trees. While the region's cloudy and rainy weather will aid in the self-cleaning of PV modules and reduce maintenance needs, it may also result in decreased energy production.

The proposed design incorporates a varying tilt following the gymnasium’s roof contour, with 54 PV modules facing east and 54 facing west. The energy generation from both orientations is nearly identical, ensuring a balanced and consistent power output. This configuration effectively flattens and extends the energy generation profile, aligning well with the operational energy demands of the university.

Furthermore, the projected daily energy yield of the PV system exceeds the current daily load consumption of the campus. To maximize this surplus energy, further investigation is recommended to explore potential applications, such as supplying power to nearby communities or accommodating the institution’s future energy needs.

Lastly, a comprehensive economic evaluation is necessary to determine the financial viability of the roof-mounted solar PV system. A financial model should be developed to assess the project's feasibility from both the owner’s and the lender’s perspectives, ensuring a sustainable and cost-effective implementation.

5. Acknowledgement

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