International Journal of Advances in Applied Sciences (IJAAS)
Vol. 15, No. 2, June 2026, pp. 820~829
ISSN: 2252-8814, DOI: 10.11591/ijaas.v15.i2.pp820-829

Assessment on the performance of bifacial monocrystalline solar photovoltaic panels in residential areas in Pampanga, Philippines

Edgardo M. Santos
Department of Electrical Engineering, Faculty of Electrical Engineering, Pampanga State University, Pampanga, Philippines

Article Info

Article history:

Received Sep 20, 2025
Revised Apr 28, 2026
Accepted May 23, 2026

Keywords:

Bifacial photovoltaic
Grid dependency
Net-metering
Performance ratio
Tropical climate

ABSTRACT

This research compared bifacial photovoltaic (BPV) in Pampanga households in limiter-only, hybrid battery, and net-metering. To evaluate the energy output, performance ratio (PR), and grid dependency, seven setups (5.65-12.5 kWp) were monitored over 31-37 days with the help of data loggers. The net-metered system of 12.5 kWp became fully independent of the grid and produced 206% of the household demands. The most ideal PR (75.17%) was achieved at the 7 kWp net-metered system. Battery-based hybrid systems minimized grid reliance by 56% and systems based on limiters obtained half supply. Net-metered configurations considerably beat the other configurations ($p < 0.001$). Results prove that BPV is viable in tropical homes, which endorses sustainable development goals (SDGs) 7 and SDG 13.

Corresponding Author:

Edgardo M. Santos
Department of Electrical Engineering, Faculty of Electrical Engineering, Pampanga State University
Cabambangan, Bacolor, Pampanga 2001, Philippines
Email: emsantos@pampangastateu.edu.ph

1. INTRODUCTION

The worldwide transition to renewable energy has emerged as imperative to tackle climate change, energy security, and to achieve sustainable development goals (SDGs) [1]. Recent advancements have established bifacial technology as a superior alternative to conventional monofacial panels, with studies demonstrating significant energy yield improvements through rear-side irradiance capture [2]. Choi and Bhakta [3] evaluated a 50 kWp bifacial multicrystalline system and reported a performance ratio (PR) of 64.47%, confirming the technology's viability for grid-connected applications. Among renewable technologies, solar photovoltaic (PV) systems, specifically, bifacial monocrystalline panel systems have attracted a lot of attention thanks to their capacity to absorb both direct and reflected light, producing higher levels of energy outputs when compared to mono-facial panels [4]. This technology is in line with the SDG 7 (affordable and clean energy) and SDG 13 (climate action) in terms of reducing greenhouse gas emissions and energy independence [5]. In the Philippines, the Renewable Energy Act of 2008 (RA 9513) further encourages the adoption of solar PV, targeting to have renewables as the source of energy to 35% by 2030 [6].

Bifacial photovoltaic (BPV) systems exhibit a better performance in areas of high irradiance, e.g., tropics, where albedo effects from surfaces such as light colored rooftops could increase energy yields by between 10-20% [7]. Darussalam *et al.* [8] experimentally investigated BPV performance in tropical regions, finding that tilted orientations (15°) produced the highest energy yield (1,951 Wh) compared to vertical configurations, though elevated temperatures (39% above ambient) during peak hours can negatively affect efficiency. Muñoz *et al.* [9] conducted a technical and financial assessment of bifacial systems in tropical Colombia, demonstrating that high-albedo surfaces (0.4) increased energy generation by 4.83% compared to monofacial baselines, with corresponding improvements in net present value (8.42%) and payback period (5.21 years). Recently, their application to urban and residential spaces where the output is increased by reflected light from buildings [10] has been stressed.

Barokah *et al.* [11] examined reflective surface variations in Bandung, Indonesia, revealing that white-painted surfaces produced the highest bifacial power output (410 W), followed by paving blocks (390 W) and asphalt (370 W), underscoring the critical role of ground albedo in tropical urban environments. Saepulloh *et al.* [12] analyzed the effect of solar radiation on tilted BPV in Indonesia, reporting that system efficiency varied significantly with weather conditions: 15.85% during partly cloudy conditions, 11.99% in sunny weather, and only 7.73% under cloudy skies. However, most studies are based on large-scale systems or monofacial panels, and there is a serious lack of empirical data for residential bifacial systems, especially in tropical climates [13]. For example, Shajid *et al.* [14] considered bifacial performance in temperate zones; very little research has been conducted about their efficiency in high-humidity, monsoon-prone climates, such as Pampanga, Philippines [15].

The energy landscape for the Philippines has challenges that are unique to the country, such as typhoons, which occur frequently and the fluctuations of irradiance per season may impact the performance of BPV [15]. According to Dutta [16], the Philippines solar energy and battery storage market is projected to expand substantially through 2031, with hybrid systems and residential applications representing key growth segments driven by falling component costs and supportive policy frameworks. Existing studies on solar PV in the country mostly analyze monofacial panels [15], with little focus on bifacial monocrystalline configurations, though these have a higher theoretical efficiency [2]. Moreover, the research on hybrid systems of bifacial panels with battery storage or net-metering in a residential setting is still limited [10]. This disparity is especially important given the focus present in RA 9513 on decentralized renewable energy solutions for rural and suburban households [6].

