International Journal of Multidisciplinary Research and Bulletin
ISSN 3108-1428
Volume 5 Issue 4 (July – Aug) 2026

PERFORMANCE COMPARISON OF MONOCRYSTALLINE AND POLYCRYSTALLINE SOLAR PANELS IN KEBBI STATE, NIGERIA

Abdullahi Bako[1*], Mansur Kabiru[2], Mahmud Farouk Rugga[3], Auwal Mustapha Iman[4], Hassan Amina Danbagudu[5]

*Correspondence: Abdullahi Bako

[1,3,5,] Department of Physics with Electronics, Federal University, Birnin Kebbi, Nigeria.

[2]Advance Aircraft Engineering Laboratory, Gusau. National Space Research and Development Agency (NARSDA), Nigeria.

[4]Nigeria Institute of Leather and Science Technology (NILEST), Zaria, Nigeria.

Article History

Received: 14 July 2026 | Accepted: 17 July 2026 | Published: 21 July 2026

DOI: 10.5281/zenodo.21477732

ABSTRACT

This study investigates the performance and efficiency of 20W monocrystalline and polycrystalline solar panels in Bayan Kara, Birnin Kebbi metropolis. Monocrystalline panels, which are made of pure silicon, are more efficient (15%–22%), take up less space, have a black appearance, and perform better in warm weather, making them ideal for areas with high solar intensity. In contrast, polycrystalline panels, constructed from multicrystalline silicon, typically have lower efficiency (13%–18%), a blue tint, and decreased performance in hot conditions, but are more cost-effective. Both types of panels usually last 25 to 35 years. The findings of the research suggest that monocrystalline panels are superior to polycrystalline panels in the specific location studied. Therefore, monocrystalline solar panels are recommended for residential solar power generation in Bayan Kara due to their higher efficiency and thermal performance, while polycrystalline panels may be a better choice for those prioritizing lower initial costs.

Keywords: performance, Efficiency 20W Monocrystalline, and Polycrystalline Solar Panel, pyronometer, Birnin Kebbi Metropolis.

1.0 INTRODUCTION

The increasing global focus on energy security, environmental preservation, and the diminishing fossil fuel reserves has hastened the quest for clean and sustainable energy alternatives. Renewable energy has become crucial for achieving sustainable development goals and reducing carbon emissions, offering a reliable path to energy independence and economic stability. Solar energy stands out as a promising renewable energy source due to its abundance, accessibility, and versatility in various environmental conditions. Solar photovoltaic (PV) systems, which directly convert sunlight into electricity, have garnered significant attention in recent times for research and technological advancements. The efficiency and performance of PV systems are heavily influenced by the type of solar cell employed, with monocrystalline and polycrystalline technologies being commonly used. Monocrystalline solar panels, crafted from single-crystal silicon, are renowned for their high efficiency, greater power output, and enhanced performance in high-temperature settings. Conversely, polycrystalline panels, made of multiple silicon crystals, present a more affordable option, albeit with slightly lower efficiency and temperature resilience. Understanding the comparative performance of these two solar technologies is crucial for optimizing renewable energy generation, particularly in regions like Birnin Kebbi, Nigeria, where solar irradiance is plentiful year-round. Solar panel efficiency is predominantly influenced by the level of solar radiation they receive, known as solar irradiance – the amount of sunlight energy incident on a specific area. In space, this irradiance is constant (around 1365 W/m²), but on Earth's surface, factors like atmospheric absorption and scattering reduce it to an average of about 1000 W/m² under clear skies when panels are directly facing the sun. The intensity of solar irradiance directly impacts a solar panel's energy production capacity. Since solar cells demonstrate non-linear behaviors, their performance is accurately assessed through characteristic curves, such as current-voltage (I–V) and power-voltage (P–V) curves, which illustrate how the cell converts light energy into electrical power.

