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Comparative Investigation of the I–V Characteristics of Photovoltaic Modules Under Varying Environmental Conditions

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ABSTRACT

The current–voltage (I–V) characteristics and performance of monocrystalline and polycrystalline photovoltaic (PV) modules under varying environmental conditions across selected locations in Nigeria was investigated. The study aimed to evaluate the electrical performance of both PV technologies under different climatic conditions. Experimental measurements were conducted using monocrystalline and polycrystalline solar panels, a solar power meter for irradiance, a thermo-hygrometer for ambient temperature and relative humidity, an anemometer for wind speed, and an MPPT solar meter for voltage, current, and output power measurements. Data were collected under outdoor conditions at regular intervals during daylight hours. Performance was assessed using I–V characteristics for both panels, open-circuit voltage, short-circuit current, and power response were all obtained. The results revealed significant variations in PV performance across the selected locations. Monocrystalline modules consistently outperformed polycrystalline modules, recording higher current outputs of approximately 2.8–3.5 A and voltage values between 17.0 and 18.5 V under peak irradiance, whereas polycrystalline modules produced currents of about 2.3–3.0 A within similar voltage ranges. Locations with higher solar irradiance and moderate atmospheric conditions exhibited improved photovoltaic performance, characterized by smoother and more stable I–V curves. In contrast, lower irradiance and cloud cover reduced output current and overall efficiency. Elevated panel temperatures caused slight reductions in voltage due to the thermal behaviour of semiconductor junctions. Comparative analysis showed that increased irradiance enhanced photocurrent generation, while excessive temperature adversely affected voltage performance. Overall, monocrystalline PV modules demonstrated superior operational stability, efficiency, and electrical response under varying environmental conditions. The study concludes that photovoltaic performance in Nigeria is strongly influenced by local climatic conditions and semiconductor material properties, with monocrystalline modules offering greater suitability for outdoor solar energy applications in tropical environments.

Keywords: Photovoltaic Performance, Monocrystalline Module, Polycrystalline Module, Current-Voltage (I–V) Characteristics, Solar Irradiance

INTRODUCTION

The increasing global demand for sustainable, reliable, and environmentally friendly energy sources has intensified research and development in renewable energy technologies, particularly solar energy systems. Fossil fuel depletion, rising greenhouse gas emissions, climate change, and increasing energy insecurity have necessitated the search for alternative energy resources capable of meeting growing energy demands without causing severe environmental degradation. Among the available renewable energy technologies, photovoltaic (PV) systems have emerged as one of the most promising and rapidly expanding technologies for direct electricity generation from solar radiation (Ebhota and Jen 2020).

Photovoltaic technology converts solar energy directly into electrical energy through the photovoltaic effect occurring in semiconductor materials (Siva *et al.,* 2022). Unlike conventional energy conversion systems, photovoltaic systems operate silently, require minimal maintenance, produce no harmful emissions during operation, and are suitable for both grid-connected and stand-alone applications. The abundance of solar energy in tropical countries such as Nigeria makes photovoltaic technology particularly attractive for rural electrification, industrial development, communication systems, water pumping, and domestic energy supply (Chanchangi *et al.,* 2023)

Nigeria lies within a high solar radiation belt and receives abundant sunshine throughout the year, with average daily solar radiation ranging between 3.5 and 7.0 kWh/m²/day depending on geographical location and seasonal conditions. Despite this enormous solar potential, electricity generation in Nigeria remains inadequate, unstable, and insufficient for industrial, commercial, and domestic needs. Consequently, there has been increasing adoption of photovoltaic systems across various regions of the country. However, the performance of photovoltaic modules is not uniform across different geographical locations due to variations in environmental and climatic conditions such as solar irradiance, ambient temperature, panel temperature, relative humidity, cloud cover, atmospheric dust, and wind speed (Oyom and Sampson 2026).)

The operation of photovoltaic modules is fundamentally governed by the principles of solid-state physics, particularly semiconductor theory and electronic transport phenomena in crystalline materials. A photovoltaic cell is essentially a semiconductor p–n junction device that converts incident photon energy into electrical energy through the generation and separation of electron-hole pairs. Silicon remains the most widely used semiconductor material for photovoltaic applications because of its suitable band-gap energy, high abundance, and relatively stable electronic properties (Chaudhary *et al.,* 2023).

In solid-state physics, the electronic behaviour of materials is explained using energy band theory (Chaudhary *et al.,* 2023). In semiconductors, electrons occupy two major energy bands: the valence band and the conduction band, separated by a forbidden energy gap known as the band-gap energy (E_g). For silicon photovoltaic cells, the band-gap energy is approximately 1.1 eV. When photons with energy greater than or equal to the band-gap energy strike the semiconductor surface, electrons absorb sufficient energy to transition from the valence band to the conduction band, thereby creating free electrons and holes (Woods-Robinson *et al.,* 2020):

$$h\nu \geq E_g \tag{1.1}$$

where;

h = Plank's constant

v = frequency of incident radiation

This process generates an electron–hole pair, which is the fundamental mechanism of current generation in PV cells.

The generated electron-hole pairs are separated by the built-in electric field existing across the depletion region of the p–n junction, producing a flow of electric current through an external circuit. The efficiency of this process depends strongly on semiconductor properties such as carrier mobility, carrier lifetime, recombination mechanisms, impurity concentration, crystal defects, and temperature-dependent electronic behavior (Lutz *et al.*, 2018).

The electrical behavior of photovoltaic cells can be described using the solar cell diode equation (Cibira 2018):

$$I = I_{ph} - I_0 \left(e^{\frac{qV}{nkT}} - 1 \right) \tag{1.2}$$

where;

I_{ph} = photocurrent,

I_0 = saturated current,

V = voltage,

n = ideality factor.

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q = electronic charge,

k = Boltzmann constant,

T = absolute temperature.

This equation shows that photovoltaic performance is strongly affected by environmental conditions. Solar irradiance primarily determines photocurrent generation, while temperature significantly affects the reverse saturation current and open-circuit voltage. Increased operating temperature enhances thermal excitation within the semiconductor lattice, increases intrinsic carrier concentration, and promotes carrier recombination (Ahmed *et al.,* 2021). Consequently, elevated panel temperature reduces conversion efficiency and power output.

