Journal of Energy Research and Reviews

Volume 16, Issue 4, Page 29-37, 2024; Article no.JENRR.113444
ISSN: 2581-8368

Comparative Analysis of Current-Voltage Characteristics of Photovoltaic (PV) Systems in Selected Climatic Regions in Cross River State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JENRR/2024/v16i4345

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/113444

Original Research Article

Received: 24/12/2023
Accepted: 27/02/2024
Published: 11/04/2024

ABSTRACT

This study investigated the effect of solar radiation's intensity and ambient temperature on the current-voltage (I-V) characteristics of monocrystalline and polycrystalline photovoltaic (PV) systems in the generation of electricity in Calabar and Okuku, Cross River State, Nigeria. Appropriate measuring devices were employed to record daily readings of these parameters at the study locations, from July to August 2022. The data were collected and results graphically analyzed and calculated. The results indicate that current (I_{sc}), voltage (V_{oc}) as well as the maximum power (P_{max}) of both module types increased positively with increase in solar radiation and ambient temperature. Results from collected and computed data also show average daily readings across the locations for solar radiation ranging between 271Wm^{-2} and 409Wm^{-2} and ambient temperature between 32^{0}C and 37^{0}C. The calculated P_{max} ranges between 49W and 63W from the 130W solar

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modules used for the investigation. Another notable result is that the polycrystalline module exhibits higher P_{max} than the monocrystalline module in both locations. In spite of the low solar radiation and ambient temperature obtained during this study period, which is considered the worst climatic period of the year (July and August), it is desirable and recommendable to employ solar modules as an alternative power generation in Calabar and Okuku, Cross River State, Nigeria.

Keywords: Current; voltage; maximum power; monocrystalline; polycrystalline.

1. INTRODUCTION

The rapid growth of photovoltaic (PV) systems in diverse geographical locations underscores the need for a comprehensive understanding of their performance characteristics. In the quest for sustainable energy solutions, solar power, particularly harnessed through PV systems, has emerged as a pivotal player in the global energy landscape [1].

Several investigations have focused on the impact of environmental variables on PV system performance. The authors in [2] conducted a seminal study examining the effect of temperature on the efficiency of solar cells. Their findings underscored the need to account for temperature variations in assessing the overall performance of PV systems. Similarly, in 2015, Bai et al. [3] delved into the effects of shading on solar panels, revealing substantial declines in output under partial shading conditions. These studies collectively emphasize the importance of considering local environmental factors in optimizing PV system designs.

Ettah et al. [4] investigated the effect of relative humidity on the performance of solar panels in Calabar. It was discovered that the relative humidity between 69% and 75% favours increase in output current from solar panels as well as Voltage. The work showed that at low relative humidity, there is an increase in the performance of solar panels. In 2021, [5] experimented on two different solar panels in a semi-Arid region (Okuku, in Yala, Cross River State) to know their performances. The data collected from measuring the solar radiation with ATES 1333 model Solar power meter and Current-Voltage with an auto range multimeter were computed and analyzed. They presented that the efficiency of polycrystalline solar panel is higher than that of a monocrystalline after various analysis.

In spite of this, limited research has specifically addressed the regional disparities in PV system performance, especially in the context of Nigeria. [6] examined solar energy potential across different regions in the country, highlighting variations in solar irradiance and climatic conditions. However, a comprehensive comparative analysis of current-voltage characteristics, especially in locations with distinct environmental features like Calabar and Okuku, remains scarce.

In order have a better understanding of PV systems, this study compares the current-voltage (I-V) characteristics of Calabar and Okuku, two different places in Nigeria's Cross River State. Examining the effectiveness and dependability of PV systems in various settings is crucial as renewable energy programmes gain traction globally. With its distinct geographic and climatic characteristics, Cross River State offers a fascinating backdrop for this kind of comparative analysis. The state capital, Calabar, represents the metropolitan and seaside landscape, whereas Okuku, located upland [7], provides an alternative viewpoint. This study attempts to provide important insights into how environmental conditions affect the performance of solar energy by examining their I-V characteristics in different locations.