A comprehensive review by Ansarinasab [17] confirmed strong linkages between renewable energy transitions and SDG achievement, particularly SDG 7 and SDG 13, while identifying critical research gaps in integrating social justice and biodiversity protection within energy transition programs. Tariq *et al.* [18] examined the role of renewable energy in achieving SDGs among group of ten (G10) countries, finding that renewable energy adoption significantly reduces carbon dioxide (CO_2) emissions, though economic growth and foreign direct investment (FDI) present complex trade-offs that require careful policy calibration. The SDG knowledge hub [19] reported that decentralized renewable solutions, including off-grid solar systems, served 490 million people globally by 2022, with projections suggesting such systems could account for 44% of new energy connections by 2030, particularly relevant for archipelagic nations like the Philippines. Recent market analysis indicates that while residential solar adoption accelerates in Southeast Asia, empirical performance data for specific technologies like BPV in monsoon-prone tropical climates remains limited, particularly regarding long-term degradation rates and seasonal variability [20].

This study fills these gaps by measuring the performance of bifacial monocrystalline PV systems in residential sites in Pampanga, in limiter-only, hybrid, and net-metered systems. By looking at energy output, PR, and reduction of grid dependency, the research offers information for practical application to optimize bifacial technology in tropical climates. It is hoped that these results can guide policymakers, installers, and homeowners toward meeting SDG targets and RA 9513 goals at the same time as furthering the global knowledge base on BPV applications in under-researched environments.

This study aimed at assessing the performance of enhanced hybrid solar power system, including BPV panel, limiter, and with lithium-ion battery storage, in the context of the energy consumption profile of different residential customers in Pampanga, Philippines. There were 7 setups of BPV systems that were observed for this study. These include system A, a 6.125 kWp (11-565 Wp) BPV with a hybrid setup of 300 Ah battery, system B, 5.65 kWp (10-5.65 Wp) BPV with a hybrid setup of 150 Ah battery; systems C1 and C2 are made up of identical 10.44 kWp (18-580 Wp) BPV connected via limiter only and lastly 3 net metering set ups, system NM1 specifically, the study sought to answer research questions: i) what were PV production in terms of kWh for the various setup of bifacial in terms of: limiter set-ups (580 watts bifacial); hybrid set-ups (using 565 watts bifacial); and net-metering setups at various capacity (5.65-12.5 kWp), ii) what are the impacts on reduction of energy grid dependency of various PV setups in Pampanga?, and iii) what were the PR of BPV at various setups in Pampanga residences?

2. METHOD

2.1. Research design

The research design used in this study is a combination of descriptive, observational, and experimental research studies as it has been carried out to fully determine the performance of BPV systems in residential areas. It used a descriptive research design to be able to document the nature and operating performance of the systems in an organized way without manipulation of the variables [21]. The methodology allowed the possibility to hold quantitative and qualitative data on the energy generation at various configurations to give a general image of the system efficiency in the real-life situation, based on the direct measurements and the history of the electricity bills [22]. This design was suitable because it answers what and how questions on how systems perform [23].

Observational case study design enabled the observation of the solar panel systems in their natural residential environment with time [24]. This methodology was able to obtain fine details of system behavior in real use scenarios without the interference of an experiment, such as the trend of energy production and consumption and the influence of local weather conditions [25]. This design, through the combination of sensor data, utility bills, and homeowner interviews, allowed the triangulation of data to maximize validity and offer rich contextual insights [26].

To test hypotheses regarding comparative performance, experimental research design was introduced [27]. This component consisted of the comparison between various configurations of the system (limiter-only and hybrid systems) and methodical manipulation of the variables (patterns of battery usage) [28]. This approach allowed to make causal conclusions concerning the aspects that influence system performance, especially the differences in energy output among systems, the influence of battery storage on the performance, and the differences in performance under different weather conditions [29].

It was also reasonable to combine these designs because: i) descriptive design offered quantified performance indices and economical savings, ii) observational design-based findings on local environmental and use conditions, and iii) experimental design allowed causal findings concerning factors that affect the performance [29]. They joined in establishing a comprehensive assessment system which is sound scientifically and practice-based to the homeowners, policy makers, and the renewable energy stakeholders in the Philippines [5]. Research design to apply the hypotheses of experimental performance. This aspect included experimental comparisons of different system configurations (e.g., limiter and hybrid arrangements) and systematic control of variables (e.g., battery usage pattern) [9]. The experimental methodology enabled the researcher to draw a causal relationship on the factors affecting the system performance, in particular in the analysis of the energy output difference between systems, the impact of battery storage on energy consumption, and the performance difference in various weather conditions. This experimental production provided some critical information to complement the data on observation.

2.2. System configurations and sampling

A purposive sampling method was used to select seven BPV systems in residential houses located in Pampanga [21]. Selection criteria needed: i) residential in Pampanga, ii) has installed BPV systems with limiter, hybrid, or net-metering, and iii) can be monitored. Table 1 summarizes the system configurations that were tested.

