Science Journal of Energy Engineering
2025, Vol. 13, No. 2, pp. 42-61
https://doi.org/10.11648/j.sjee.20251302.12

Research Article

Feasibility and Performance Analysis of Solar Energy Integration into National Grid for Improved Power Supply, Using Umuezerokam Community, Nigeria as a Case Study

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Abstract

Nigeria, as a developing country, faces persistent challenges with epileptic power supply, particularly in rural communities. This study investigates the technical feasibility and performance of integrating solar energy into Nigeria's national grid to enhance electricity supply, using Umuezerokam community in Imo State as a case study. The objective is to assess the solar energy potential and system performance of a 750 kW grid-tied photovoltaic (PV) system through advanced simulation using the Solargis-pvPlanner tool. Key performance indicators, including Global Tilted Irradiation (GTI) averaging 140–160 kWh/m²/month, specific PV output ranging from 99.2 to 125 kWh/kWp, and a Performance Ratio (PR) averaging 80.7%, were analyzed based on site-specific solar and meteorological data. The results reveal that Umuezerokam experiences an annual average solar irradiance of approximately 4.6 kWh/m²/day, making it highly suitable for solar electricity generation. Simulation outcomes show that the proposed solar PV system can produce about 1.019 GWh annually, meeting the estimated energy needs of over 300 households and improving daily electricity supply from an average of 5–6 hours to about 11 hours. The study concludes that solar energy integration into the national grid is technically feasible and capable of significantly enhancing electricity supply in rural Nigeria. Furthermore, adopting such solutions would contribute to Nigeria's sustainable development goals by promoting the use of renewable energy. These findings provide critical insights for policymakers, investors, and local authorities seeking to address energy poverty through clean energy technologies.

Keywords

Solargis Simulation, Performance Analysis of Solar PV, Solar Energy Feasibility, Grid-tied Solar Systems

1. Introduction

Solar energy stands as a pivotal renewable energy source for achieving sustainable power supply globally. In developing nations like Nigeria, where electricity generation and distribution remain inadequate, solar energy offers a viable solution to mitigate persistent power shortages. Nigeria benefits from an average solar radiation of 5.5 kWh/m² per day [1], making it well-suited for solar photovoltaic (PV) deployment. Despite this potential, the country remains heavily dependent on fossil fuels, with natural gas accounting for over 70% of total electricity generation [2]. Rural communities,

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Received: 13 April 2025; **Accepted:** 28 April 2025; **Published:** 18 June 2025

such as Umuezerokam in Imo State, experience significant power deficits due to limited access to the national grid and poor infrastructure.

Grid-tied solar PV systems have been widely adopted across the world to improve electricity reliability, reduce dependence on fossil fuels, and support cleaner energy transitions. Studies have shown that solar integration can improve voltage profiles, minimize transmission losses, and contribute to grid stability. For example, [3] analyzed the impact of high solar penetration on grid stability in the United States and emphasized the need for flexible power systems. [4] demonstrated through simulation that combining solar PV with energy storage can help manage intermittency and maintain stability. Similarly, [5] observed that hybrid solar-grid systems in rural Nigerian communities reduce diesel consumption, offering both economic and environmental benefits.

Recent advancements in solar technology and grid planning have also addressed various aspects of performance and reliability. [6] developed a wave-shape-based algorithm for detecting partial shading conditions in photovoltaic (PV) arrays using only voltage and current measurements. By analyzing the skewness of the superimposed power waveform, their method effectively distinguishes partial shading from short-circuit and high-resistance faults without requiring communication links or training datasets. The algorithm, implemented in a central intelligent electronic device (IED), was validated through simulations on a 5×5 grid-connected PV system, demonstrating improved fault detection and protection for PV integration. [7] highlighted the critical role of infrastructure by proposing a robust co-planning framework for transmission networks and privately-owned renewable sources. Their model simultaneously minimizes transmission expansion cost, congestion, and load curtailment while ensuring investment viability for private RES developers—insights that are particularly relevant for rural electrification in Nigeria. [8] conducted a comprehensive design of a 100-kilowatt rooftop solar power plant using bifacial PV technology and PVsyst software, focusing on the impact of bifacial coefficients, rear-side irradiance, optimal installation angles, and shading analysis. Their design process incorporated multiple tools including PVsyst, AutoCAD, ETAP, and RETScreen, and emphasized the importance of detailed simulation and economic evaluation. These findings are particularly relevant for high-solar-potential regions like Nigeria, where accurate system configuration and performance estimation are crucial for successful solar deployment. In another study, [9] demonstrated that the installation of mirrors around PV modules can enhance solar radiation capture and increase power output — an approach that may be especially useful in regions with high solar potential like Nigeria.