The intrinsic carrier concentration of a semiconductor varies with temperature according to:

$$n_i \propto T^{3/2} e^{-\frac{E_g}{2kT}} \qquad 1.3$$

This relationship indicates that increasing temperature increases intrinsic carrier concentration and recombination losses, thereby reducing photovoltaic efficiency. This temperature dependence is particularly important in tropical regions such as South-South and South-East Nigeria, where elevated ambient temperatures and intense solar radiation significantly affect PV module behaviour (Okafor *et al.,* 2024).

Environmental conditions also influence photovoltaic performance through atmospheric effects. Relative humidity, cloud cover, and atmospheric aerosols reduce the amount of solar radiation reaching the PV surface by absorption and scattering processes (Ettah *et al.*, 2012). Coastal regions such as Calabar, Eket, and Uyo are characterized by high humidity and frequent cloud cover, which reduce effective solar irradiance and overall module performance. Inland regions such as Obubra, Ogoja, and Obanlikwu typically experience higher solar irradiance but also higher operating temperatures, resulting in increased thermal losses. Midland regions such as Abakaliki, Ezza South, Abomege, and Ikot Ekpene often exhibit relatively balanced environmental conditions favorable for stable PV operation.

The current-voltage (I–V) characteristics of photovoltaic modules provide important information about their operational behavior and electrical performance (Dang *et al.*, 2023). Parameters such as short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), fill factor (FF), maximum power point (MPP), and conversion efficiency are commonly used to evaluate photovoltaic systems. The fill factor is expressed as:

$$FF = \frac{V_{mp} I_{mp}}{V_{oc} I_{sc}} \; 1.4$$

while the conversion efficiency is given by:

$$\eta = \frac{\text{Pout}}{G\,.\,A} \text{ X } 100\% \qquad 1.5$$

Where;

P_{out} = Output power (W)

G = Solar irradiance (W/m²)

A = Panel area (m²),

Understanding how these parameters vary under different environmental conditions is essential for photovoltaic system optimization, performance prediction, and long-term reliability assessment.

Several studies have investigated photovoltaic performance in different climatic regions worldwide. Previous studies generally reported that high solar irradiance improves photocurrent generation, while elevated temperatures reduce voltage output and efficiency (Bao *et al.*, 2025). Humidity and cloud cover have also been shown to reduce solar radiation intensity and photovoltaic output (Oyom *et al.*, 2023). However, most existing studies focus on isolated locations or specific climatic conditions, with limited comparative investigations covering multiple climatic zones within Nigeria.

Therefore, this study seeks to experimentally evaluate the performance of photovoltaic modules across ten selected locations in South-South and South-East Nigeria, namely Abakaliki, Abomege, Calabar, Eket, Ezza South, Ikot Ekpene, Obanlikwu, Obubra, Ogoja, and Uyo. The study aims to establish the influence of environmental parameters on photovoltaic performance using solid-state physics principles and semiconductor theory as the fundamental scientific basis.

The findings of this research provide important scientific and engineering information for photovoltaic system design, deployment, optimization, and renewable energy policy development in Nigeria. The study will also contribute to the understanding of photovoltaic behaviour under tropical environmental conditions and provide baseline data for future photovoltaic and semiconductor energy research.

Formation Of The P–N Junction

A solar cell is formed by creating a p–n junction through doping:

- p-type semiconductor: excess holes
- n-type semiconductor: excess electrons

When these materials are joined, diffusion of charge carriers occurs, leading to the formation of a depletion region and an internal electric field (Yue *et al.,* 2022).

The built-in potential V_{bi} of the junction is given by:

$$V_{bi} = \frac{kT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right) \quad 1.6$$

where;

k = Boltzmann constant,

T = temperature (K),

q = electron charge,

N_A, N_D = doping concentrations,

n_i = intrinsic carrier concentration.

This electric field is responsible for separating photogenerated charge carriers, thereby producing current.

One of the earliest notable studies in southern Nigeria was carried out by (Ettah *et al.,* 2012) on the effect of relative humidity on solar panel efficiency in Calabar, Nigeria. The study reported that low relative humidity values between 69% and 75% favored increased current generation and improved photovoltaic efficiency. The authors observed that increased atmospheric moisture reduced the amount of incident solar radiation reaching the photovoltaic surface, thereby reducing output power and efficiency.

According to (Omer 2017), Nigeria possesses significant solar energy potential due to its geographical location within the tropical region, receiving average daily solar radiation ranging from 3.5 kWh/m²/day in the coastal south to over 7.0 kWh/m²/day in the northern region. Consequently, several researchers have investigated the influence of environmental and climatic conditions on photovoltaic (PV) module performance across different parts of the country.

Ettah, *et al.,* (2015) conducted a comparative study on the effects of relative humidity on solar electricity generation in Uyo and Port Harcourt. Their results revealed that Uyo, which recorded relatively lower humidity values, generated higher photocurrent and power efficiency compared to Port Harcourt where humidity values exceeded 80%. The study further established that photovoltaic efficiency and photocurrent generation are inversely proportional to relative humidity.

Another important contribution by (Ettah *et al.,* 2009) investigated the effect of solar panel temperature on power output efficiency in Calabar, Nigeria. The study experimentally confirmed that increased panel temperature reduced photovoltaic efficiency due to increased carrier recombination and enhanced reverse saturation current within the semiconductor junction. This finding agrees with semiconductor band-gap theory and the solar cell diode equation.

Njok and Ogbulezie (2018) investigated the performance of photovoltaics installed close to Calabar River. Their work examined the effects of temperature and relative humidity on photovoltaic output current, voltage, power, and efficiency. The study showed that voltage remained relatively stable between relative humidity values of 65% and 75%, while efficiency increased with temperature up to approximately 47°C before declining due to thermal losses.

Okono *et al.,* (2022) performed a statistical analysis and distribution study of global solar radiation and ambient temperature over Southern Nigeria using meteorological and satellite data. Their work analyzed seventeen locations within the southern ecological zones and reported that inland regions generally recorded higher solar irradiance values compared to coastal locations due to reduced atmospheric attenuation and cloud cover.

Several studies in northern Nigeria have also demonstrated the influence of environmental parameters on photovoltaic performance. Research conducted in Dutsin-Ma, Katsina State, revealed that photovoltaic power output increases with increasing solar irradiance and moderate temperature conditions but decreases significantly under high humidity conditions. The authors observed that maximum panel performance occurred at temperatures between 42°C and 45°C with humidity values below 40%.