Table 1. Summary of BPV system configurations

System	Capacity (kWp)	Configuration	Battery	Inverter	Days monitored
NM1	12.5	Net-metered	None	Deye	31
NM2	7.0	Net-metered	None	Deye	32
NM3	5.65	Net-metered + hybrid	150 Ah	Deye SUN-5K	31
A	6.215	Hybrid + limiter	300 Ah	Deye	31
B	5.65	Hybrid + limiter	150 Ah	Deye SUN-5K	31
C1	10.44	Limiter-only	None	Solax	37
C2	10.44	Limiter-only	None	Solax	37

2.3. Instrument and data collection

The inverters were linked to data loggers that recorded voltage, current, and power generation after every 5 minutes. Solarman business app (accuracy ±1), as shown in Figure 1, was used to monitor electrical parameters, such as daily, monthly, and annual kWh production, battery state-of-charge, and grid import/export trends in real-time. Each site was measured with environmental sensors (pyranometer and PT100) to determine the solar irradiance and the module temperature. The consumption patterns of household energy came through the utility bills and were confirmed by the interviews with the homeowners. The system was observed for three months. The installations had standard tilt angles (15° to 30°) and shading-free positioning and were all inverter settings (e.g., maximum power point tracking (MPPT) thresholds) to become comparative.

Figure 1. Solarman business app

2.4. Data analysis

The energy generation, the reduction in grid dependency of the different PV installations, and the system efficiency are calculated and measured in this paper as the key performance indicators to evaluate the technical performance of the system. To test the variability of the energy output, standard deviation will be used, and ANOVA will be used to test the difference between the group means. The reduction in energy grid dependency of several PV systems was calculated using the following formulas:

i) Self-used energy = energy produced by limiter and hybrid setups corresponding to household electrical consumption.
ii) Billed kWh = energy utilized coming from the grid (distribution utility).
iii) Total energy used = self-used + billed kWh.
iv) % PV kWh supply = total energy harvested /total energy consumption.

Figure 2 shows the hardware design of the PV system. The physical installation in the Pampanga residence with ten 565 W JA solar bifacial panels (two strings of five) attached on a raised steel structure at 15° incline. It consists of Deye SUN-5K inverter, direct current (DC)/alternating current (AC) breakers, surge protection, and net metering connection in accordance with the Philippine electrical code [5]. Mounting is elevated to allow rear-side irradiance to be captured using ground albedo effects. Figure 3 shows a schematic diagram of a 5.65 kW hybrid-ready bifacial solar PV system in Pampanga, Philippines, showing ten 565 W bifacial panels (two strings of five) connected to Deye SUN-5K inverter with DC/AC circuit breakers, surge protection, and a bidirectional net meter for grid feedback. Designed for future battery integration (150 Ah/300 Ah) per UL 1703 standards and Philippine electrical code requirements using 4 mm^2 DC and 8 mm^2 THHN copper cables [5].