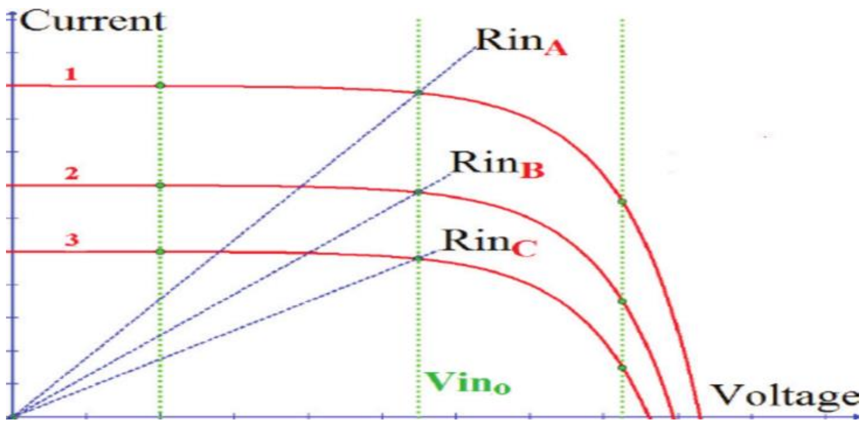

Figure 1: Voltage Current Curve

Figure 1 illustrates the behavior of a solar cell when connected to an external load R. The load introduces a linear relationship represented by the line $I/V = I/R$, indicating that the output power depends on the resistance value. When $R$is very small, the operating point shifts to the MN region, where the cell functions like a constant-current source and approaches the short-circuit current (I_{SC}). Conversely, a large Rmoves the operating point to the PS region, where the cell behaves as a constant-voltage source near the open-circuit voltage (V_{OC}). At the optimal load R_{opt}, the solar cell delivers its maximum power, corresponding to the maximum voltage ($V_{\max}$) and maximum current ($I_{\max}$).

The following current-voltage curve parameters are frequently used to ascertain the output properties of solar cells:

1. Short circuit current (I_{SC}) is the maximum output current from the solar cell
2. Open circuit voltage (V_{OC}) is the maximum voltage capacity that can be reached
3. Maximum power (p_{max}) in Figure 1, is at point A (V_{Max}),I_{Max}).
4. Fill Factor (FF) is a price that is close to the constant of a particular solar cell.

In essence, fill factor is a gauge of the solar cell's quality. It is computed by contrasting the output power at open-circuit and short-circuit voltages with the theoretical maximum power. As shown in Figure 2, the basic equivalent sequence for a PV solar cell is a current source powered by sunlight connected in parallel to the diode. Nonetheless, short-circuit current and open-circuit voltage are the two crucial factors for PV solar cells, as shown in Figure 3.

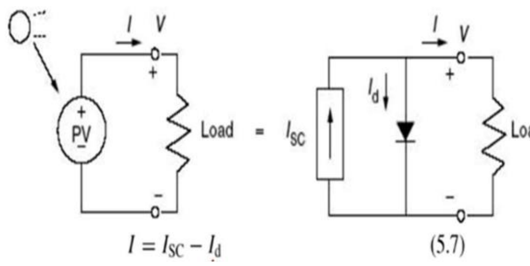

Figure 2: Solar Cell Equivalent Sequence

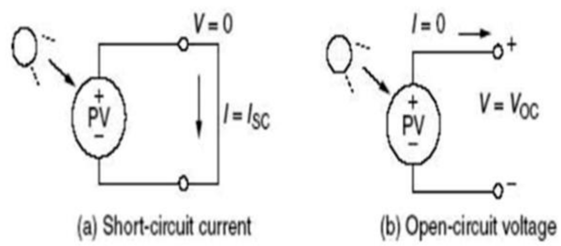

Figure 3: Testing Series

This study compared the performance and efficiency of 20W monocrystalline and polycrystalline solar panels in the Birnin Kebbi metropolis. The study aims to evaluate how factors like operational conditions, materials used, and environmental influences impact the performance of solar technology in real-world scenarios. The findings are expected to offer valuable insights into selecting and utilizing suitable solar technology for small-scale and household renewable energy systems in tropical regions

2.0 Review of other work

Research on renewable energy technologies has expanded significantly over the past decades, with solar photovoltaic (PV) systems receiving particular attention due to their versatility and potential for large-scale deployment. Numerous studies have examined the performance characteristics, efficiency, and reliability of different types of solar panels, especially monocrystalline and polycrystalline modules, under varying environmental and operational conditions. According to [3-6, 7], solar energy plays a crucial role in promoting global sustainability by reducing carbon emissions and ensuring long-term energy security. Similarly, [8-12] highlighted that the performance of solar panels is strongly influenced by environmental parameters such as temperature, irradiance, and material quality, noting that monocrystalline panels often exhibit superior efficiency due to their uniform crystal structure. Other researchers, including [13], have emphasized that while solar energy is a promising renewable resource, its successful implementation depends on addressing both technical and socio-economic challenges. Solar energy is gaining global attention as a renewable and sustainable source of power due to its potential to reduce carbon emissions, enhance energy independence, and provide cost savings, making it an attractive alternative to conventional energy sources [14, 15]. [16,17] presents the performance of solar panels is influenced by environmental conditions, which directly affect the electrical energy they generate. Studies using single-diode models with the five-parameter system have identified monocrystalline solar panels as among the most effective and optimal types. Despite its promise, the effective implementation of solar energy systems can be influenced by technical, environmental, and social factors [18]. Nigeria, with abundant solar irradiance throughout the year, has significant potential for solar energy generation. However, [19] presents that many solar energy projects have not achieved their intended outcomes due to implementation barriers. Photovoltaic (PV) solar cells are widely recognized as a viable solution to the country's current energy challenges and as an ideal energy source for the future [20]. Current commercial efficiencies are approximately 26% for crystalline silicon cells and 22% for thin-film modules presented in [21]. To make PV solar systems more viable and cost-competitive, efforts have focused on increasing efficiency and reducing production costs. Over the last decade, the efficiency of crystalline silicon and thin-film solar modules has improved from around 18% and 10% to 26% and 22%, respectively. Simultaneously, production costs have declined dramatically, with the average price of a solar module reaching $0.50 per watt by July 2016, whereas the average cost of solar cells decreased from $81.12 per watt in 1978 to $0.34 per watt in 2017 [21]. In this study, monocrystalline and polycrystalline solar panels are compared. It aims to investigate the efficiency differences between the two types, examine how factors such as environmental conditions, material quality, and manufacturing processes affect their performance, and assess the practical implications of these differences in terms of cost and application. The study provides a comprehensive evaluation to guide optimal solar panel selection for energy generation.