The significance of this study extends beyond regional boundaries. Understanding how local conditions affect the electrical behaviour of PV systems is essential for optimizing their design, improving efficiency, and ensuring the longevity of solar infrastructures [8]. Furthermore, the findings of this research can contribute to the development of tailored strategies for the implementation of solar energy solutions in similar geographical contexts globally. A fundamental aspect of this investigation involves the performance evaluation of both monocrystalline and polycrystalline solar panels. These technologies, distinguished by the structure of their solar cells, are widely employed in solar energy systems [9]. The choice between monocrystalline and polycrystalline panels can significantly impact the efficiency of a PV system. Our exploration aligns with the growing body of literature that emphasizes the importance of technology-specific assessments in understanding the diverse applications of solar energy [10-11]. An important objective is to determine which PV technology is more suitable for each study area. This investigation contributes to the practical application of solar energy solutions by providing insights into the technology that aligns best with the environmental conditions prevalent in Calabar and Okuku.

The study area will be described in the following sections. The technique used, data gathering processes, and analysis of current-voltage curves collected from PV systems in Calabar and Okuku will also be revealed. The findings of this study have the potential to broaden the conversation about the practical consequences of harvesting solar energy in a variety of environmental contexts, thereby stimulating developments in the field of renewable energy research and application.

2. METHODOLOGY

2.1 Study Area

Calabar and Okuku, situated within Cross River State, Nigeria, offer a distinctive geographical backdrop for the study of PV systems. Cross River State is located in the southeastern part of Nigeria and is characterized by diverse landscapes ranging from coastal areas to inland regions. Calabar, the state capital, is a bustling urban center located along the Atlantic coast, while Okuku represents an inland community, providing a contrast in terms of geographical and climatic conditions.

Calabar has a unique climate known as the tropical monsoon climate, with distinct wet and dry seasons. Being a coastal city, Calabar tends to have milder temperature variations due to the moderating effect of the Atlantic Ocean. The region is located at 4°57'06"N and 8°19'19"E, at an elevation of 32m above sea level and has a typical ambient temperature of around 28.2^{0}C [12]. Cloudiness and significant precipitation help to reduce daily temperatures, and consistent land and sea breezes help to maintain a truly equitable climate. It has precipitation virtually all year except during the core months of the dry season, which occur in two short intervals over a calendar year: January to March and October to December [13].

Okuku in Yala is located in the northern part of Cross River State and is bordered by Benue state in the north, Ikom and Obubra Local Government Areas in the south, Bekwara and Ogoja Local Government Areas in the east, and Ebonyi state in the west [14]. Yala is located at the equator at latitude $6^{o}5^{I}$N and longitude $8^{0}5^{1}$E. It has an area of 1,739km^{2} and has a population of 210,843. Okuku, situated inland, may experience slightly more pronounced temperature fluctuations than Calabar. The temperature is generally consistent, with a monthly average of around 270^{o}C. Agriculture, fishing, mining, and trading are the main economic activities in the area.

Solar irradiance, which varies across different geographical locations [15], is a key determinant of PV systems. Calabar and Okuku likely exhibit differences in solar radiation levels due to their geographical positioning as earlier buttressed. The study will explore how these variations influence the energy generation capabilities of PV systems in each location.

2.2 Equipment Used

The equipment used for data collection in this study are the Hyelec auto range digital multi-meter (Model MS 8236) used to measure the open circuit voltage (V_{oc}) and short circuit current (I_{sc}) readings from both the monocrystalline and polycrystalline modules. The digital solar +power meter (Model TES 1333) was simultaneously used to take readings of the solar radiation in Wm^{-2}. The KT 908 digital indoor and outdoor thermo-hygrometer was deployed to gather ambient temperature and solar panel temperature readings in degrees Celsius (^{o}C).

Two types of commercial solar modules were used for the measurement. The solar modules used were Yingli Solar YS130 (monocrystalline and polycrystalline), with the same electronic specifications. These specifications are; power output – 130W peak, voltage at peak power – 17.5V, current at peak power – 7.42A, open circuit voltage – 22.05V, short circuit current – 8.31A, module efficiency – 18.5%, surface area of panel – 0.98m^{2}.

2.3 Instrumentation

The research involves the inspection of data for current-voltage (I-V) of PV systems and climatic parameters using the various measuring equipment. PV output power parameters monitored were open circuit voltage and short circuit current while the climatic parameters measured were solar radiation and ambient temperature as well as solar temperature for each of the module types.

Instantaneous data using the above equipment were collected at interval of 15 minutes between the hours of 6:00 to 18:00 Local Time (GMT + 1) at each study location to ensure effective and accurate data collection. The measurements were made between the months of July and August 2022.