In semi-arid regions of northern Nigeria, (Ettah *et al.,* 2021) conducted performance analysis of monocrystalline and polycrystalline solar panels and found that monocrystalline modules consistently generated higher output power under intense solar irradiance conditions.

Collectively, Nigerian photovoltaic studies demonstrate that solar irradiance is the dominant parameter controlling photocurrent generation, while temperature and humidity strongly affect voltage output, fill factor, efficiency, and overall photovoltaic stability. Coastal regions generally experience reduced photovoltaic efficiency due to high humidity and cloud cover, whereas inland regions possess higher solar energy potential but experience thermal losses associated with elevated panel temperatures.

Although numerous studies have investigated photovoltaic performance in isolated Nigerian locations, limited comparative studies exist involving multiple climatic zones within South-South and South-East Nigeria using identical experimental conditions and both monocrystalline and polycrystalline modules. Therefore, the present study contributes to the existing body of knowledge by experimentally comparing photovoltaic performance across inland, midland, and coastal regions using solid-state physics principles and field measurements. Other investigations include:

Yakubu *et al.,* (2022) investigated the performance of a bifacial solar PV system in Nigeria under various climatic regions according to them bifacial PV modules are known to be location-dependent. The In-Plane solar radiation received by tilted monofacial and bifacial PV modules was calculated and compared using an analytical model. In all climatic regions, the bifacial PV system receives more in-plane solar irradiance. The systems were simulated on PVsyst to determine the energy yield, and their results show that under natural ground (vegetation and sand) of the various regions and optimization of the tilt angle, the bifacial PV system yielded more energy than the monofacial system. The bifacial gain varies depending on location, and system parameters must be optimized to improve the bifacial energy gain.

MATERIALS AND METHOD

Materials used in this research are; Thermo-hygrometer SM206 solar power meter, GM816 anemometer, digital stop watch, UNI-T solar MPPT meter, two Commercial PV Modules (80watt) with same technical specification as follows: Maximum power = 80W output tolerance = ±5%, Maximum current (Imp) = 4.58A, Maximum voltage (Vmp) = 17.5V, Short circuit current (Isc) = 4.85A, Short circuit voltage (Voc) = 21.55V, Surface area of panel = 0.61m^2. These technical specifications were given by the manufacturer at a standard test condition of solar radiation, 1000w/m^2 and temperature of 25^{0}C.

This study adopted an experimental field measurement approach to comparatively investigate the current–voltage (I–V) characteristics and performance of monocrystalline and polycrystalline photovoltaic (PV) modules under varying environmental conditions. The experiment was conducted under natural outdoor atmospheric conditions in selected locations in Nigeria between 6a.m – 6p.m every day for three months (August September October). The thermo-hygrometer was used for measuring ambient temperature and relative humidity, an anemometer for measuring wind speed, and a digital MPPT solar meter for measuring electrical parameters such as voltage, current, and output power.

The commercial PV modules were mounted on adjustable support structures and oriented southward at an optimum tilt angle to ensure maximum incident solar radiation on the PV modules. the tilt angle was selected based on the geographical latitude of each study location. Since all experimental sites are located within the tropical region (4°–7° N latitude), the optimum fixed annual tilt angle was approximated using

$$\beta \approx \phi$$

Where;

- β= module tilt angle (°)
- ϕ= latitude of the location (°)

The same tilt angle was used for both the monocrystalline and polycrystalline modules at each location to ensure identical exposure conditions.

Measurements were conducted simultaneously on both photovoltaic modules and the spacing between the modules was maintained at approximately **0.5 m** to prevent mutual shading and thermal interference. At each current-voltage, output current, and output power measurement, solar irradiance, ambient temperature, relative humidity, wind speed was recorded. The measured data were used to evaluate the electrical behaviour and operational performance of the modules using current–voltage (I–V) characteristics.

The operation of the photovoltaic modules was explained using semiconductor and solid-state physics principles. The photovoltaic effect occurring within the semiconductor p–n junction generated electron-hole pairs when incident photon energy satisfied the condition:

$$h\nu \geq E_g$$

The electrical performance of the modules was further analysed using the solar cell diode equation:

$$I = I_{ph} - I_0\left(e^{\frac{qV}{nkT}} - 1\right)$$

The measured data were analysed graphically and comparatively using solar data plotter to generate the I–V characteristics for both modules to examine the relationships between environmental variables and PV performance. Comparative analysis of voltage response, current output and mean values as seen on the table below were carried out to determine the influence of environmental parameters on photovoltaic performance and to identify the module type with superior operational characteristics under tropical outdoor conditions.

RESULTS AND DISCUSSION

Table 1: Average Measured and Computed Parameters

LOCATIONS	SOLAR RADIATION (WM^{-2})	VOLTAGE (V)		CURRENT (A)		OUTPUT POWER (W)		EFFICIENCY (%)		RELATIVE HUMIDITY (%)	PANEL TEMP. (0C)		AMBIENT TEMP. (^0C)	WIND SPEED M/S	FILL FACTOR (%)		PERFORMANCE RATIO (%)	
		MONO	POLY	MONO	POLY	MONO	POLY	MONO	POLY		MONO	POLY			MONO	POLY	MONO	POLY
ABAKALIKI	511.2	15.1	13.0	1.4	1.2	21.1	15.6	31.9	27.2	66.0	28.3	29.1	26.9	1.0	18.7	13.8	51.6	38.1
EZZA SOUTH	473.0	15.3	12.2	1.3	1.2	19.9	14.6	31.0	27.0	68.6	27.8	28.2	27.1	0.5	17.6	12.9	52.6	38.6
ABOMEGE	463.8	15.2	12.0	1.3	1.1	19.8	13.2	30.4	28.3	65.8	27.2	28.5	26.4	1.0	17.5	11.7	53.4	35.6
OBUBRA	589.3	15.6	13.0	1.7	1.2	28.7	20.3	36.0	25.0	59.1	32.4	33.0	30.8	1.1	25.4	18.0	60.9	43.1
OGOJA	565.9	15.9	14.6	1.8	1.6	30.4	23.4	38.0	37.0	58.4	32.8	34.4	31.2	0.6	26.9	20.7	67.1	51.7
OBANLIKU	548.8	15.4	13.7	1.7	1.4	26.2	19.2	35.5	32.0	62.0	31.4	32.0	30.1	1.0	23.2	17.0	59.7	43.7
IKOT EKPENE	595.0	15.6	12.4	1.7	1.4	26.5	17.4	40.0	31.0	60.0	30.3	30.7	29.6	0.3	23.5	15.4	55.7	36.6
EKET	324.9	15.7	10.3	1.1	0.8	17.3	8.2	23.0	18.0	73.4	22.1	23.5	23.6	1.5	15.3	7.3	66.6	31.5
UYO	522.7	15.8	14.0	1.4	1.2	22.1	16.8	28.0	23.0	71.5	26.0	27.8	24.8	0.4	19.6	14.9	52.9	40.2
CALABAR	511.5	16.6	15.0	1.3	1.1	21.6	16.5	26.0	21.0	69.4	25.1	26.2	24.5	1.0	19.1	14.6	52.8	40.3