2.1 Research Gap and Objectives

Despite the growing adoption of solar energy, a need remains for detailed comparative studies on the efficiency and performance characteristics of monocrystalline and polycrystalline solar panels under controlled conditions. Existing research often reports general efficiency values, but limited empirical data is evaluating how environmental factors, material quality, and operational parameters influence real-world performance. Addressing this gap is essential to optimizing solar panel selection for residential and commercial applications.

The objectives of this study are:

1. To investigate the efficiency and performance characteristics of monocrystalline and polycrystalline solar panels through experimental evaluation.
2. To analyse and compare the data obtained from the experiments to assess differences in efficiency, electrical output, and overall performance between the two panel types.
3. To design and implement a controlled experimental setup to measure key performance parameters, including electrical output, temperature coefficients, and degradation rates, under standardized testing conditions.

By achieving these objectives, this study provides a comprehensive evaluation of solar panel performance, facilitating informed decisions for effective solar energy deployment in regions with high solar irradiance.

3.0 MATERIALS AND METHODS

This study utilized 20W monocrystalline and polycrystalline solar panels sourced from a reputable supplier. Both panels were installed side by side in a location with consistent sunlight exposure to ensure uniform testing conditions. The panels were connected to a charge controller and a battery to store the generated electricity. The voltage and current outputs of each panel were measured using a digital multimeter, and the power output was calculated by multiplying these values together. Efficiency was determined by dividing the measured power output by the rated power of each panel (20W). Comparative analysis considered not only efficiency but also factors such as cost, durability, and appearance. Light intensity was measured using a lux meter, and the values were converted to approximate irradiance in W/m^2 using a conversion factor of 0.0080 W/m^2 per lux. Variations in daily solar radiation at the surface of the Earth were monitored to account for changes in illumination during the morning and evening (Figure 1).

Monocrystalline solar cells, composed of single-crystal silicon, were highlighted due to their widespread application in devices ranging from calculators and clocks to water heaters and satellites. These cells typically have a 50-55-year lifespan and an average 0.6% annual efficiency decline in reference [11, 21]. making them suitable for urban areas and locations with limited installation space.

3.1 Materials used

The material used for this research is presented in Figures 4 & 5.

Figure 4: Lux Meter **Figure 5:** Multimeter

Table I summarizes the key specifications of the monocrystalline solar cell used in this study. The module is composed of crystalline silicon and has a rated maximum power output of 20 W, with a maximum power voltage (Vmp) of 17.5 V and a corresponding current (Imp) of 1.14 A. The open-circuit voltage (Voc) and short-circuit current (Isc) were measured at 22.05 V and 1.25 A, respectively, with an output tolerance of ±5%. The solar cell has dimensions of 430 × 360 × 20 mm and was tested under standard conditions at a temperature coefficient (TC) of 25 °C. These parameters were used as the baseline for evaluating the performance of the monocrystalline solar cells with specifications as shown below.

Table I indicates the specifications of the Monocrystalline solar cell as shown below

SOLAR MODULE	MONOCRYSTALLINE SOLAR PANEL
Materials	Crystalline silicon
Maximum power (Mxp)	20w
Maximum power voltage (Imp)	17.5v.
Output Tolerance	± 5
Maximum power current (Imp)	1.14A
Open circuit voltage (Voc)	22.05
Short circuit (I_{SC})	1.25A
Size (mm)	430 ×360 ×20
TC	25^{0}

The key specifications of the polycrystalline solar cell are identical to those of the monocrystalline solar cell to ensure a clear and accurate comparison of the results. The module is composed of crystalline silicon and has a rated maximum power output of 20 W, with a maximum power voltage (Vmp) of 17.5 V and a corresponding current (Imp) of 1.14 A. The open-circuit voltage (Voc) and short-circuit current (Isc) were measured at 22.05 V and 1.25 A, respectively, with an output tolerance of ±5%. The solar cell has dimensions of 430 × 360 × 20 mm and was tested under standard conditions at a temperature coefficient (TC) of 25 °C. To assess the performance of the polycrystalline solar cells with specifications as shown in Table II.