The output power of solar modules was simply computed as Output

$$Power\ (Watts) = Voltage\ (V)\ \times Current\ (I)$$

The collected data, including current-voltage curves and environmental parameters, were subjected to a comprehensive analysis. The analysis also included a comparative evaluation of the current-voltage characteristics between the Calabar and Okuku locations. Furthermore, the research adhered to ethical guidelines, and permissions were obtained from relevant authorities for the installation of PV systems in both Calabar and Okuku campuses.

3. RESULTS AND DISCUSSION

Figs 1 and 2 are the graphical representations of the I-V characteristics of both monocrystalline Solar panels in Calabar and Okuku, based on the measured as well as computed data presented in Table 1. Figs 3 and 4 show I-V graphs of both polycrystalline solar panels in Calabar and Okuku, based on the measured as well as computed data presented in Table.1.

There was appreciable solar radiation and ambient temperature in Calabar and Okuku as seen in Figs 1 and 4. The low appreciation in solar radiation and temperature was expected considering that the research was carried out during the rainy season. Average solar radiation readings were observed to be high in Calabar between 9am and 1pm; Okuku between 9am and 4pm. The graph of I-V shows a typical forward bias P-N junction. In the two lactations, the graph indicates that the current increases with increase in solar radiation for both Monocrystalline and Polycrystalline solar modules. This agrees with the authors in [16].