Figure 2. Hardware design of the 5.65 kW bifacial solar panels

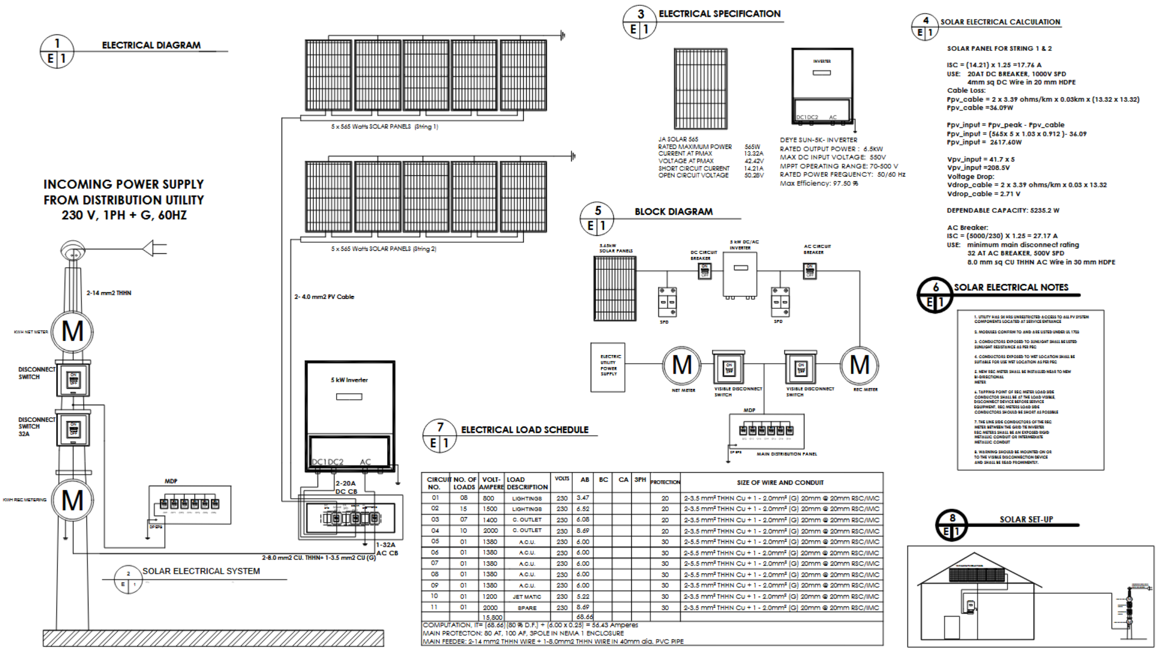

Figure 3. Schematic diagram of the 5.65 kW PV system

Figure 4 shows the flow diagram of the PV system. The schematic illustration of power flow in relation to the solar array, home panel board, and utility grid through SolaX inverter. These elements are surge protecting (surge protective device circuit breaker (SPD CB)), grounding, and bidirectional meter to provide net metering. When it becomes excessive, it is sent back to grid where all the potential solar energy production is realized [5].

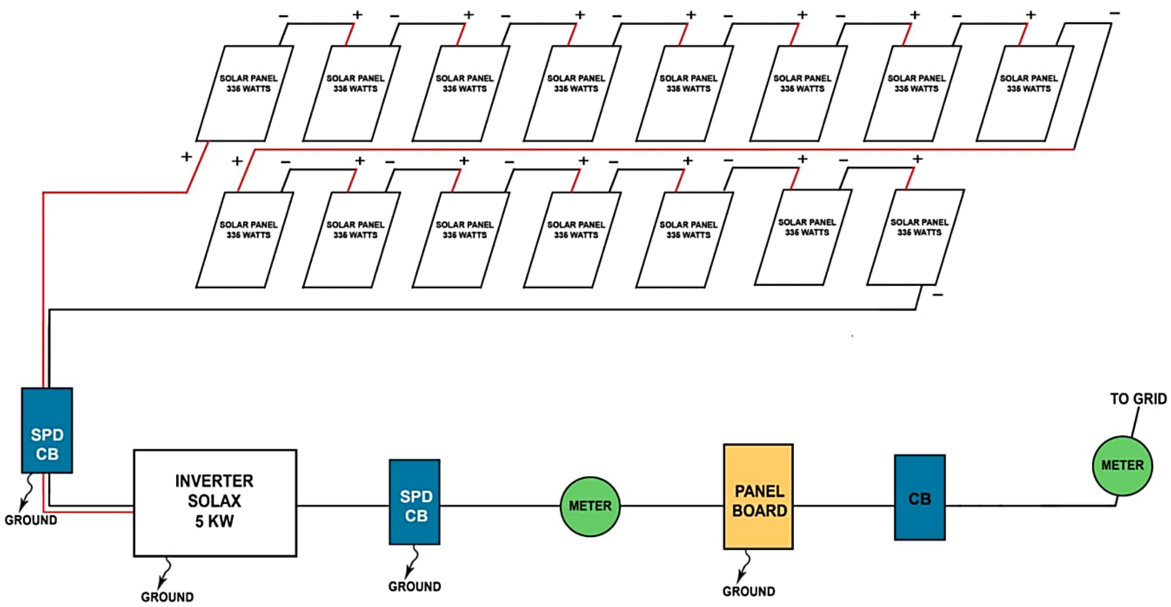

Figure 4. Flow chart of the PV system

The efficiency of the installation was calculated by means of PR. The PR is used to determine the closeness of plant production and prediction of the output of the plant. The PR of a solar PV system is determined by simply dividing the actual energy output by the theoretical maximum energy output, and multiplying the result by one hundred percent as in (1). Simply put, it is the measure of the efficiency of a solar system to change sunlight into electricity and considers through several losses. This is the maximum power that the system would produce under the ideal conditions, taking into consideration such variables as the solar radiation, the area of panels, and the efficiency of modules.

$$Performance\ ratio = \frac{Actual\ energy\ output}{Theoretical\ maximum\ energy\ output} \times 100\% \quad (1)$$

2.5. Ethical considerations

The ethical aspects of this study are of great significance since they ensure integrity, transparency, and respect to all stakeholders in the study process. To start with, the residential property owner provided informed consent with the purpose of the study, the methods of data collection, and the way the measurement data of their energy consumption will be used, without providing them any entitlement to back out at any point. All the data collected was anonymized and stored in a safe way to protect the privacy of the homeowner. The academic integrity was guaranteed by the publication of the methodology, including limits to the study and possible biases. The environmental responsibility will be ensured by considering the solar system components throughout their lifecycles and following the due process for the disposal of materials such as lithium-ion batteries. The results of the study are also presented in an objective manner without overgeneralizing, but taking into consideration the effects of climate on the results of Pampanga. Safety is observed for the latter during monitoring to provide safety for the researchers and the inhabitants. By addressing these areas of ethical concern, the research was to provide valuable information about renewable energy and maintain the standards of research conduct and social responsibility. These actions are consistent with the provisions of the Renewable Energy Act of 2008 and consistent with the greater goal of sustainable energy development of the Philippines.