Table II: The specifications of the Polycrystalline solar cell are as shown below

SOLAR MODULE	POLYCRYSTALLINE SOLAR PANEL
Materials	Crystalline silicon
Maximum power (Mxp)	20w
Maximum power voltage (Imp)	1.75V
Output Tolerance	± 5
Maximum power current (Imp)	1.14A
Open circuit voltage (Voc)	22.05
Short circuit (I_{SC})	1.25 A
Size (mm)	419×359×20
TC	25^{o}

The intensity of the entering solar light (P_{in}) can be used to compute the amount of incoming solar energy (P_{in}), namely

P_{in} = I. A_{Panel}.................................. (1)

P_{in} = Power entering Solar panel, A_P = Solar radiation intensity at observation (W/m^2).

3.2 Methodology

The experimental setup was carefully designed to minimize external influences such as shading, reflection, and temperature imbalance between the two panels. Both solar panels were mounted on the same horizontal plane and oriented at an optimal tilt angle corresponding to the geographic latitude of Birnin Kebbi to maximize solar exposure. Ambient temperature and panel surface temperature were also monitored to assess their impact on performance. The experimental data were analyzed statistically to evaluate the comparative efficiency of the monocrystalline and polycrystalline solar panels, taking into consideration additional factors such as cost, durability, and long-term performance characteristics, as similarly reported in previous studies [22–26].

3.3.1 The quantity of energy produced by solar cells P_{out}

By measuring the solar panel's voltage and output current, one may determine how much energy the Pout solar panel produces. The formula can then be used to determine the solar panel's output power.

$P_{out} = V.I$ … … … … … … … … … … … … … … … … (2)

Where:

P_{out} = Output power from solar panels (Watts)

V = Voltage in (Volt), and I = Current in (Ampere)

Thus, the efficiency value of solar panels, the following equation:

$$n = \frac{P_{out}}{P_{in}} \times 100\% \ldots \ldots \ldots \ldots (3)$$

Where:

$n = Efficiency\ of\ solar\ panels$, P_{out} = Maximum power, and P_{in} = energy/power going into solar panels (Watts)

Maximum Power Calculation: The calculation of Maximum Power P_{max} Which can be generated by a 20WP Monocrystalline Solar Cell Panel,

$$P_{max} = V_{OC} . I_{sc} . F_f \ldots \ldots \ldots (4)$$

Where:

P_{max} = Maximum power, V_{OC} = Open circuit voltage, I_{SC} = Short circuit current, and F_F = Fill factor

4.0 RESULT AND DISCUSSION

The results obtained from this study, Comparative Study of the Performance and Efficiency of 20W Monocrystalline and Polycrystalline Solar Panels in Birnin Kebbi Metropolis, are presented and analyzed. The findings indicate that monocrystalline solar panels exhibit higher efficiency compared to polycrystalline panels, particularly in the Bayan Kara area of Birnin Kebbi metropolis, under the tested environmental conditions.3.1 Solar Cell Research Results Analysis

Light intensity 313.313 w/m^2

a. The quantity of solar energy that enters (Pin): The information gathered from each interval of the variation in light intensity from the lowest to the highest light was derived from the observations. The amount of incoming solar energy is then calculated by processing the data. The computations for the initial data are as follows:

I = 313 W/m^2, A_{panel} = O. 1805m^2

Thus, $P_{in} = \mathrm{I} \times A_{Panel} = 56.5$ Watt

4.1 The incoming Energy Generated by the Solar Cell (P_{Out})

The information gathered from each interval of the variation in light intensity from the lowest to the highest light was derived from the observations. The amount of incoming solar energy is then calculated using the data. For the first set of data, the power output P_{out} is.

9.27 V × 0. 3 A = 2.781 Watt

4.2 Efficiency Value

The output efficiency of solar panels on battery charging can be determined by first calculating the quantity of solar energy that enters the system (Pin) and the amount that exits it (Pout). The efficiency calculation is

$$\text{Efficiency} = \frac{\text{Amount of Out Energy } (P_{out})}{\text{Amount of in Energy } (P_{in})} \times 100\ \% = \frac{5.37}{47.6} \times 100\ \% = 11.28\%$$