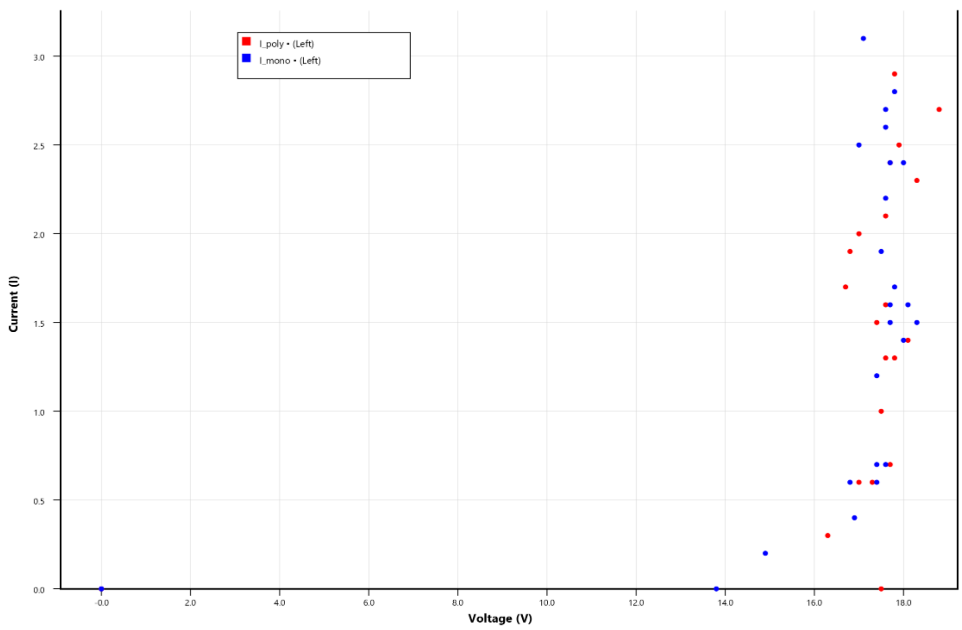

Figure 1.1: IV Curve

Location: Abakaliki

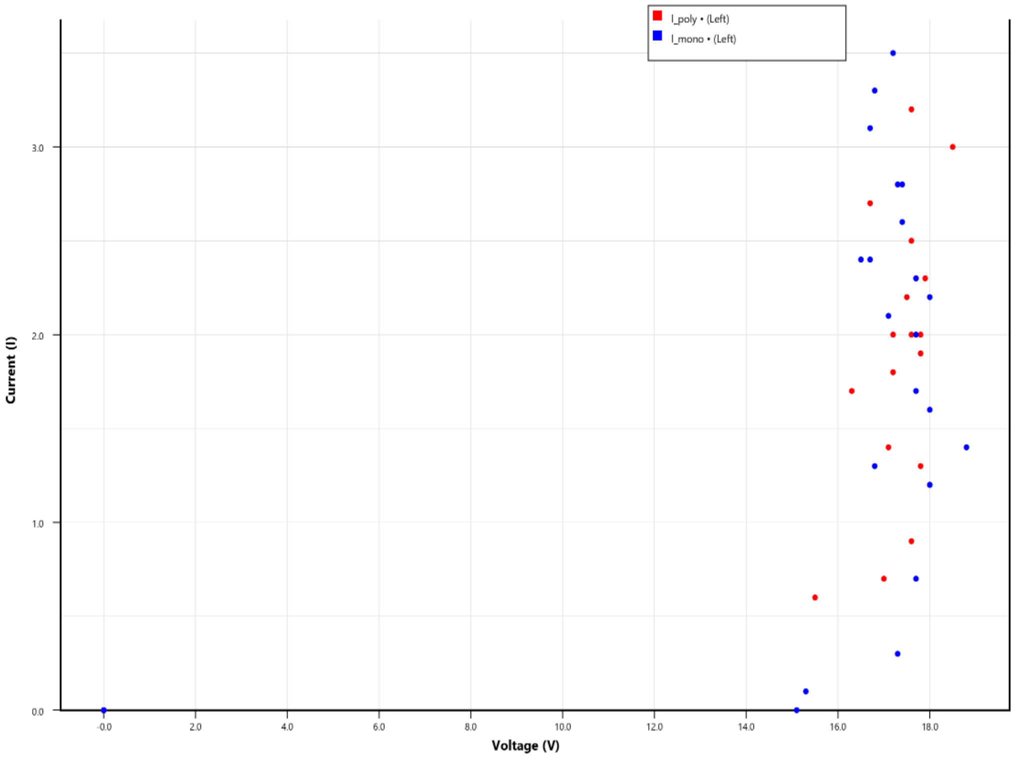

Figure 1.2: IV Curve

Location: Abomege

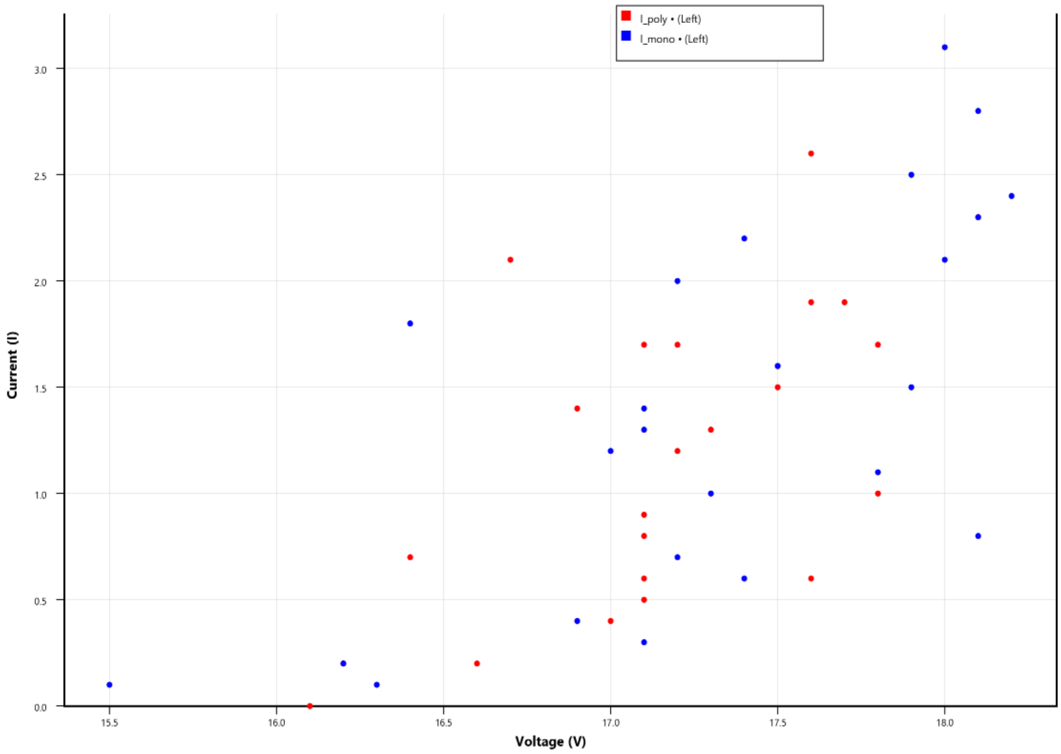

Figure 1.3: IV Curve