Despite these developments, solar energy integration in Nigeria remains at an early stage. Key challenges persist, especially regarding grid stability and power quality due to the intermittent nature of solar generation. Fluctuations in solar irradiance often lead to voltage variations and frequency instability. While studies such as [10] have shown that battery energy storage systems (BESS) and grid reinforcement can address these issues, high storage costs and inadequate policy support in Nigeria continue to limit implementation. Moreover, there is limited empirical research using advanced simulation tools such as SolarGIS to study real-world solar-grid interactions in rural Nigerian settings.

This study aims to evaluate the technical feasibility of integrating a 750 kW grid-tied solar PV system in Umuezerokam, Imo State, using SolarGIS-pvPlanner simulations. It will assess solar energy potential, system performance, and grid impact. The outcome will provide critical insights into the viability of large-scale solar adoption in rural communities and help inform strategies for overcoming integration barriers. Ultimately, this research seeks to support Nigeria's renewable energy roadmap and contribute to achieving its sustainable development goals (SDGs).

2. Materials and Methods

This study evaluates the technical feasibility of integrating a 750 kW grid-tied solar photovoltaic (PV) system into the electricity infrastructure of Umuezerokam, a rural community in Owerri West Local Government Area, Imo State, Nigeria. The methodology involves a combination of primary and secondary data collection, system design, and performance analysis using SolarGIS-pvPlanner simulations.

2.1. Study Area

Umuezerokam is located in Owerri west Local Government Area of Imo State, in the southeastern part of Nigeria and experiences a tropical rainforest climate with distinct wet and dry seasons. The region receives an average solar irradiance of 4.5 to 5.5 kWh/m^2 per day, making it suitable for solar energy generation. The terrain is relatively flat, which simplifies solar panel installation, while the moderate population density ensures adequate space for deploying solar infrastructure. Electricity supply in the community is unreliable due to frequent power outages and voltage fluctuations associated with the national grid. These conditions make Umuezerokam an ideal case study for assessing the feasibility of grid-tied solar PV systems in rural Nigeria.

Figure 1. Umuezerokam location and map view (googlemap).

2.2. Data Collection Methods

Both primary and secondary data collection methods were employed to evaluate the solar energy potential and grid conditions in the study area. Primary data collection involved field visits, surveys, and direct observations, while secondary data was obtained from relevant electricity regulatory agencies and meteorological databases.

Primary data was gathered through site visits to assess the physical and infrastructural conditions affecting solar deployment. Household surveys and structured interviews were conducted with residents to determine their energy consumption patterns, monthly electricity usage, and reliance on alternative power sources. Direct measurements were taken from selected households to estimate their average load demand, which was subsequently used to project the energy requirements for the entire community.

Secondary data was sourced from the Enugu Electricity Distribution Company (EEDC) and the Nigerian Electricity Regulatory Commission (NERC). These datasets provided insights into the region's existing electricity supply, grid stability, and load distribution. Historical solar irradiance and meteorological data were obtained from SolarGIS, including parameters such as global horizontal irradiance (GHI), direct normal irradiance (DNI), and diffuse horizontal irradiance (DHI). These parameters were essential for modeling the solar energy system and estimating its expected power output.

2.3. Solar Power System Design

The 750 kWp grid-connected photovoltaic (PV) system consists of Sharp Monocrystalline PV modules arranged in series-parallel combinations to optimize energy capture. The modules are installed in an open area to prevent shading effects. The system incorporates a DC/DC Buck converter with Maximum Power Point Tracking (MPPT) to maximize power output under varying sunlight and temperature conditions.

The DC/DC converter steps up the low DC voltage from the PV panels before feeding it into a three-phase DC/AC inverter, which converts DC power to 400 V AC. The inverter ensures voltage regulation, frequency stability, and synchronization with the grid. A Phase Locked Loop (PLL) module further aligns the inverter's output phase with the grid to prevent phase mismatches.