4.2.1 Maximum Power of the Panel: *Module*

The maximum power that a 20-WP monocrystalline solar cell panel can produce is calculated as follows:

$$P_{Max} = V_{OC} \times I_{SC} \times \mathrm{FF}$$

An equation is used to determine the value of FF, and the results can be computed as V_{OC} stands for open circuit voltage, I_{SC} for short circuit current, V_{mp} for maximum power voltage, and I_{mp} for maximum power current. Based on the findings derived from the solar cell module's parameter data. After processing the data to ascertain the Fill Factor generated by the solar module, the following steps are taken:

$$V_{mP} = 17.5V,\ I_{mp} = 1.14A,\ V_{OC} = 22.05,\ I_{SC} = 1.25A$$

Thus,

$$\mathrm{FF} = \frac{V_{mp} X\, I_{mp}}{V_{OC} X\, I_{SC}},\quad \frac{17.5\ X\ 1.14}{22.05\ X\ 1.25} = 0.73$$

The calculation of the maximum power that can be generated by a 50 W Polycrystalline Solar Cell Panel, namely:

$$P_{max} = V_{OC} \times I_{SC} \times \mathrm{FF}$$

From the observations obtained from the parameter data of the sample module. The data is then processed to determine the maximum power generated by the solar module.

International Journal of Multidisciplinary Research and Bulletin
ISSN 3108-1428
Volume 5 Issue 4 (July – Aug) 2026

$V_{OC} = 11.2V, and\ I_{SC} = 1.52A$ And the

FF = 0.73, and P_{max} = 12.43Watt

To calculate the value of FF, an equation is used, and the results can be calculated as follows:

From the observations generated from the parameter data of the solar cell module. The data is then processed to determine the Fill Factor produced by the solar module as follows:

Such that: FF = $\frac{V_{mp} \times I_{mp}}{V_{oc} \times I_{SC}} = \frac{17.5 \times 1.14}{22.05 \times 1.25} = 0.73$

Table III presents a comparative performance analysis of monocrystalline and polycrystalline solar cells, based on their maximum power output and fill factor. The monocrystalline cell exhibited a higher power output of **20.121 W**, indicating greater efficiency in converting solar irradiance into electrical energy compared to the polycrystalline cell, which produced **12.43 W** under identical test conditions. Both cell types maintained a **fill factor (FF)** of **0.73**, suggesting similar electrical characteristics but differing conversion efficiencies due to their material structures and crystal purity.

Table III. Summary of the Maximum Power Output and Fill Factor for Monocrystalline and Polycrystalline Solar Cells

SOLAR CELL	POWER OUTPUT	FILL FACTOR
MONOCRYSTALLINE	20.121	0.73
POLYCRYSTALLINE	12.43	0.73

The analysis of the experiment of 20W monocrystalline and polycrystalline solar panels reveals several key findings regarding energy generation and efficiency. Figure 6 shows that the amount of energy incident on a solar panel is directly proportional to both its surface area and the intensity of sunlight it receives. The graphical data indicate that incoming energy follows a trend that aligns closely with variations in solar irradiance, confirming the predictable relationship between sunlight intensity and panel input energy. As shown in Figures 7 and 8, the power output of both monocrystalline and polycrystalline solar panels increases proportionally with the incident energy. The plotted trends further indicate a consistent angular response relative to incoming radiation. Moreover, the monocrystalline panel demonstrates superior energy conversion performance compared with the polycrystalline panel, reflecting its higher material purity and inherent efficiency advantages.

International Journal of Multidisciplinary Research and Bulletin
ISSN 3108-1428
Volume 5 Issue 4 (July – Aug) 2026