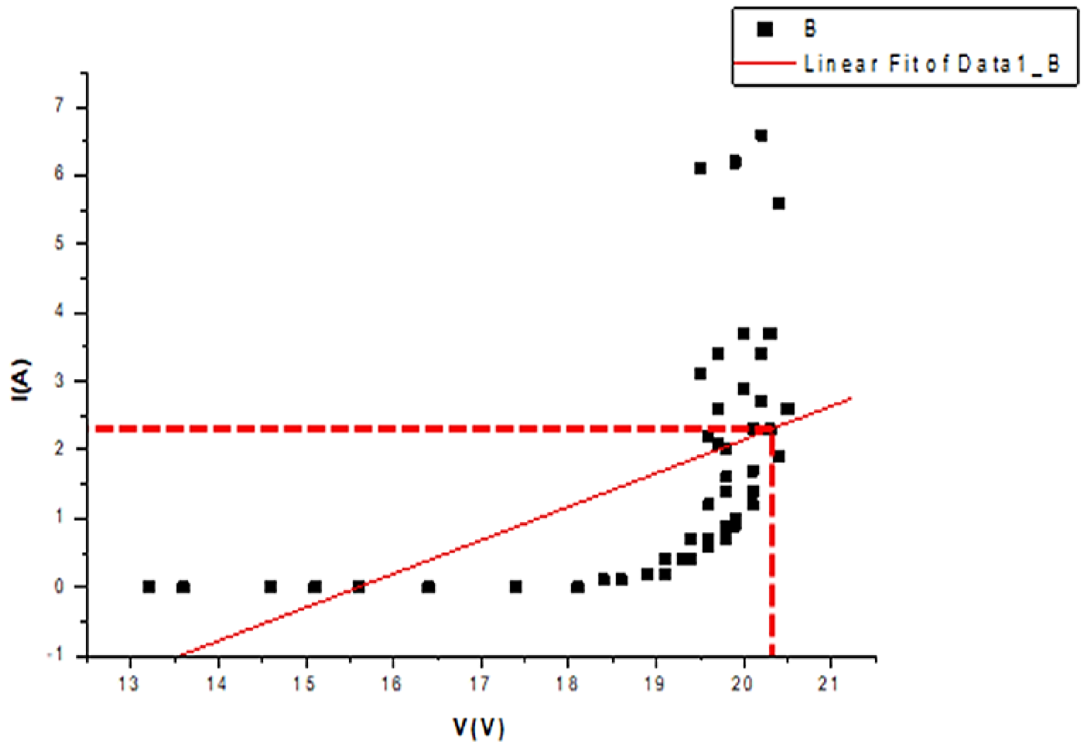

Fig. 1. A graph of current against voltage of monocrystalline for Calabar

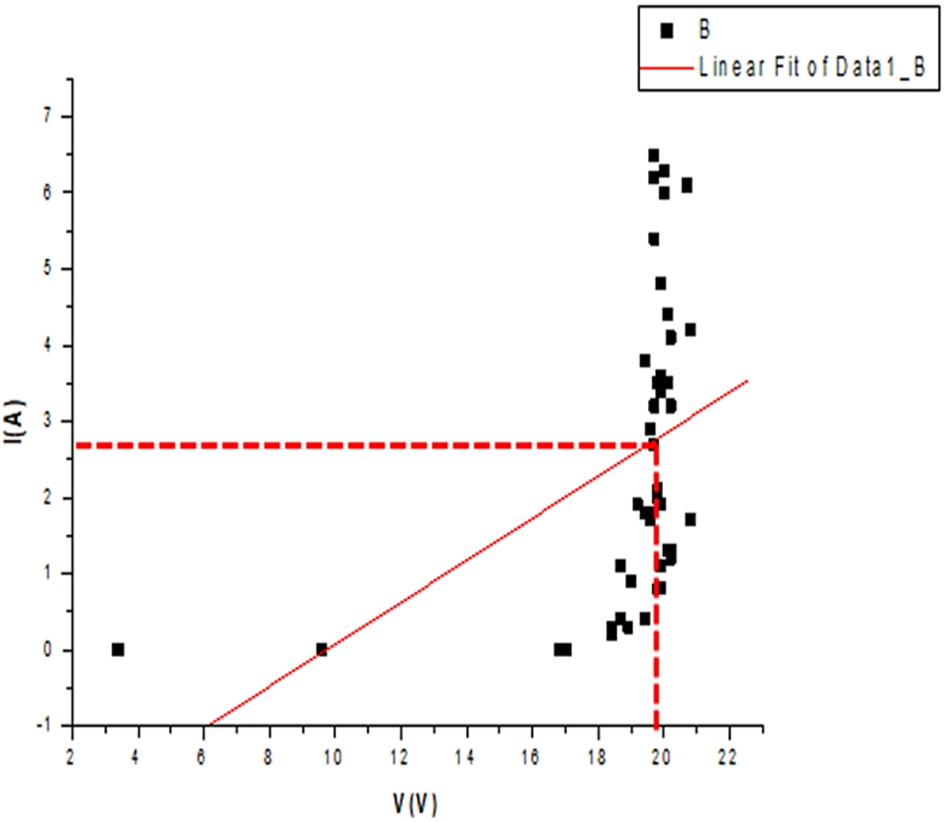

Fig. 2. A graph of Current against voltage of monocrystalline for Okuku

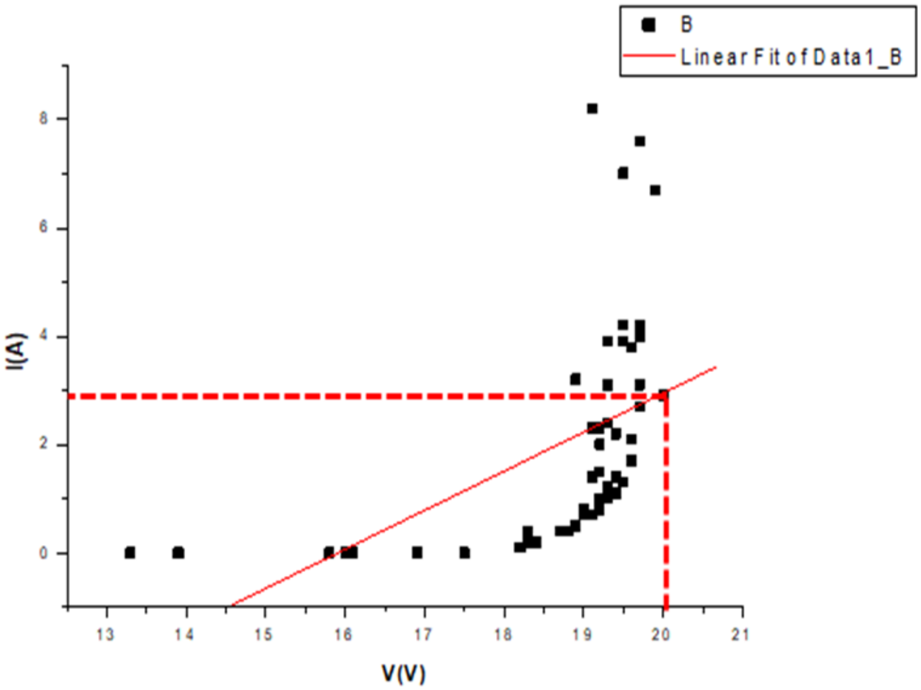

Fig. 3. A graph of current against voltage of polycrystalline for Calabar

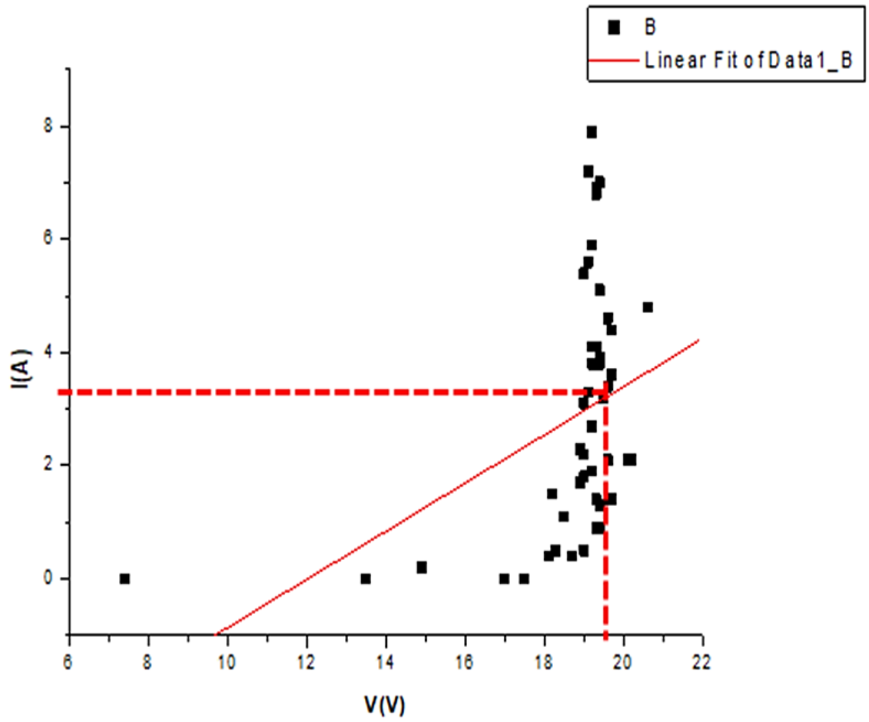

Fig. 4. A graph of current against voltage of polycrystalline for Okuku

Table 1. Analysis of measured and computed data

Measured and computed Parameters	Location	
	Calabar	Okuku
Mean daily Solar radiation (Wm^{-2})	271	409
Maximum daily Solar Radiation (Wm^{-2})	960	992
Mean daily Ambient Temperature (^0C)	32	37
Maximum daily Ambient Temperature (^0C)	37	45
Minimum daily Ambient Temperature (^0C)	24	28

From the equation $P_{max} = I_{max} \times V_{max}$ (1)

We can find the maximum power from the I-V characteristics for each PV module in each location

For Calabar:

Monocrystalline, I_{sc} = 2.4A, V_{oc} = 20.3V
$P_{max} = 2.4A \times 20.3V$
$P_{max} = 49W$
Polycrystalline, I_{sc} = 2.85A, V_{oc} = 20.1V
$P_{max} = 2.85A \times 20.1V$
$P_{max} = 57W$

For Okuku:

Monocrystalline, I_{sc} = 2.52A, V_{oc} = 19.8V
$P_{max} = 2.52A \times 19.8V$
$P_{max} = 50W$
Polycrystalline, I_{sc} = 3.2A, V_{oc} = 19.6V
$P_{max} = 3.2A \times 19.6V$
$P_{max} = 63W$

In Calabar, results show an average daily solar radiation of 271Wm^{-2} and average daily ambient temperature of 32^{0}C. Also, from the graphs, the maximum powers were calculated as 49W for monocrystalline and 57W for polycrystalline PV system, respectively.

In Okuku, results show an average daily Solar radiation of 409Wm^{-2} and average daily ambient temperature of 37^{0}C. Also, from the graphs, the maximum powers were calculated as 50W for monocrystalline and 63W for polycrystalline PV system, respectively.