3. RESULTS AND DISCUSSION

3.1. Photovoltaic production of various setups

A comparative study of PV energy production of seven different system configurations indicated that there was a huge variation in performance. The summary of the important statistical results of the PV harvest comparison study is in Table 2. This was supported by Krustal-Wallis test, which showed significant differences among setups (H =90.91, p <0.001), and required a further comparison in pairs. The NM1 (12.5 kWp net-metered) appeared to be the most efficient system with medium production of 42.40 kWh, much higher than any other systems (p <0.05). NM2 (7 kWp net-metered) was second and had a 32.85 kWh median performance, which set apart performance groups (groups A and B in the Tukey test).

Table 2. Summary table of the key results from the PV harvest comparison study

Setup	N	Median (kWh)	Mean (kWh)	Performance group	Key comparisons
NM1-12.5 kWp	32	42.40	39.34	A (Best)	Outperforms all (p <0.05)
NM2-7 kWp	32	32.85	31.13	B	8.23 kWh < NM1 (p <0.05)
A-6.215 kWp+300 Ah	31	22.50	21.89	C	No diff vs NM3/C1/C2
NM3-5.65 kWp+150 Ah	31	23.80	21.59	C	6 kWh > B (p =0.005)
C1-10.44 kWp	37	22.30	20.95	C	No diff vs C2 (p =0.524)
C2-10.44 kWp	37	22.70	21.06	C	-
B-5.65 kWp+150 Ah	31	17.80	17.72	C (Worst)	Underperforms all (p <0.05)

An intermediate performance cluster was established with 4 systems (A-6.215 kWp hybrid, NM3-5.65 kWp net-metered, C1-10.44 kWp limiter and C2-10.44 kWp limiter) producing statistically similar amounts (22-24 kWh median). It is worth noting that 10.44 kWp limiter systems (C1 and C2) did not differ significantly (p =0.524), indicating that the two limiter systems performed well at this power capacity. The B system (5.65 kWp hybrid) was performing much worse as it produced a median of 17.80 kWh. Such deviation indicates the possibility of installation, maintenance, or component problems that need additional examination. The results are consistent with global research on BPV performance. Choi and Bhakta [3] reported similar PR (64.47) of 50 kWp bifacial systems in South Korea. Darussalam *et al.* [8] observed that 15° tilted orientations in tropical Indonesia provided the best yields of energy (1,951 Wh), which is in line with the installation orientations in this research study. These results support those of Muñoz *et al.* [9], who concluded that grid-interactive bifacial systems in tropical Colombia produced 4.83% more generation than monofacial baselines.

3.2. Impacts on reduction to energy grid dependency of various photovoltaic set-ups

Table 3 shows the grid dependency reduction performance to all evaluated PV configurations. Grid dependency analysis showed there were clear performance levels depending on system configuration:

i) Systems with net-meters were the most energy independent:
   - NM1 (12.5 kWp) was producing 206.46% of household demand and exporting unnecessary electricity to the grid 649.14 kWh, bill-free electricity.
   - NM2 (7 kWp) provided 102.16% of the consumption with a small surplus (21.10 kWh).
   - NM3 (5.65 kWp+150 Ah) was 98.67% self-sufficient, but it had to import a power of 1.33% of the grid.

ii) Battery-stored hybrid systems reported moderate grid reduction:
   - System A (300 Ah battery): ratio of load supplied: 44.32% (55.68% grid dependency).
   - System B (150 Ah battery): 46.77% load injected (53.23% grid dependency)
   - Limiter-only systems (C1, C2) always covered half of the energy requirement, which was partially yet steadily independent of the grid.

Such results are in line with research in other countries. Saepulloh *et al.* [12] indicated that efficiency of bifacial systems across different seasons within the tropical region of Indonesia ranged between 7.73% (cloudy) and 15.85% (partly cloudy), which justified the seasonal performance differences. The annual PR of 54.21% (47.95-65.79) of the 12.5 kWp system is in agreement with the PRs recorded by Castro *et al.* [15]. In their analysis of hybrid renewable energy systems in the Philippines' Busuanga Island cluster. According to Barokah *et al.* [11], ground surface albedo plays a very important role in rear-side capture, as white covers generate 410 W in contrast to 370 W for asphalt, supporting the high mounting strategy which is utilized in this research to maximize the use of reflected light.

Table 3. Summary table for PV system performance and grid dependency reduction

Set up	kWp	Battery	Average daily kWh consumption	# of days testing	Total kWh harvest	Billed kwh	Self-used	Total energy used	Excess	Supplied load (%)
BPV w/net metering 1	12.5		19.67	31	1,258.91	609.77		609.77	-649.14	206.46
BPV Hybrid + limiter A	6.215	300	27.50	31	678.7	852.50	678.70	1,531.20	852.50	44.32
BPV Hybrid + limiter B	5.65	150	20.17	31	549.2	625.15	549.20	1,174.35	625.15	46.77
BPV limiter C-1	10		20.95	37	775.3	775.15	775.30	1,550.45	775.15	50.00
BPV limiter C-2	10		21.06	37	779.08	779.22	779.08	1,558.30	779.22	50.00
BPV w/net metering 2	7	100	30.47	32	996	974.90		974.90	-21.10	102.16
BPV w/net metering 3 +150AH	5.65	150	21.88	31	669.4	678.40		678.40	678.40	98.67