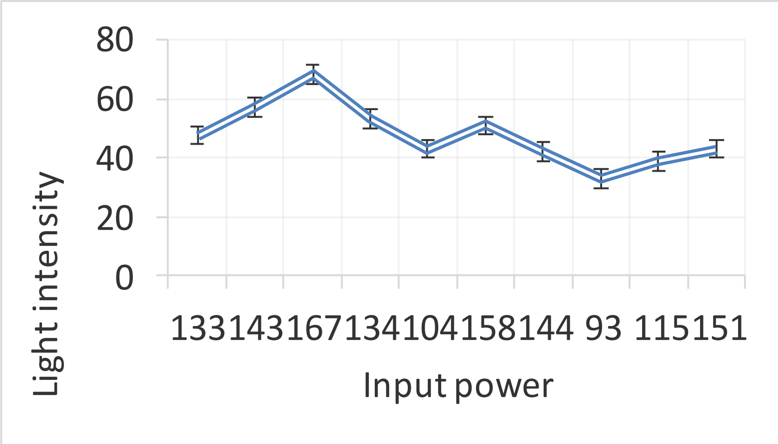

Figure 6: The solar panel's energy/power and sunshine intensity graph at 20 WP

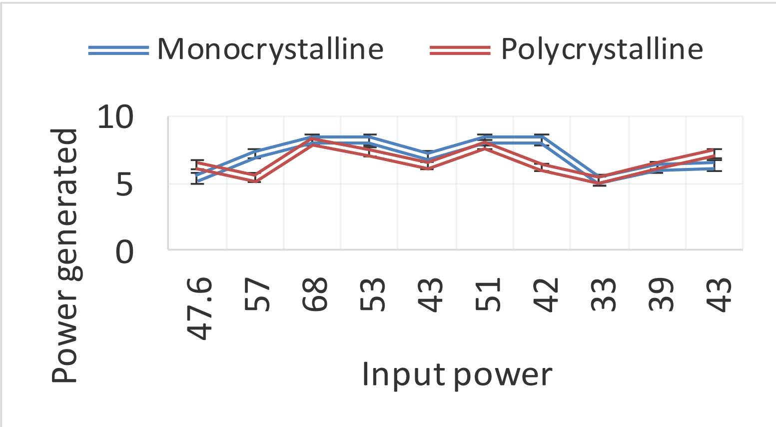

Figure 7: Graph showing the correlation between the power and energy entering the solar panel

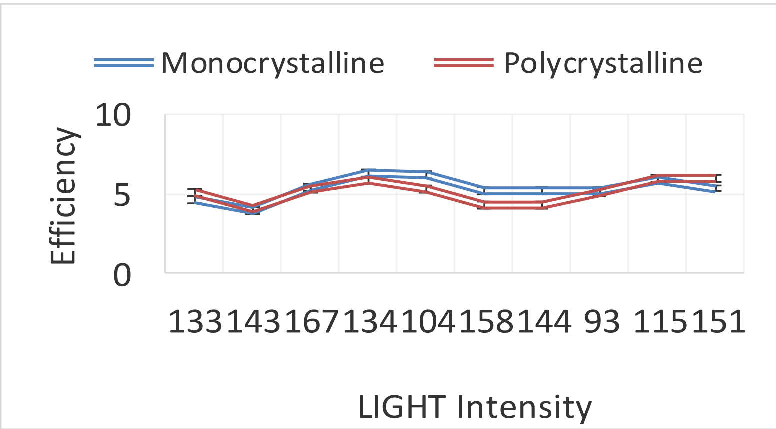

Figure 8: Graph showing the correlation between sunlight intensity and a 20 Wp solar panel's efficiency

Quantitatively, the monocrystalline panel achieved an efficiency of 5.20%, while the polycrystalline panel reached 4.25% under similar test conditions. Considering the average efficiency over the testing period, monocrystalline panels exhibited approximately 0.25% higher efficiency than polycrystalline panels. These results highlight that monocrystalline solar panels not only produce more power under equivalent conditions but also maintain better performance in varying sunlight intensities. Overall, the findings indicate that monocrystalline panels are more effective in converting sunlight into electricity, making them the preferred choice for residential power generation in regions with high solar irradiance, such as the Bayan Kara area. In addition to efficiency, factors such as space efficiency and performance under warm conditions further reinforce the suitability of monocrystalline panels over polycrystalline alternatives, as shown in Figures 7 and 8.

5.0 CONCLUSION

The experimental results comparing 20W monocrystalline and polycrystalline solar panels indicate that monocrystalline panels exhibit higher efficiency under identical light conditions. The study tested the panels at varying light intensities, ranging from 133 to 158 W/m², to determine optimal hourly performance. Measurements showed that increasing light intensity directly enhances both voltage and current output from the panels. The monocrystalline solar panel achieved an efficiency of 5.20%, compared to 4.25% for the polycrystalline panel, demonstrating its superior ability to convert sunlight into electrical energy. This efficiency advantage is attributed to the higher purity of silicon and better light absorption characteristics of monocrystalline panels.

In summary, monocrystalline solar panels are the more suitable option for residential power generation in the Bayan Kara area. Their higher efficiency, better performance in warm conditions, and space-efficient design make them optimal for regions with high solar irradiance, such as Bayan Kara, ensuring more effective and reliable energy production compared to polycrystalline panels.

Article Publication Details
This article is published in the **International Journal of Multidisciplinary Research and Bulletin**, ISSN 3108-1428 (Online). In Volume 5 Issue 4 (July – Aug) 2026
The journal is published and managed by **IRPG**.

Acknowledgements
This research was supported by the Department of Physics, Faculty of Science, Federal University, Birnin Kebbi, Kebbi State, Nigeria.

We sincerely thank the editors and the reviewers for their valuable suggestions on this paper.

Funding
This study was not externally funded and was fully supported by the authors.

Data availability
The newly created data is available for reasonable requests and should not be shared publicly.

Declarations

Ethics approval and consent to participate
The author(s) declare that it is not applicable.

Consent for publication
The author(s) declare that this is not applicable.

Competing interests
The author(s) declare that they have no competing interests.