From the relation used in calculating the solar module's maximum power given in equation (1); it is obvious that the maximum power is directly proportional to the output current. Contrary to findings and reports made by [17-18] which posited that monocrystalline solar modules have greater maximum power than polycrystalline modules, results in this research work have shown that in the two study areas, average daily solar radiation, ambient temperature and the maximum power of polycrystalline modules, are higher than that of monocrystalline as shown in Table 1 and Figs 3 and 4 respectively. With a daily average ambient temperature of 32^0C in Calabar and 37^0C in Okuku, the polycrystalline solar module produces higher maximum power. This is because polycrystalline modules have a lower temperature coefficient of power relative to the monocrystalline modules [19].

Increase in solar radiation brings about a proportional increase in current (I_{sc}) leading to increase in maximum power. This is shown by linear straight-line graph in Figs 1 to 4. Similarly, to the findings and report made by [20-21], at low relative humidity, an increase in solar radiation will cause an increase in the output power generation which leads to increase in output power. Furthermore, research work by [22] corresponds with the findings in this work which shows that polycrystalline solar modules have higher output power than monocrystalline.

The average solar radiation and ambient temperature of both monocrystalline and polycrystalline solar modules as shown in Table 1 all portray good potentials for solar electricity generation in the two study areas. Considering that these investigations were conducted in the rainy season, solar radiation and temperature as expected are not very high. These potentials may be affected by the extent of deviation of the active climatic parameters (solar radiation and ambient temperature) from the Standard Test Condition (STC) under which the modules were designed to operate. However, the amount of average solar radiation and ambient temperature as shown in Table 1 are favourable and are expected to improve during the dry season for substantial electricity generation using both monocrystalline and polycrystalline modules in Calabar and Okuku of Cross River state.

4. CONCLUSION

In order to maximize the use of the abundant potential of the sun, especially for the generation of electricity in Calabar and Okuku, Cross River State, Nigeria, it was necessary to research into the I-V characteristics of monocrystalline and polycrystalline modules to compare the maximum power. Results of the data collected, computed and analyzed from the two study locations indicate that the current and voltage as well as the output power of monocrystalline and polycrystalline solar modules increases with increase in solar radiation and ambient temperature. Polycrystalline modules were found to exhibit maximum power than monocrystalline in both locations making polycrystalline module a better choice for solar electricity generation in the two study areas.

Results also show that the average solar radiation and ambient temperature of both module types used for the investigation lie between $271Wm^{-2}$ – $409Wm^{-2}$ and 32^0C – 37^0C with the maximum power lying between 49W – 63W from the 130W modules across the two locations. The short fall in the solar module current and voltage were seen to have been affected by low solar radiation brought about by cloud covering during rainy season. It is however expected that during the dry season, the effects of some of these limiting factors may diminish, leading to considerable increase in the output power.

Based on the findings and results of this investigation, the following recommendations are plausible;

- Having shown that the output power of solar modules may exhibit some short fall in performance in Calabar and Okuku, Cross River State, Nigeria, it is recommended that larger solar arrays be considered in all designs for solar installations in order to increase the output power.
- Polycrystalline solar modules are highly recommended as the preferred choice over monocrystalline solar modules for the generation of electricity in the two locations, due to their higher output power as shown in this study.
- The use of solar module is generally recommended for the generation of electricity in the study locations, through the utilization of the abundant solar radiation in the locations. This will reduce dependence on fossil fuel-based power generating systems with a view to ensuring a clean and green environment and to mitigate climate change.
- Further research is recommended to ascertain estimated values for power during the dry season.
- The sufficient collected and computed data showing how the electrical characteristics of