3.3. Performance ratios of bifacial photovoltaic at various set-ups

Table 4 shows the PR comparison across all system configurations. Analysis of PR showed that there were significant differences in efficiency in different configurations:

i) NM2 (7 kWp net-metered) was the highest PR (median 80.55% and mean 75.17%), which is significantly more than all other setups ($p < 0.05$). This means that it will have the best panel technology and net-metering setup to achieve efficiency in energy conversion.

ii) Middle-tier systems (PR range: 52-60 included) had hybrid and net-metered systems. It is worth noting that system A (300 Ah battery) showed a 6.95% higher PR as compared to system B (150 Ah battery), which affirms the fact that higher the capacity of the battery, the better the performance of the overall system. NM3 (5.65 kWp net-metered) demonstrated similar behavior to the larger NM1 system, indicating that benefits of net-metering can be used to counter the capacity differences.

iii) Worst-performing systems were limiter-only systems (C1/C2) with PR values of about 35-38% points, and highlight the performance disadvantages of systems that do not store or provide net-metering. They have statistically identical PR values ($p = 0.513$), which proves the consistent performance on the same setups.

Table 4. Summary table of the PR comparison of PV setups

Setup	Type	Median PR (%)	Mean PR (%)	Statistical grouping	Key comparisons
NM2 (7 kWp)	Net-metering	80.55	75.17	A (Highest)	Superior to all others (p <0.05)
A (6.215 kWp BPV +300 Ah)	Hybrid	60.08	59.47	B	No diff vs NM3 (p >0.05)
NM3 (5.65 kWp BPV +150 Ah)	Net-metering	55.99	55.39	B	No diff vs B (p =0.114)
NM1 (12.5 kWp BPV)	Net-metering	56.19	53.30	B	No diff vs NM3 (p >0.05)
B (5.65 kWp BPV +150 Ah)	Hybrid	52.14	52.52	B	6.95% < A (p <0.05)
C1 (10 kWp BPV Limiter)	Limiter-only	38.57	35.14	C (Lowest)	No diff vs C2 (p =0.513)
C2 (10 kWp BPV Limiter)	Limiter-only	38.85	35.00	C	-

These PR results are in tandem with global standards. Bifacial systems have been reported to gain 10-20% in energy yield through albedo effects [6], which is consistent with the 75.17% PR achieved by the NM2 system in this study. The seasonal PR variations (47.95-65.79) observed here can be attributed to monsoon effects on PV efficiency in Southeast Asia, as documented in studies of weather-related performance variability [11]. The performance increase of 6.95% with increased battery capacity aligns with the findings of Zubair and Abbas [10], who demonstrated that optimized energy storage configurations significantly improve the effectiveness of bifacial systems in tropical climates. Figure 5 illustrates a bar graph of the average PR of all seven configurations of BPV systems tested in this paper. The seven system setups (NM1, NM2, NM3, A, B, C1, and C2) appear on the x-axis, whereas the PR percentage (0-90%) is presented on the y-axis. NM2 (7 kWp net-metered) has the highest bar at 75.17% and is significantly superior to all other configurations. A middle group of systems with similar PR values consists of A (59.47%), NM3 (55.39%), NM1 (53.30%), and B (52.52%). C1 and C2 (limiter-only) have the shortest bars at approximately 35%, making them the least efficient of all setups. This chart clearly demonstrates the high performance of net-metered configurations and the limitations of limiter-only systems [8].

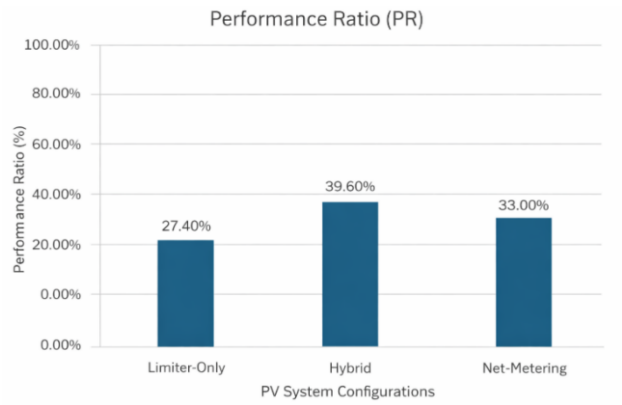

Figure 5. Summary of the PR

4. CONCLUSION

This paper tested bifacial solar PV systems on Pampanga homes and proved the opportunities it has in powering up households in tropical areas with energy autonomy. Net-metered stations always performed better compared to hybrid and limiter-only systems. The net-metered system of 12.5 kWp was completely able to produce a net meter on the grid, which generated 206.46% of household needs. The 7 kWp net-metered system had highest PR (75.17%). Battery storage made the hybrids less grid-dependent (44-56% reduction), with 300 Ah batteries performing better than 150 Ah batteries (6.95%). Limiter-only systems gave uniform yet partial (50%) grid independence. The results uphold SDG 7 and SDG 13 as they show less reliance on fossil fuels. Future work should address: i) monitoring degradation rates over a long period (5-10 years); ii) efficient integration and sizing of batteries; iii) policy analysis of net-metering; iv) comparison of bifacial and monofacial systems from a techno-economic perspective; and v) extreme weather and climate resilience research. These initiatives will inform policymakers, installers, and homeowners to optimize the deployment of BPV in tropical developing economies.