References

1. Rahman, F. A., Aziz, M. M. A., Saidur, R., Bakar, W. A. W. A., Hainin, M. R., Putrajaya, R., & Hassan, N. A., "Pollution to solution: Capture and sequestration of carbon dioxide (CO2) and its utilization as a renewable energy source for a sustainable future," Renewable and Sustainable Energy Reviews, vol. 71, no. 10, pp. 112-126, Jan. 2017, http://dx.doi.org/10.1016/j.rser.2017.01.011.

2. Gwani Mohammed, Bako, A**.,** Umar Muhammad Kangiwa, Gado Abubakar Abubakar, "Design, Fabrication and Testing of a SEPIC DC-DC Converter for Interfacing Solar PV Module," International Journal for Modern Trends in Science and Technology, vol. 8, no. 12, pp. 269-277, Mar. 2022, https://doi.org/10.1093/ce/zkac001.

3. Bako, A., Kabiru, M., Samaila, B., & Isah, H., "Design and performance evaluation of a DC-DC step-up SEPIC converter for photovoltaic-based off-grid application," Journal of Energy Engineering and Thermodynamics, vol. 2, no. 6, pp. 2815-0945, Nov. 2022, https://doi.org/10.55529/jeet.26.1.17.

4. Yildiz, A., Ozturk, E., Atilgan, A., Sbeta, M., Atli, A., & Serin, T., "An understanding of the band gap shrinkage in Sn-doped ZnO for dye-sensitized solar cells," Journal of Electronic Materials, vol. 46, no. 12, pp. 6739-6744, Oct. 2017, DOI: 10.1007/s11664-017-5778-0.

5. Bako, A., Isah Ibrahim Garba, Sufyanu M. Ambursa, Fauziya Lawal M., Fatima A. Kafinta, "High Step-Up Sepic Converter with Double Voltage Multiplier Module for A Photovoltaic System," Iconic Research and Engineering Journals, vol. 8, no. 7, pp. 546, Jan. 2025, ISSN 2456-8880.

6. Jiang, F., & Wong, A. “Study on the performance of different types of PV modules in Singapore” In 2005 International Power Engineering Conference, vol. 6, no.8, pp. 1-109, Nov. 2005, IEEE.DOI: 10.1109/IPEC.2005.206888.

7. Adeleke, A. J., Ajunwa, O. M., Golden, J. A., Antia, U. E., Adesulu-Dahunsi, A. T., Adewara, O. A., & Luka, Y., “Anaerobic digestion technology for biogas production: current situation in Nigeria (a review),” UMYU Journal of Microbiology Research, vol. 8, no. 2, pp. 153-164, https://doi.org/10.47430/ujmr.2382.018.

8. Prasad, H. O., Mahanta, S. K., & Bojjagani, S., “Analysis of Reduction in Thermal Power Air Emission Burden by Substituting Solar Energy Plants,” J. Environ. Science & Energy. vol. 64, no. 1, pp. 1413-1422, Jan. 2022, https://doi.org/10.1016/j.enconman.2004.06.029

9. Cañón-Bermúdez, J. D., & Mulcué-Nieto, L. F., “Indium aluminum nitride: A review on growth, properties, and applications in photovoltaic solar cells,” Heliyon, vol. 10, no. 22, Aug. 2024, pp. 64-60 https://doi.org/10.1016/j.heliyon.2024.e40322

10. Musa, A. H. Abdullahi bako, Auwal Mustapha Imam, Muhammad Naziru yahayya, Huzaifa Isah., “Evaluation of Non-Isolated DC-DC Boost Converter for Interfacing Solar PV Panel,” Journal of Energy Conservation, vol. 1, no. 4, pp. 11-22, ISSN: 1115-7534.

11. Bako, A., Voochaiphum, B., Suchat, S., & Buranasiri, P. “Optimizing indoor digital holography for photovoltaic surface analysis: a novel approach for solar PV testing conditions,” In International Workshop on Thin Films for Electronics, Electro-Optics, Energy, and Sensors, Vol. 13663, pp. 41-48, July. 2025, https://doi.org/10.1117/12.3071529

12. Abdullahi, A., Olatunji, O. I., & Bako, R. U. “Climate Change and Small-Scale Poultry Production in Selected Local Government Areas of Kwara State,” International Journal of Research and Scientific Innovation, vol. X, no. XII, https://doi.org/10.51244/IJRSI.2023.1012059.

13. Ahmad, R., Bako, A., Sagagi, Y. M., Muhammad, R., & Samaila, B. “Design and Construction of Automatic Hall Light Control with Visitor Counter System Circuit,” Centre for Undergraduate Research, University of Abuja, Vol 1, No. 2, Dec. 2023, ISSN: 1115-7534.

