Advanced Journal of Science, Technology and Engineering
ISSN 2997-5972 • Volume 6, Issue 1, 2026 • pp. 133–143

RESEARCH ARTICLE

Received: 15 Jul 2026, Accepted: 6 Aug 2026, Published: 8 Sep 2026

Comparative Analysis of Solar Panels and their Characteristics

Okpeki U. K.[1]; Adegoke A. S.[2]; Oyubu A. O.[3]; Obuseh E. E.[4]; Oyovwe B. E.[5].; Unuajowofia U.[6]

[1,3,4,6]*Department of Electrical/Electronic Engineering, Delta State University, Delta State, Nigeria.*
[2]*Department of Computer Engineering, Lagos State University of Science and Technology, Ikorodu, Lagos.*
[5]*Department of Computer Engineering, Delta State University, Abraka, Nigeria.*

Abstract

The global shift towards renewable energy has intensified interest in solar photo-voltaic as a clean and sustainable energy source, particularly in regions like Nigeria, where energy reliability remains a critical issue. However, selecting the most suitable solar panel type for diverse climatic conditions remains a challenge due to significant variability in panel performance. This study aimed to address this gap by conducting a comparative analysis of monocrystalline and polycrystalline solar panels under real-world conditions across three distinct Nigerian locations: Oleh, Ughelli, and Uyo. The methodology involved mounting panels at tilt angles of 15° and 45°, recording performance metrics such as voltage, current, and power output using pyranometers and a digital multimeter. Data were analyzed comparatively using Python and Microsoft Excel to assess the impact of environmental factors and tilt angles on panel efficiency. Results revealed that monocrystalline panels consistently outperformed polycrystalline counterparts, particularly at a 45° tilt angle, which optimized solar energy capture during peak sunlight hours. These findings underscore the importance of tilt angle adjustments and panel selection in enhancing energy efficiency in tropical regions. The study concludes that adopting monocrystalline panels with optimized tilt angles presents a viable strategy for maximizing solar energy generation in Nigeria, contributing to sustainable energy solutions.

Keywords: Efficiency; Monocrystalline; Photovoltaic; Polycrystalline; Solar Panels; Tilt Angle.

How to Cite: Okpeki, U. K., Adegoke, A. S., Oyubu, A. O., Obuseh, E. E., Oyovwe, B. E., & Unuajowofia, U. (2026). Comparative Analysis of Solar Panels and their Characteristics. Advanced Journal of Science, Technology and Engineering, 6(1), 133–143. https://doi.org/10.52589/AJSTE-YR8ISF2D

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INTRODUCTION

Nigeria's abundant solar energy resources offer a promising solution to its ongoing energy challenges, including unreliable electricity supply and dependence on fossil fuels. With high levels of solar radiation throughout the year, the country has immense potential to embrace solar power as a sustainable and reliable energy source. However, the performance of solar photovoltaic (PV) systems depends heavily on how well they are designed and installed to suit local conditions. Solar panels come in two main types: Monocrystalline and polycrystalline. Monocrystalline panels, made from a single silicon crystal, are highly efficient and ideal for locations where space is limited. Polycrystalline panels, on the other hand, are manufactured using multiple silicon crystals, making them more affordable but slightly less efficient. Beyond the type of panel, their orientation and tilt angle play a crucial role in determining how much sunlight they can capture, which directly impacts their energy output.

Research shows that adjusting the tilt angle of solar panels to match the latitude of the installation site can significantly enhance energy production. By ensuring that the panels are positioned to receive maximum sunlight throughout the day, their efficiency can improve dramatically (Mamun et al., 2022). Additionally, factors like dust and dirt accumulation (known as soiling) can reduce a panel's efficiency by as much as 25%, making regular cleaning and maintenance critical to their long-term performance (Nwokolo et al., 2023),

In tropical regions like Nigeria, the challenge of optimizing solar panel installations is compounded by diverse weather conditions and geographic variations. Research from similar climates has shown that even small adjustments in tilt angle can make a substantial difference in both energy output and key electrical parameters, such as voltage and current. Studies have also highlighted that tilt angles optimized for local conditions significantly enhance solar panel performance (Khan et al., 2019). Despite these advancements, there is still a lack of comparative studies focusing on the real-world performance of Monocrystalline and polycrystalline panels under identical conditions across multiple Nigerian locations. This research aims to bridge that gap by evaluating the performance of these two types of solar panels in three distinct locations: Oleh, Ughelli, and Uyo. By examining how tilt angles and environmental factors influence their efficiency, this research hopes to offer practical insights into optimizing solar PV installations. Ultimately, this work contributes to Nigeria's efforts to harness solar energy effectively and transition toward more sustainable energy solutions.