monocrystalline and polycrystalline solar modules vary with climatic parameters of temperature and solar radiation in the two locations can be harnessed for further research and analysis in this study area to uncover other findings that this research work may not have covered.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Gordo E, Khalaf N, Strangeowl T, Dolino R, Bennett N. Factors affecting solar power production efficiency; 2015. Available:https://docplayer.net/17325217-Factors-affecting-solar-power-production-efficiency.html(Retrieved 3/2/24)
2. Singh P, Ravindra NM. Temperature dependence of solar cell performance—An analysis. Solar Energy Materials and Solar Cells. 2012;101:36–45.
3. Bai, J., Cao, Y., Hao, Y., Zhang, Z., Liu, S., & Cao, F. (2015). Characteristic output of PV systems under partial shading or mismatch conditions. Solar Energy, 112, 41–54.
4. Ettah EB, Udoimuk AB, Obiefuna JN, Opara FE. The effect of relative humidity on the efficiency of solar panels in Calabar, Nigeria. Universal Journal of Management and Social Sciences. 2012; 2(3):8–11.
5. Ettah E, Ekah U, Oyom E, Akonjom N. Performance analysis of monocrystalline and polycrystalline solar panels in a semi-arid region. International Journal of Engineering and Science Invention. 2021; 10(7):10-14.
6. Ozoegwu CG. The solar energy assessment methods for Nigeria: The current status, the future directions and a neural time series method. Renewable and Sustainable Energy Reviews. 2018;92: 146–159.
7. Amadi SO, Agbor ME, Udo SO. Vulnerability of Calabar rainfall to climatic variability events: A critical factor in integrated water resources management in the tropical coastal location in southeastern Nigeria. International Journal of Sustaible Development and Planning. 2021;16(1):115-122.
8. Wijeratne WPU, Yang RJ, Too E, Wakefield R. Design and development of distributed solar PV systems: Do the current tools work? Sustainable Cities and Society. 2019;45:553–578.
9. Akonjom NA, Umuji JI, Ekah UJ. Performance evaluation of polycrystalline photovoltaic modules in a guinea savannah and mangrove swamp. World Journal of Advanced Engineering Technology and Sciences. 2021;4(1):11-21.
10. McMaster R, Noble B, Poelzer G. Assessing local capacity for community appropriate sustainable energy transitions in northern and remote Indigenous communities. Renewable and Sustainable Energy Reviews. 2024;191:1-9
11. Sudarsan A, Kurukkanari C, Bendi D. A state-of-the-art review on readiness assessment tools in the adoption of renewable energy. Environmental Science and Pollution Research. 2023;30(12): 32214–32229.
12. Agbo EP. The role of statistical methods and tools for weather forecasting and modeling. Weather Forecasting. IntechOpen. 2021;3-22.
13. Njok AO, Kamgba FA, Panjwani MK, Mangi FH. The influence of solar power and solar flux on the efficiency of polycrystalline photovoltaics installed close to a river. Indonesian Journal of Electrical Engineering and Computer Science. 2020; 17(2):988–996.
14. Ugbem LP, Godfrey EU, Ojim EE, Ejuiwa MC. Correlation between height and selected anthropometric parameters of the upper limbs of the efiks people in Cross River State, Nigeria. Journal of Pharmaceutical and Biomedical Sciences. 2016;6(1):46-49.
15. Okono MA, Agbo EP, Ekah BJ, Ekah UJ, Ettah EB, Edet CO. Statistical analysis and distribution of global solar radiation and temperature over southern Nigeria. Journal of the Nigerian Society of Physical Sciences. 2022;4(3):1-14.
16. Ettah EB, Eno EE, Udoimuk AB. The effects of solar panel temperature on the power output efficiency in calabar, nigeria. Journal of Radiography & Radiation Sciences. 2009;23(1):1-7
17. Abdelkader MR, Al-Salaymeh A, Al-Hamamre Z, Sharaf F. A comparative analysis of the Performance of Monocrystalline and Multiycrystalline PV Cells in Semi Arid Climate Conditions: The case of jordan. Jordan Journal of

Mechanical & Industrial Engineering. 2010; 4(5):543-552.

18. Ugwuoke PE, Okeke CE. Performance assessment of three different pv modules as a function of solar insolation in South Eastern Nigeria. International Journal of Applied Science and Technology. 2012; 2(3):319–327.
19. Dash PK, Gupta NC. Effect of temperature on power output from different commercially available photovoltaic modules. International Journal of Engineering Research and Applications. 2015;5(1):148–151.
20. Ettah E, Ushie P, Obiefuna J, Nwachukwu N. Comparative study of the effects of relative humidity on solar electricity generation in UYO and Port-Harcourt, Nigeria. International Journal of Mathematics and Physical Sciences Research. 2015;3(2):66–70.
21. Kazem HA, Chaichan MT, Al-Shezawi IM, Al-Saidi HS, Al-Rubkhi HS, Al-Sinani JK, Al-Waeli AH. Effect of humidity on the PV performance in Oman. Asian Transactions on Engineering. 2012;2(4): 29–32.
22. ALİ HM. Experimental investigation of monocrystalline and polycrystalline solar modules at different inclination angles. Journal of Thermal Engineering. 2018; 4(4):2137–2148.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/113444