FUNDING INFORMATION

The authors received no funding or financial support for this research. The study was conducted independently, and there are no competing financial or non-financial interests related to this work.

AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Edgardo M. Santos	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest regarding the publication of this paper. No financial or personal relationships with other people or organizations have inappropriately influenced or could be perceived to have influenced the work reported in this study. The equipment and brands mentioned (e.g., JA solar panels, Deye inverter, Solarman monitoring system) are for technical reference only and do not imply endorsement or a commercial relationship. The research was conducted objectively, and the analysis presented is based solely on the empirical data collected.

INFORMED CONSENT

Prior to their inclusion in this study, informed consent was obtained from all homeowners participating in the research. The consent process involved a detailed explanation of the study's purpose, the nature of the data to be collected (including energy consumption, production data, and limited demographic information), and the methods of data collection, such as the use of data loggers and the Solarman business app. Participants were explicitly informed that their participation was voluntary and that they had the right to withdraw at any time without penalty. All data collected was anonymized to protect participant privacy and stored securely to prevent unauthorized access.

ETHICAL APPROVAL

This observational study was conducted in accordance with the ethical principles for research involving human participants as outlined in the Declaration of Helsinki. Formal ethical review and approval for this study were waived by the Research Management Office of the Pampanga State University because the research involved the analysis of anonymized energy data from pre-existing, operational residential solar PV systems. The study procedures posed minimal risk to participants, as no experimental interventions were performed. All data collection and handling protocols were designed to prioritize participant privacy and data security. The research solely involved the monitoring of system performance and aggregated energy consumption patterns. No personally identifiable information was collected or used in the analysis or publication of results.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [EMS], upon reasonable request. The data are not publicly available due to privacy restrictions, as they contain information that could compromise the privacy of the research participants.

REFERENCES

[1] The International Energy Agency (IEA), "World energy outlook 2023," iea.org. 2023. Accessed: Sep. 20, 2025. [Online]. Available: https://www.iea.org/reports/world-energy-outlook-2023
[2] A. A. Azooz and Z. T. Ali, "Modeling analysis of bifacial photovoltaic panels performance," *Journal of Renewable and Sustainable Energy*, vol. 17, no. 1, Jan. 2025, doi: 10.1063/5.0233385.
[3] Y. Choi and S. Bhakta, "Performance evaluation of 50 kWp bifacial multi-crystalline silicon solar photovoltaic energy system," *Journal of Mechanical Science and Technology*, vol. 39, no. 4, pp. 1617–1623, Apr. 2025, doi: 10.1007/s12206-025-2102-4.

[4] D. L. Dias, G. A. Rampinelli, G. N. Garrido, J. A. Tejero, M. S. D. C. Ortín, and L. E. Bremermann, "Performance assessment of bifacial and monofacial PV systems on different types of soils in a low-latitude site," *Renewable Energy*, vol. 246, Jun. 2025, doi: 10.1016/j.renene.2025.122868.

[5] United Nations, *Sustainable development goals report 2023: towards a rescue plan for people and planet*, New York, United States: United Nations, 2023.

[6] Government of the Philippines, "RA 9513 implementation review," climate.gov.ph. Accessed: Sep. 20, 2025. [Online]. Available: https://climate.gov.ph/public/ckfinder/userfiles/files/Knowledge/RA9513.pdf

[7] H. Shaikh and B. Bhasme, "Experimental analysis of vertical bifacial photovoltaics with flat and curved reflectors under tropical climatic conditions," *Journal of Renewable and Sustainable Energy*, vol. 17, no. 6, Nov. 2025, doi: 10.1063/5.0303489.

[8] R. Darussalam *et al.*, "Energy yields and performance analysis of vertical and tilted oriented bifacial photovoltaic modules in tropical region," *International Journal of Electrical and Computer Engineering*, vol. 15, no. 5, Oct. 2025, pp. 4508-4519, doi: 10.11591/ijece.v15i5.pp4508-4519.

[9] Y. Muñoz, M. D. L. Rosa, L. C. Acevedo, and W. Velandia, "Technical and financial assessment of photovoltaic solar systems with bifacial technology comparing four scenarios with different albedos with respect to the base scenario with monofacial technology, in a tropical location in Colombia," *International Journal of Energy Economics and Policy*, vol. 13, no. 4, pp. 389–393, Jul. 2023, doi: 10.32479/ijeep.14194.

[10] M. Zubair and G. Abbas, "Optimization of bifacial PV panels in a residential sector for maximum economic benefits based on load profile," *Energy Reports*, vol. 13, pp. 5252–5265, 2025, doi: 10.1016/j.egyr.2025.04.062.