The efficiency and effectiveness of photovoltaic (PV) systems are heavily impacted by various factors, including tilt angle, azimuth orientation, and soiling. These elements play a crucial role in determining energy output, overall system performance, and environmental sustainability. To better understand and optimize these influences, researchers have employed a range of approaches, including experimental studies, computational models, and theoretical analyses. The tilt angle plays a critical role in optimizing the amount of solar radiation absorbed by PV panels. Mamun et al. (2022) emphasized that aligning panels with the latitude of a location ensures optimal performance. Their experimental work in Malaysia demonstrated that tilt angles of 15° maximize energy capture under both constant and variable irradiation levels, with outdoor conditions showing a 3.45 W power drop for every 5° increase in tilt angle beyond the optimum. Similarly, Sharma et al. (2022) evaluated a large-scale PV plant in India, finding that adjusting tilt angles seasonally increased energy capture by 2.41%, resulting in a 0.26% rise in capacity utilization factor. Soiling, caused by dust and environmental pollutants, significantly reduces the efficiency of PV systems.

Nwokolo et al. (2023) examined the combined impact of soiling and tilt angles, concluding that soiling-induced losses can depreciate system efficiency by nearly 0.47% annually, underscoring the importance of regular cleaning and optimal tilt adjustment to mitigate these losses.

Several studies have leveraged mathematical models and simulations to optimize tilt angles for various climatic conditions. Hafez et al. (2017) reviewed computational techniques for determining tilt angles, including artificial intelligence methods like particle swarm optimization (PSO) and genetic algorithms. These models were shown to improve energy capture by fine-tuning tilt angles based on site-specific conditions. Similarly, Xu et al. (2020) proposed a model incorporating dust deposition and tilt angle interactions, providing a more accurate framework for optimizing PV performance in soiled environments.

While theoretical models offer precision, experimental studies reveal practical limitations. For instance, Khan et al. (2019) found discrepancies in the predicted and actual performance of PV panels due to unaccounted environmental factors such as wind speed and shading. Additionally, Mamun et al. highlighted the inefficiency of static panels in dynamic environments, suggesting that semi-automated tilt systems could bridge this gap. Despite significant progress, gaps remain in understanding the long-term impact of tilt adjustments and soiling on PV systems. Few studies have explored the integration of automated cleaning systems with tilt-optimized PV setups to enhance energy yield and reduce maintenance costs. Additionally, most research focuses on high-latitude regions, leaving low-latitude areas like Nigeria underrepresented. Furthermore, the combined effects of tilt angles, azimuth adjustments, and real-time environmental factors such as humidity and temperature variations require further exploration. This research aims to fill a critical gap by providing empirical data on the real-world performance of Monocrystalline and polycrystalline solar panels under varying tilt angles in Nigeria's diverse climatic regions. Unlike existing studies that predominantly focus on theoretical models or high-latitude regions, this study evaluates both panel types in three distinct locations: Oleh, Ughelli, and Uyo. By analyzing environmental factors such as soiling, temperature, and sunlight intensity, the research will offer actionable insights for optimizing solar panel installations in tropical and low-latitude regions, contributing to a more sustainable energy future for Nigeria and similar regions.

MATERIALS AND METHODS

This study is designed to compare the performance of Monocrystalline and polycrystalline solar panels under real-world conditions across three distinct locations. The materials used are Mono-crystalline, Polycrystalline solar panels of 300W each, adjustable frame, bolts and nuts, a digital multimeter, a pyranometer, an inclinometer and Python software used for the analysis. The parameters of the materials are given in Table 1. The experimental setup model is also given in Figure 1. The research focuses on how environmental factors, panel types, and tilt angles affect solar energy generation and efficiency. To achieve this, panels were mounted at tilt angles of 15° and 45°, and their performance was monitored using precision instruments. Data collected were analyzed using advanced tools, providing insights to optimize solar energy systems for tropical climates.