Location: Calabar

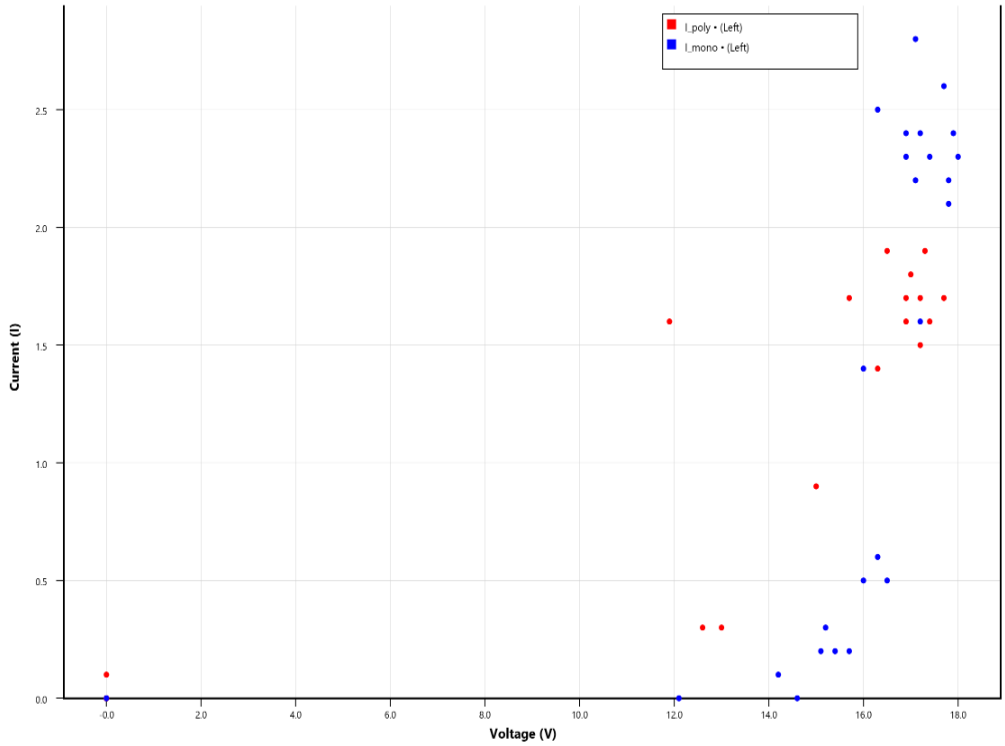

Figure 1.4: IV Curve

Location: Eket

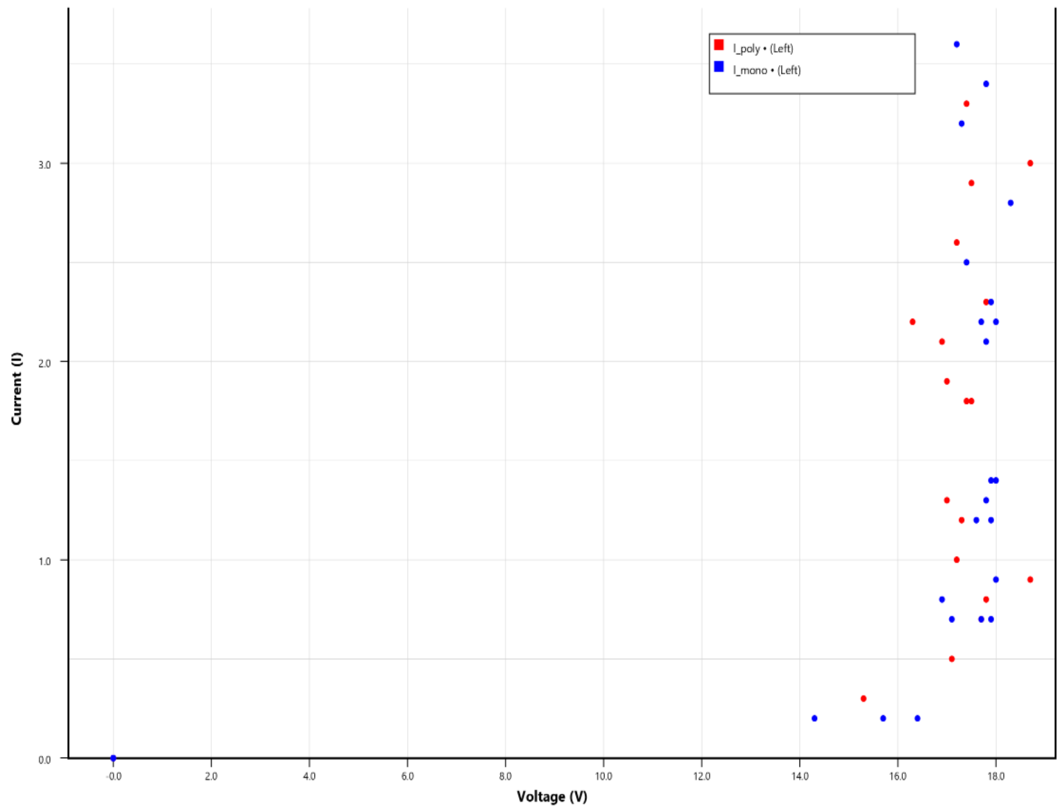

Figure 1.5: IV Curve

Location: Ezza south

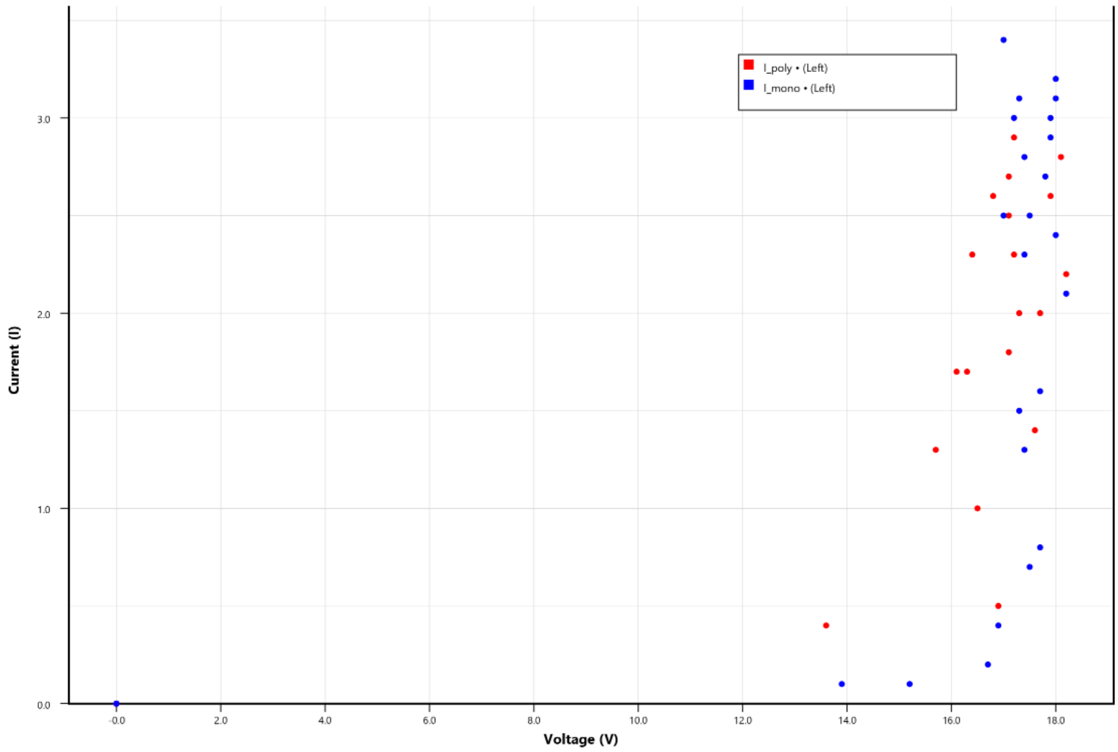