[11] R. Barokah, N. N. Suryaman, and A. Rajani, "Experimental study of bifacial solar panels with reflective surface variations in Bandung, Indonesia," *Rekayasa Energi Manufaktur Jurnal*, vol. 10, no. 2, pp. 81–88, 2025, doi: 10.21070/r.e.m.v10i2.1758.

[12] L. Saepulloh, U. Komarudin, and R. Darussalam, "The effect of solar radiation on the performance of tilted bifacial photovoltaics," *Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering)*, vol. 14, no. 6, pp. 2404–2413, Dec. 2025, doi: 10.23960/jtepl.v14i6.2404-2413.

[13] F. M. Fossland, "Comparative performance analysis of two high-latitude solar photovoltaic systems," M.Sc. thesis, Department of Physics and Technology, UiT The Arctic University of Norway, Tromsø, Norway, 2023.

[14] S. R. Shajid, M. H. K. Jim, M. G. Kibria, and M. Mourshed, "Impact of dust, humidity, and design flaws on PV performance: a review," *Energy Reports*, vol. 15, Jun. 2026, doi: 10.1016/j.egyr.2025.108926.

[15] M. T. Castro, L. L. Delina, E. A. Esparcia, and J. D. Ocon, "Storm hardening and insuring energy systems in typhoon-prone regions: a techno-economic analysis of hybrid renewable energy systems in the Philippines' Busuanga island cluster," *Energy Strategy Reviews*, vol. 50, Nov. 2023, doi: 10.1016/j.esr.2023.101188.

[16] S. Dutta, "Philippines energy storage market (2025-2031): trends, companies, industry, forecast, share, analysis, segmentation, value, competitive landscape, growth, size & revenue, outlook," 6wresearch.com. Accessed: Sep. 20, 2025. [Online]. Available: https://www.6wresearch.com/industry-report/philippines-energy-storage-market

[17] M. Ansarinasab, "The role of renewable energy transition in achieving carbon neutrality within the SDG framework: challenges, and prospects," *Gondwana Research*, vol. 153, pp. 236–252, May 2026, doi: 10.1016/j.gr.2025.11.022.

[18] A. Tariq, F. Nawaz, S. A. Haider, G. A. El Rafae, U. Kayani, and A. L. Aziz, "Transitioning towards low carbon economy: role of renewable energy, economic growth and FDI in achieving SDGs," *International Journal of Energy Economics and Policy*, vol. 15, no. 3, pp. 403–410, Apr. 2025, doi: 10.32479/ijeep.18476.

[19] SDG Knowledge Hub, "92% of world's population has electricity access: SDG 7 progress report," sdg.iisd.org. Accessed: Sep. 20, 2025. [Online]. Available: https://sdg.iisd.org/news/92-of-worlds-population-has-electricity-access-sdg-7-progress-report/

[20] M. Hassan, "Descriptive research design: types, methods, and examples," researchmethod.net. Accessed: Sep. 20, 2025. [Online]. Available: https://researchmethod.net/descriptive-research-design/

[21] B. Williams, "Types of descriptive research design: a detailed overview," insight7.io. Accessed: Sep. 20, 2025. [Online]. Available: https://insight7.io/types-of-descriptive-research-design-a-detailed-overview/

[22] J. W. Creswell and D. J. Creswell, *Research design: qualitative, quantitative and mixed methods approaches*. Thousand Oaks, United States: SAGE Publications, 2018.

[23] R. K. Yin, *Case study research and applications: design and methods*. Thousand Oaks, United States: SAGE Publications, 2017.

[24] R. E. Stake, *The art of case study research*. Thousand Oaks, United States: SAGE Publications, 1995.

[25] N. K. Denzin and Y. S. Lincoln, *The sage handbook of qualitative research*. Thousand Oaks, United States: SAGE Publications, 2018.

[26] A. Field, *Discovering statistics using IBM SPSS statistics*, 5th ed. Thousand Oaks, United States: SAGE Publications, 2018.

[27] W. R. Shadish, T. D. Cook, and D. T. Campbell, *Experimental and quasi-experimental designs for generalized causal inference*. Boston, United States: Houghton Mifflin, 2002.

[28] D. T. Campbell and J. C. Stanley, *Experimental and quasi-experimental designs for research*. Boston, United States: Houghton Mifflin, 1963.

[29] J. W. Creswell and C. N. Poth, *Qualitative inquiry and research design: choosing among five approaches*. Thousand Oaks, United States: SAGE Publications, 2018.

BIOGRAPHIES OF AUTHORS

Edgardo M. Santos is an associate professor in the Department of Electrical Engineering at Pampanga State University. He holds a bachelor's degree in Electrical Engineering, a Master of Engineering Program in Electrical Engineering, and a Doctor of Philosophy in Engineering Management. His research expertise spans power electronics, electrical power system stability, solar energy, and PV application systems, with a strong focus on developing and optimizing sustainable energy technologies for real-world implementation. He can be contacted at email: emsantos@pampangastateu.edu.ph.