Study Area

The study was conducted in three diverse locations to capture a wide range of environmental and geographical conditions. Oleh located at 5.5069° N and 6.1968° E, has a tropical climate

https://doi.org/10.52589/AJSTE-YR8ISF2D

characterized by a wet season from April to October and a dry season from November to March. With an average annual temperature of 27°C, Oleh served as a representative rural environment for this study.Ughelli positioned at 5.5000° N and 6.0000° E, Ughelli offered a unique urbanized environment with higher humidity levels and potential pollution influences. Uyo situated at 5.0513° N and 7.9335° E, this coastal environment that adds further geographical diversity. Uyo experiences high solar radiation and varying weather conditions, making it ideal for studying panel performance in humid, tropical climates. These locations were chosen to ensure the results would apply to a wide range of real-world scenarios.

Solar Panel Selection

To ensure a meaningful comparison, both Monocrystalline and polycrystalline solar panels were selected with identical power ratings of 300 W. These panel types were chosen for their widespread use and distinct performance characteristics. The Monocrystalline panels, with an efficiency of 19.5%, were expected to outperform the polycrystalline panels, which have a lower efficiency of 16.5%. Both panels were provided by the same manufacturer, SunPro Power, ensuring uniformity in build quality and specifications. Table 1 shows the selected panel specifications.

Table 1: Solar Panel Specification

Specification	Monocrystalline Solar Panel	Polycrystalline Solar Panel
Panel Type	Monocrystalline(300watts)	Polycrystalline(300watts)
Power Rating	300W	300W
Efficiency	19.5%	16.5%
Dimensions (mm)	1640 X 992 X 35mm	1956 X 992 X 40mm
Open Circuit Voltage (Voc)	41.2V	38.5V
Short Circuit Current (Isc)	9.45A	9.8A
Manufacturer	SunPro Power	SunPro Power

Experimental Setup

The experimental setup was designed to provide a controlled environment for assessing the panels' performance. Adjustable frames allowed the panels to be mounted at precise tilt angles of 15° and 45°, ensuring optimal exposure to sunlight. These angles were selected to represent typical configurations in tropical regions, where the sun’s position varies significantly throughout the day. At each location, the panels were aligned true south to maximize solar energy capture. The 15° tilt angle was ideal for capturing midday sunlight, while the 45° tilt angle was chosen to evaluate performance during early morning and late afternoon when the sun is lower in the sky. An inclinometer was used to ensure accurate angle adjustments for consistency across all sites. Figure 1 shows the experimental setup.