Figure 1.6: IV Curve

Location: Ikot Ekpene

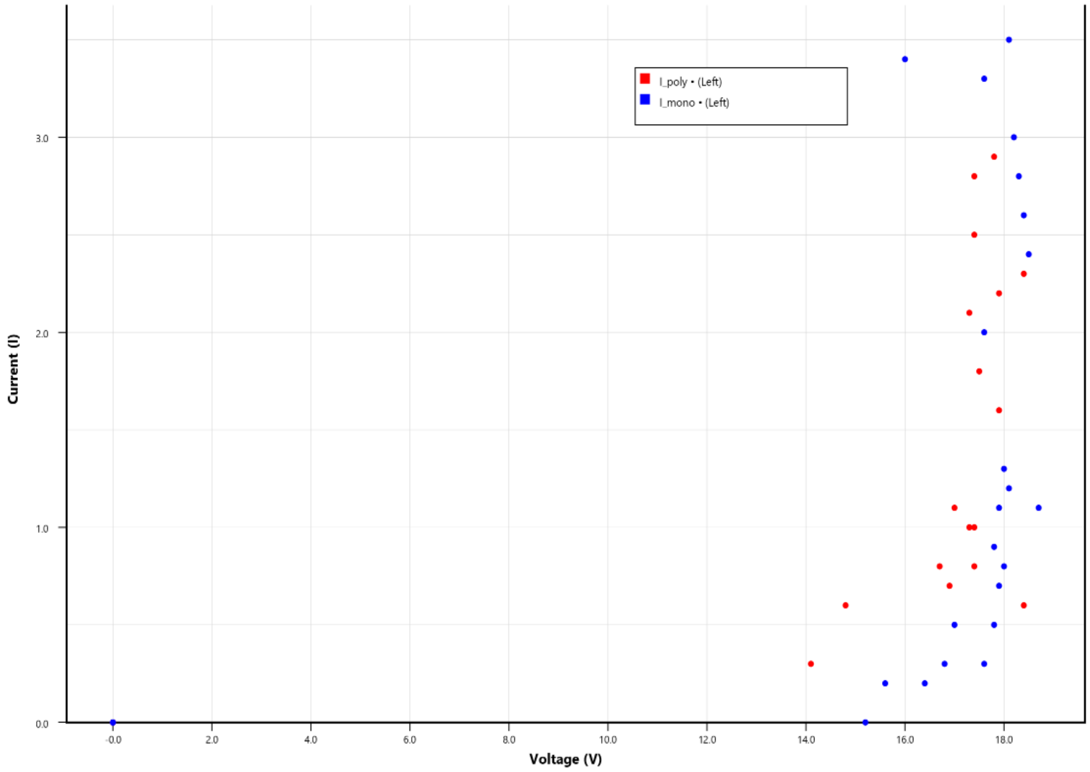

Figure 1.7: IV Curve

Location: Obanlikwu

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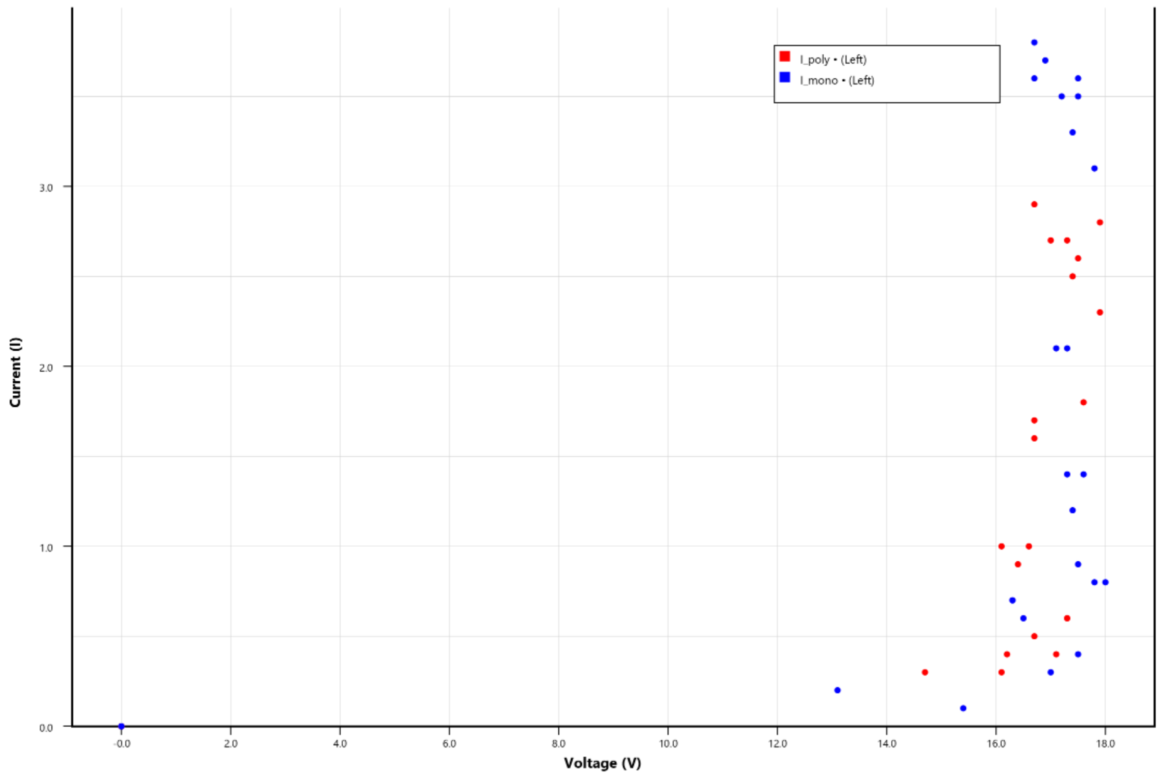