14. Ali, A. Y., Clement, Y. G., Bako, U. A., Lekwot, V. E., Choji, I. D., Ameso, V. C., ... & Bitrus, A., “Evaluation Of Energy Facilities And Service Availability In The Value Of Rental Apartments In Karu Local Government Area, Nasarawa State, Nigeria,” In FESCON Conference Proceedings, Vol. 5, No. 1, pp. 120-138, Jun. 2025, DOI: 10.4314/njbas.v27i2.10

15. Ibrahim, A. T., Amajama, J., Obojor-Ogar, L., & Hogan-Bassey, J. E., "A comprehensive empirical assessment of the influence of wind speed on the operational efficiency of the photovoltaic (PV) modules within the climatic context of Calabar, Southern Nigeria," International Journal of Natural and Applied Sciences, (IJNAS), vol. 17, no. 1& 2, pp. 22 – 29, April. 2024, https://doi.org/10.1016/j.rser.2013.12.027.

16. Benghanem, M., Haddad, S., Alzahrani, A., Mellit, A., Almohamadi, H., Khushaim, M., & Aida, M. S., "Evaluation of the performance of polycrystalline and monocrystalline PV technologies in a hot and arid region: an experimental analysis," Sustainability, vol. 15, no. 20, pp. 14831, https://doi.org/10.3390/su152014831.

17. Kesler, S., Kivrak, S., Dincer, F., Rustemli, S., Karaaslan, M., Unal, E., & Erdiven, U., "The analysis of PV power potential and system installation in Manavgat, Turkey: A case study in winter season," Renewable and Sustainable Energy Reviews, vol. 31, no. 1, pp. 671-680, https://doi.org/10.1016/j.rser.2013.12.027.

18. Chandra, S., Agrawal, S., & Chauhan, D. S., "Effect of ambient temperature and wind speed on performance ratio of polycrystalline solar photovoltaic module: An experimental analysis," International Energy Journal, vol. 18, no.2, pp.234-245, https://doi.org/10.1016/j.rser.2016.09.051.

19. Mirzaei, M., & Mohiabadi, M. Z., "A comparative analysis of long-term field test of monocrystalline and polycrystalline PV power generation in semi-arid climate conditions," Energy for Sustainable Development, Vol. 38, pp. 93-101, June 2017, https://doi.org/10.1016/j.esd.2017.01.002.

20. Raghavendra, K. V. G., Kumar, N. T. U., & Kazim, W., "An efficient optical inspection of photovoltaic modules deploying edge detectors and ancillary techniques," International Journal of Electrical and Computer Engineering (IJECE), vol. 12, no. 5, pp. 4772~4781, Oct. 2022, DOI: 10.11591/ijece.v12i5.pp4772-4781.

21. Ayadi, O., Shadid, R., Bani-Abdullah, A., Alrbai, M., Abu-Mualla, M., & Balah, N., "Experimental comparison between Monocrystalline, Polycrystalline, and Thin-film solar systems under sunny climatic conditions," Energy Reports, vol. 8, no. 3, pp. 218-230, July 2022, https://doi.org/10.1016/j.egyr.2022.06.121.

22. Benghanem, M., Haddad, S., Alzahrani, A., Mellit, A., Almohamadi, H., Khushaim, M., & Aida, M. S., "Evaluation of the performance of polycrystalline and monocrystalline PV technologies in

a hot and arid region: an experimental analysis," Sustainability, vol. 15, no. 20, pp. 14831, October 2023, https://doi.org/10.3390/su152014831.

23. Amelia, A. R., Irwan, Y. M., Leow, W. Z., Irwanto, M., Safwati, I., & Zhafarina, M. "Investigation of the effect temperature on photovoltaic (PV) panel output performance," *Int. J. Adv. Sci. Eng. Inf. Technol*, vol. *6*, *no.* 5, pp. 682-688, Oct. 2016, DOI: 10.18517/ijaseit.6.5.938.

24. Chandra, S., Agrawal, S., & Chauhan, D. S., "Effect of ambient temperature and wind speed on performance ratio of polycrystalline solar photovoltaic module: An experimental analysis," International Energy Journal, vol. 18, no. 2, pp. 234-264, Dec.2018, https://doi.org/10.1063/5.0157029.

25. Genc, A. K. A. K. N., Karakilic, A., & Karafil, N., "Effects of temperature and solar irradiation on performance of monocrystalline, polycrystalline, and thin-film PV panels," International Journal on Technical and Physical Problems of Engineering (IJTPE), Vol. 51, no. 5, pp. 254-260, June 2022, ISSN 2077-3528.

26. Edalati, S., Ameri, M., & Iranmanesh, M., "Comparative performance investigation of mono-and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates," *Applied Energy*, Vol. 160, no. 15, pp. 255-265. December 2015, https://doi.org/10.1016/j.apenergy.2015.09.064.