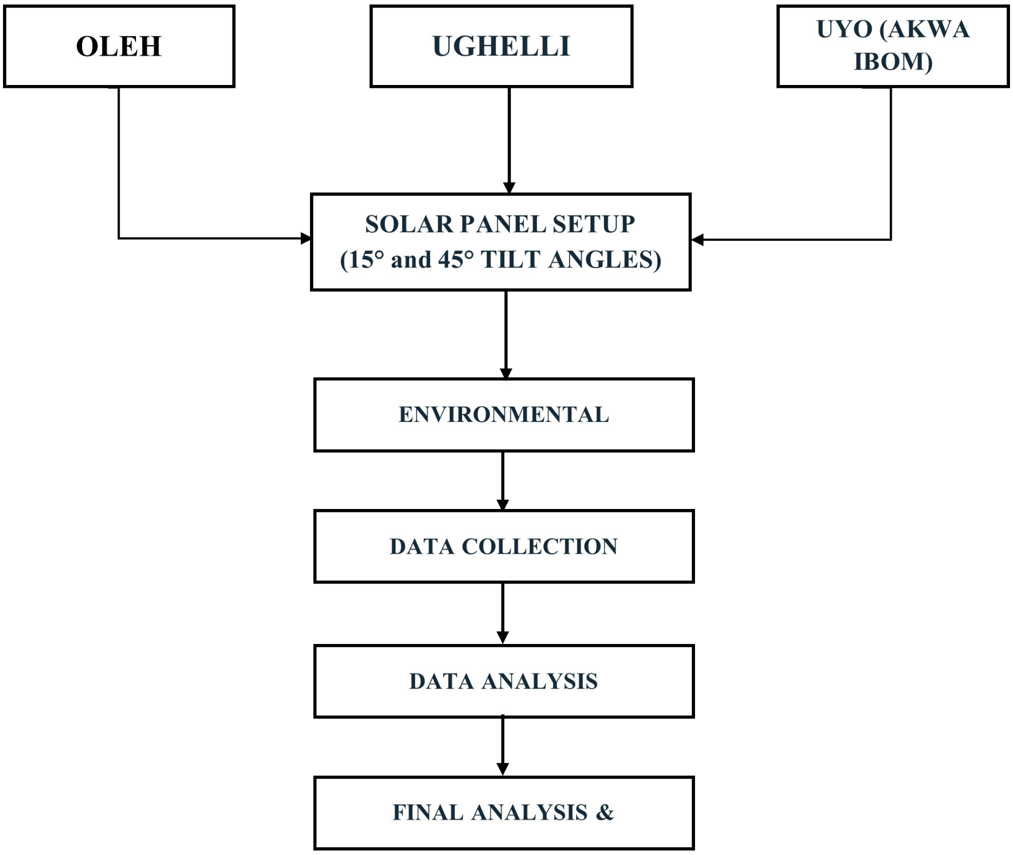

Figure 1: Flow diagram of the experimental Setup

Measurement Instruments

Accurate data collection was a critical aspect of this study and was achieved through the deployment of specialized instruments. A pyranometer was used to measure the solar radiation incident on the panels, expressed in watts per square meter (W/m²). This instrument provided precise readings of sunlight intensity, which is a fundamental factor in assessing solar panel performance. Additionally, a digital multimeter was employed to record essential electrical parameters, including voltage (V) and current (A). These measurements were integral to calculating the power output of each panel under various conditions. To ensure the panels were aligned at the designated tilt angles of 15° and 45°, an inclinometer was used. This instrument allowed for accurate verification and adjustment of the panel orientations, ensuring consistency across all test setups and locations. These tools collectively ensured the reliability and precision of the data collected during the experimental phase.

Data Collection

Data were collected hourly between 10 a.m. and 2 p.m. over six days in August. This time frame was chosen to capture peak solar radiation, providing consistent and stable conditions for performance evaluation. Parameters such as solar radiation, voltage, current, and power output were recorded for both panel types at each tilt angle. Tables 2-7 show the data collected.

Table 2: Solar Panel Performance Dataset in Oleh at 15° Tilt (Day 1)

TIME	Solar Radiation (W/m²)	Mc - Voltage (V)	Mc-Current (A)	Mc-Power Output (W)	Pc-Voltage (V)	Pc-Current (A)	Pc-Power Output (W)
10:00 AM	755.16	41.75	5.49	229.12	38.40	5.20	199.68
11:00 AM	685.89	38.35	8.11	310.93	35.60	7.80	277.68
12:00 PM	692.76	32.40	9.32	301.79	30.20	9.00	271.80
1:00 PM	675.11	32.16	5.79	186.13	30.40	5.50	167.20
2:00 PM	714.76	39.74	9.96	395.92	36.80	9.60	353.28

Table 3: Solar Panel Performance Dataset in Oleh at 45° Tilt (Day 2)

TIME	Solar Radiation (W/m²)	Mc - Voltage (V)	Mc-Current (A)	Mc-Power Output (W)	Pc-Voltage (V)	Pc-Current (A)	Pc-Power Output (W)
10:00 AM	507.02	43.16	7.22	311.57	40.50	6.80	275.40
11:00 AM	441.92	31.40	6.96	218.52	29.20	6.55	191.06
12:00 PM	405.81	36.39	7.66	278.76	33.80	7.20	243.36
1:00 PM	935.23	37.10	9.23	342.30	34.90	8.80	306.12
2:00 PM	480.08	38.70	7.68	297.29	36.00	7.40	266.40