Figure 1.8: IV Curve

Location: Obubra

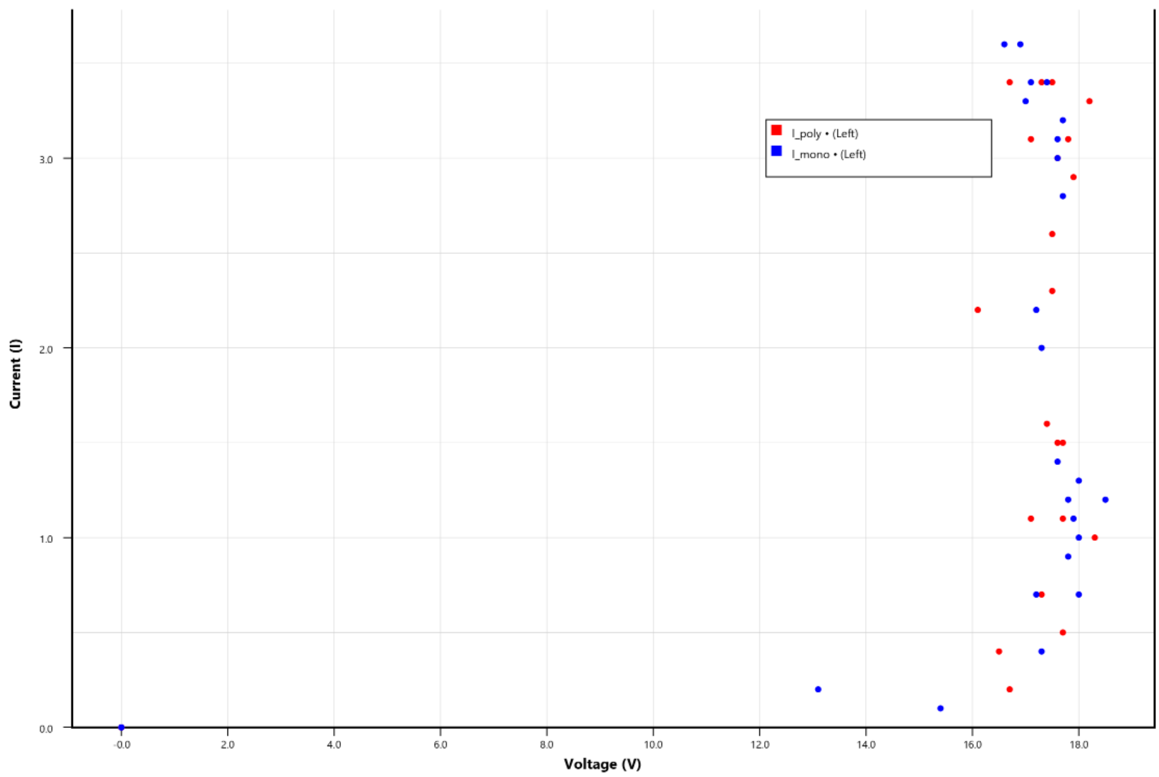

Figure 1.9: IV Curve

Location: Ogoja

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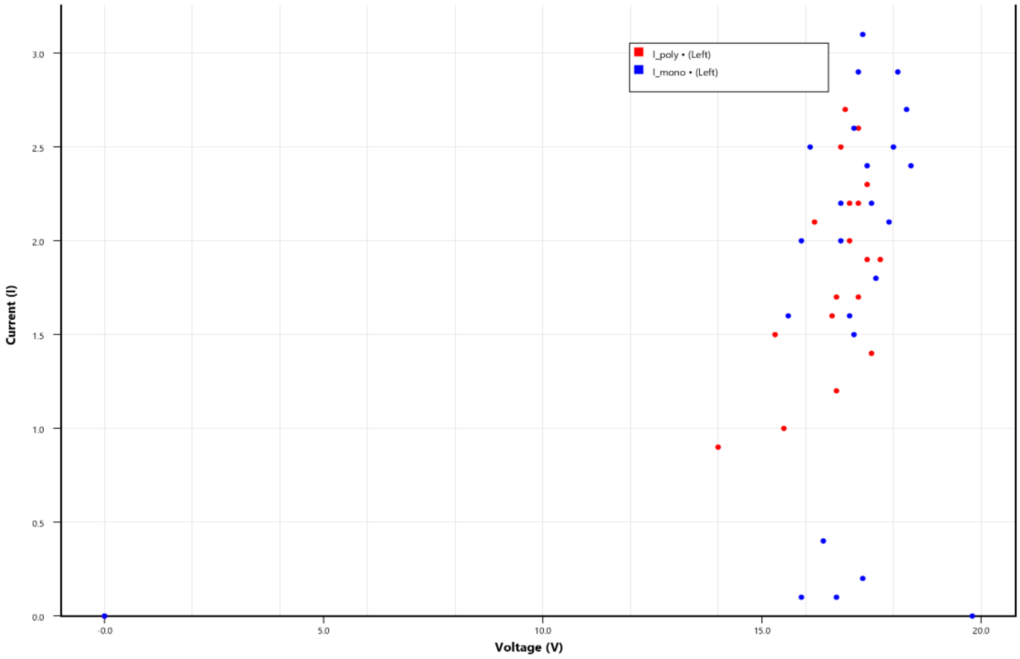

Figure 1.10: IV Curve

Location: Uyo

Figures 1.1–1.10 above represents the current–voltage (I–V) characteristics of monocrystalline (I_mono) and polycrystalline (I_poly) photovoltaic modules across ten locations: Abakaliki, Abomege, Calabar, Eket, Ezza South, Ikot Ekpene, Obanlikwu, Obubra, Ogoja, and Uyo. These curves are fundamental for evaluating electrical performance, power output, and operating efficiency of PV systems under varying environmental conditions. Although the curve does not in reality reflect the exact I-V characteristics of diodes because of environmental factors. But the I–V curves exhibit the typical PV behavior i.e. Current remains relatively high and stable at low voltages, then gradually decreases as voltage increases. The region near the "knee" of the curve represents the maximum power point (MPP). Monocrystalline modules generally show slightly higher current values than polycrystalline modules at similar voltages.

This behavior aligns with standard photovoltaic theory (Villalva *et al.,* 2009).

From the graph above the highest current outputs (≈2.5–3.5 A) are observed in Ogoja, Obubra, Ikot Ekpene, and Obanlikwu. Moderate current levels occur in Ezza South, Abomege, and Abakaliki. While lower current outputs are evident in Calabar, Eket and Uyo.

This trend reflects earlier observations where higher solar radiation leads to higher photocurrent generation, confirming that current is directly proportional to irradiance.

The voltage across all locations remains relatively consistent (≈17–19 V), with minor variations due to temperature differences. Slightly lower Voltage values are observed in high-temperature locations (e.g., Obubra, Ogoja), due to the negative temperature coefficient of voltage.

Coastal regions (Calabar, Eket, Uyo) show slightly higher Voc stability, likely due to lower operating temperatures.

However, voltage variations are less pronounced compared to current variations, indicating that irradiance affects current more strongly than voltage.

Well-defined curves with sharp knees are observed in Ogoja, Obanlikwu, Obubra, and Ikot Ekpene, indicating high fill factor, efficient power extraction, minimal losses. Flattened or scattered curves are seen in Calabar, Eket, and Uyo, suggesting reduced irradiance, higher humidity effects, Increased performance variability. Moderate curve quality is observed in Abakaliki, Abomege, and Ezza South.

Monocrystalline modules consistently produce slightly higher current values, more clustered and stable I–V points. While polycrystalline modules show similar trends but with slightly lower current output. In some locations they exhibit more spread indicating that monocrystalline modules have a marginally higher efficiency, although the difference is not significant compared to environmental influences.