Table 4: Solar Panel Performance Dataset in Ughelli at 15° Tilt (Day 3)

TIME	Solar Radiation (W/m²)	Mc - Voltage (V)	Mc-Current (A)	Mc-Power Output (W)	Pc-Voltage (V)	Pc-Current (A)	Pc-Power Output (W)
10:00 AM	665.21	38.09	5.43	206.63	35.30	5.20	183.56
11:00 AM	911.58	34.89	5.47	190.90	32.40	5.25	170.10
12:00 PM	660.06	32.21	8.17	263.05	30.10	7.80	234.78
1:00 PM	896.12	32.40	9.75	315.77	30.50	9.25	282.13
2:00 PM	705.61	31.94	9.68	309.31	29.80	9.30	277.14

Table 5: Solar Panel Performance Dataset in Ughelli at 45° Tilt (Day 4)

TIME	Solar Radiation (W/m²)	Mc - Voltage (V)	Mc-Current (A)	Mc-Power Output (W)	Pc-Voltage (V)	Pc-Current (A)	Pc-Power Output (W)
10:00 AM	867.52	40.74	8.40	342.30	37.80	7.80	294.84
11:00 AM	955.10	30.41	8.05	244.64	28.10	7.50	210.75
12:00 PM	829.11	40.97	5.49	225.03	38.10	5.10	194.31
1:00 PM	694.49	41.50	5.46	226.62	38.70	5.20	201.24
2:00 PM	681.70	30.15	5.28	159.17	27.50	5.00	137.50

Table 6: Solar Panel Performance Dataset in Uyo at 15° Tilt (Day 5)

TIME	Solar Radiation (W/m²)	Mc - Voltage (V)	Mc-Current (A)	Mc-Power Output (W)	Pc-Voltage (V)	Pc-Current (A)	Pc-Power Output (W)
10:00 AM	451.83	38.68	7.24	279.95	36.50	6.95	253.68
11:00 AM	796.02	31.38	8.64	271.11	29.20	8.30	242.36
12:00 PM	523.96	43.66	8.71	380.31	40.80	8.40	342.72
1:00 PM	908.37	31.24	6.53	204.18	29.60	6.25	185.00
2:00 PM	808.82	42.01	5.60	235.18	39.60	5.30	209.88

Table 7: Solar Panel Performance Dataset in Uyo at 45° Tilt (Day 6)

TIME	Solar Radiation (W/m²)	Mc - Voltage (V)	Mc-Current (A)	Mc-Power Output (W)	Pc-Voltage (V)	Pc-Current (A)	Pc-Power Output (W)
10:00 AM	929.63	34.62	5.43	188.10	32.00	5.10	163.20
11:00 AM	693.05	33.49	6.19	207.18	31.00	5.90	182.90
12:00 PM	648.74	37.55	9.20	345.38	34.50	8.70	300.15
1:00 PM	504.47	44.31	7.61	337.25	41.40	7.20	298.08
2:00 PM	685.17	38.37	7.57	290.26	35.50	7.20	255.60

Data Analysis

The collected data were processed and analyzed using a combination of software tools. Microsoft Excel was employed for initial data organization and basic statistical calculations, while Python was utilized for more advanced analysis and visualization. Libraries such as pandas and Matplotlib enabled the creation of detailed graphs and charts to compare the performance of the panels under different conditions. Key metrics analyzed included Power Output, Tilt Angle Impact**,** and Panel Type Comparison

Advanced Journal of Science, Technology and Engineering
ISSN 2997-5972 • Volume 6, Issue 1, 2026 • pp. 133–143

RESULTS AND DISCUSSION

This section presents the findings from the performance analysis of Monocrystalline and polycrystalline solar panels across three locations: Oleh, Ughelli, and Uyo. The results are discussed in relation to power output, the effect of tilt angles, and comparative performance, offering insights into the strengths and limitations of each panel type under varying environmental conditions.

Power Output Comparison

The power output of both Monocrystalline (MC) and polycrystalline (PC) panels was analyzed at tilt angles of 15° and 45°.

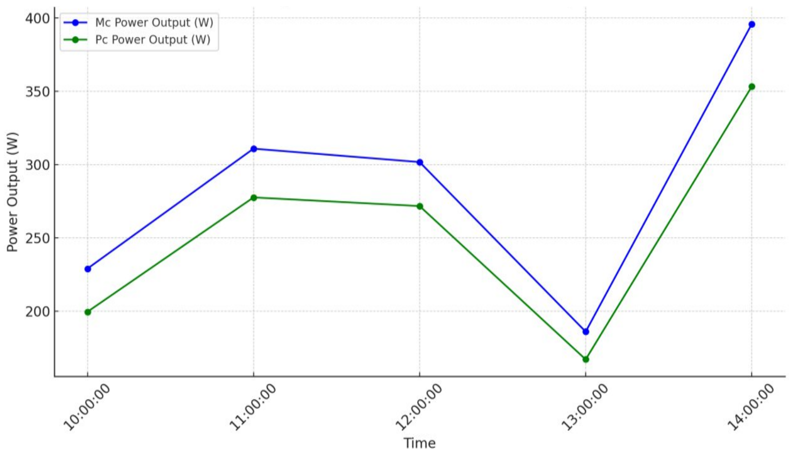

Figure 2: Power Output Comparison in Oleh at 15° tilt

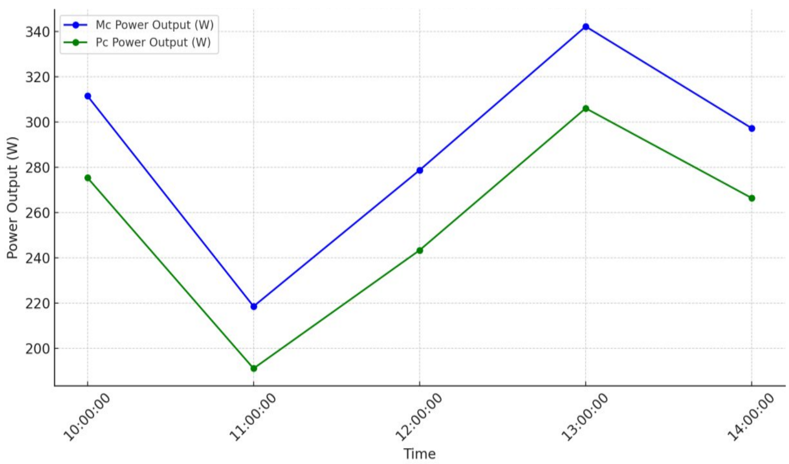

Figure 3. Power output Comparison in Oleh at 45^0 tilt

Oleh: In Figure 2, at a 15° tilt, the MC panel consistently outperformed the PC panel throughout the day, with the most significant differences observed during peak sunlight hours (12:00 PM - 2:00 PM). In Figure 3 at 45° tilt, the MC panel maintained its superior performance, though the gap between the two panels narrowed slightly, suggesting environmental variability.

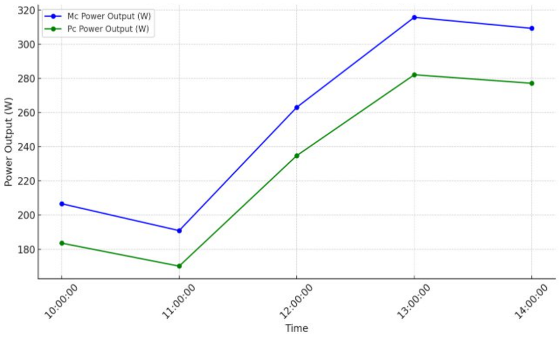

Figure 4: Power Output Comparison in Ughelli at 15° tilt

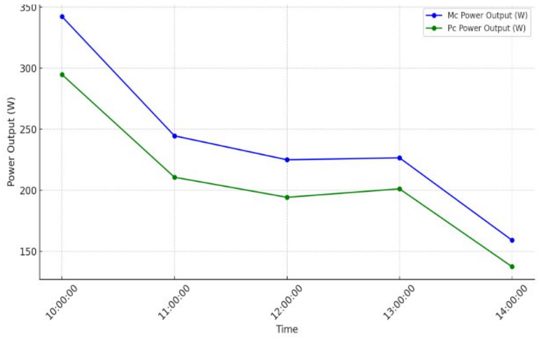

Figure 5. Power Output comparison in Ughelli at 45^0 tilt

Ughelli: In Figure 4, at a 15° tilt, MC panels again demonstrated higher efficiency, with peak output exceeding 300 W during midday hours. In Figure 5 at a 45° tilt, fluctuations in output were more pronounced, likely due to changing weather conditions, including rainfall. MC panels retained their efficiency advantage despite these fluctuations.