The above I–V analysis confirms that: Photocurrent is strongly dependent on solar radiation, voltage is slightly affected by temperature, humidity indirectly reduces performance by lowering irradiance, module type has a minor effect compared to environmental conditions.

Conclusively, all locations exhibit standard PV I–V characteristics, Inland locations show higher current output and better curve quality, Coastal locations exhibit reduced and less stable performance, Monocrystalline modules slightly outperform polycrystalline modules, Irradiance is the dominant factor influencing PV electrical output.

CONCLUSION

This study presented a comparative investigation of the current–voltage (I–V) characteristics and performance of monocrystalline and polycrystalline photovoltaic (PV) modules under varying environmental conditions across selected climatic regions in Nigeria. The results demonstrate that the electrical performance of both PV technologies is strongly influenced by variations in solar irradiance, panel temperature, ambient temperature, relative humidity, and wind speed. While increased solar irradiance enhanced current generation and output power, elevated panel temperatures reduced the operating voltage and overall conversion efficiency, confirming the sensitivity of photovoltaic systems to environmental variability.

A key finding of this study is the consistently superior performance of the monocrystalline module over the polycrystalline module across the investigated locations. The monocrystalline module exhibited higher output power, conversion efficiency, fill factor, and performance ratio under comparable operating conditions, indicating greater resilience to environmental fluctuations. In addition, clear spatial variations in module performance were observed among the study locations, highlighting the influence of regional climatic characteristics on photovoltaic energy yield and emphasizing the need for location-specific system evaluation and technology selection.

The principal scientific contribution of this work lies in the comprehensive field-based comparison of photovoltaic module performance across multiple environmental zones using measured I–V characteristics and derived performance indices under real operating conditions. Unlike studies conducted under controlled laboratory environments or limited geographical coverage, this investigation provides practical evidence of how climatic variability influences photovoltaic performance in tropical regions. The findings establish a valuable dataset for validating photovoltaic performance models, optimizing system design, and improving technology selection for diverse environmental conditions.

Overall, this study demonstrates that incorporating local climatic characteristics into photovoltaic system planning can significantly improve energy yield, system reliability, and long-term operational efficiency. The results provide useful guidance for researchers, engineers, policymakers, and investors seeking to accelerate the deployment of efficient and sustainable solar energy technologies in Nigeria and regions with similar tropical climates.

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