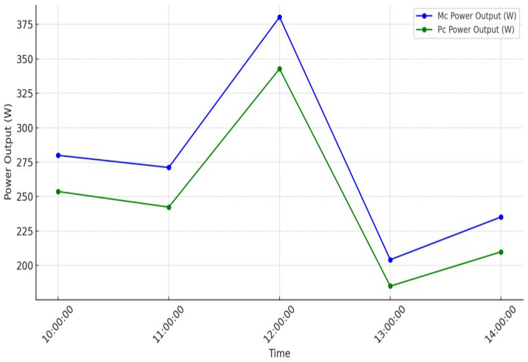

Figure 6: Power Output Comparison in Uyo at 15° tilt

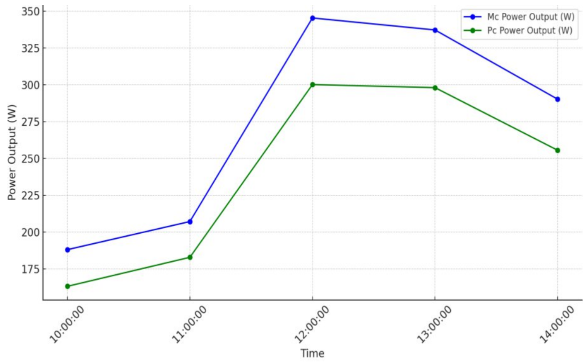

Figure 7. Power output comparison in Uyo at 45^0 tilt

Uyo: In Figure 6, at a 15° tilt, MC panels consistently produced higher power output, with noticeable peaks during midday. In Figure 7, at a 45° tilt, both panels showed more variability, but Mc panels still outperformed Pc panels, albeit with a smaller margin.

Tilt Angle Performance Analysis

The tilt angle significantly influenced the performance of both panel types. Across all locations: a 45° tilt generally resulted in higher power output compared to a 15° tilt, particularly during peak sunlight hours.The 45° tilt allowed for better alignment with the sun's path, maximizing energy capture.

Comparative Analysis

Monocrystalline panels consistently outperformed polycrystalline panels in terms of power output, voltage, and current across all conditions. The efficiency advantages of MC panels make them better suited for environments with high solar radiation and limited installation space. Conversely, PC panels, while less efficient, remain a cost-effective option for less demanding energy needs.

The results underscore the impact of environmental factors, such as solar radiation intensity and tilt angle, on the performance of solar panels. Monocrystalline panels demonstrated clear advantages in efficiency and power output, particularly in high-radiation environments. However, the performance of polycrystalline panels under suboptimal conditions highlights their potential as a viable alternative in cost-sensitive scenarios.

These findings contribute to a deeper understanding of solar panel performance in tropical climates and emphasize the importance of tailoring installation parameters to local conditions to achieve optimal energy generation.

CONCLUSION

This study evaluated the performance of Monocrystalline and polycrystalline solar panels under real-world conditions in three distinct locations: Oleh, Ughelli, and Uyo. The findings highlight the significant impact of tilt angles, environmental factors, and panel type on energy generation and efficiency. Monocrystalline panels consistently outperformed polycrystalline panels, demonstrating superior efficiency and power output, especially during peak sunlight hours. However, polycrystalline panels provided a cost-effective alternative with reasonable performance under less demanding conditions.

The analysis also revealed that a 45° tilt angle generally optimized energy capture, aligning better with the sun's path in the studied tropical regions. These insights offer valuable guidance for stakeholders in selecting appropriate solar technologies and optimizing installation configurations to enhance solar energy utilization in tropical climates.

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