To facilitate grid connection, the AC output is passed through a step-up transformer to match the 11 kV distribution network. A filter system is included to reduce electrical noise and harmonics during DC-AC conversion, ensuring compliance with grid standards. The system is integrated into Nigeria's 50 Hz national grid where the generated power is transmitted at 330 kV (primary transmission), stepped down to 132 kV (secondary transmission), and further reduced to 33/11 kV for distribution to end users.

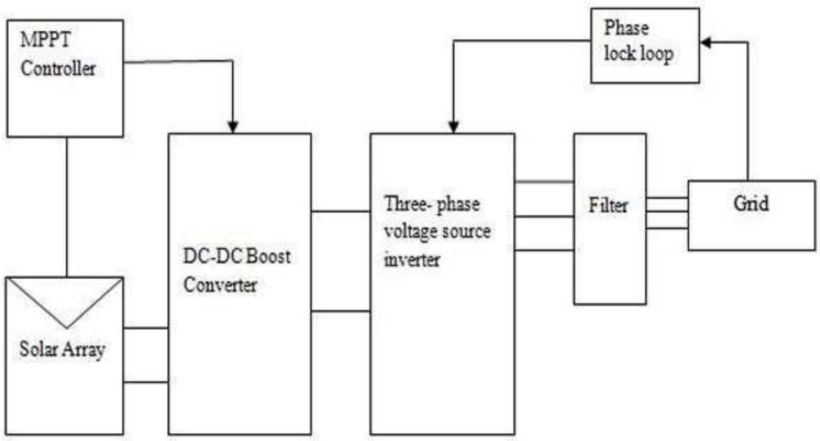

Figure 2*. Solar PV grid integrated model [11].*

2.4. Solar Power Plant Capacity for the Community

The capacity of the solar power plant required for Umuezerokam was estimated based on the community's average monthly energy consumption. The total estimated energy demand was derived using household energy consumption data collected from surveys and direct measurements. The calculation was based on the top ten households with the highest electricity consumption, extrapolated to represent the entire community. The relationship used for this estimation is expressed as:

$$CEMEC = THEC \times EHC \quad (1)$$

Where; $CEMEC$ = $community\ estimated\ avg\ monthly\ energy\ con\ (kWh)$

$THEC$ = $top\ households\ avg\ monthly\ energy\ con\ (kWh)$

EHC = $estimated\ no\ of\ households\ in\ the\ community$

$$THEC = \frac{Avg(H1+H2+H3+H4+H5+H6+H7+H8+H9+H10)}{10} \quad (2)$$

Where H1 - H10 represent the monthly energy consumption values of the ten selected households.

The community's estimated average load demand (THLD) was then determined using:

$$THLD = \frac{THEC}{no\ of\ hours\ of\ Electricity/month} \quad (3)$$

Where THLD is the Top households average monthly load demand

Estimated Community avg load demand = THLD × 300 (4)

To determine the required installed capacity of the solar PV system, the planned energy generation was estimated using:

$$Installed\ capacity = \frac{planned\ energy\ generation/month}{daily\ peak\ sun\ hours\ \times no\ of\ days\ in\ a\ month} \quad (5)$$

where the planned energy generation per month is set to be higher than the community's estimated energy consumption (CEMEC) to account for system losses and fluctuations in solar radiation.

The daily peak sun hours for Umuezerokam were derived from [12], which analyzed solar insolation levels in Owerri. The average daily peak sun hours from this study was found to be 4.44 hours, as summarized in table 1.

Table 1*. Average daily peak sun and insolation hours.*

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S (hours)	5.28	5.48	5.17	5.34	5.52	4.39	3.11	3.24	3.33	4.22	5.75	5.78
S_0 (hours)	11.69	11.8	11.94	12.09	12.22	12.28	12.25	12.14	12.00	11.84	11.72	11.66

Where $S = avg\ daily\ peak\ sun\ hours$
$S_0 = avg\ daily\ insolation\ hours$

$$Hours\ of\ Electricityper\ day = \frac{daily\ energy\ generation\ (Kwh)}{daily\ energy\ demand\ (Kw)} \quad (6)$$

Taking 6 hours as the constant electricity usage time,

$$community\ monthly\ energy\ demand\ (Kwh) = \frac{energy\ consumed\ per\ month}{6 \times no\ of\ days\ in\ a\ month} \quad (7)$$

2.5. Performance Analysis and Grid Impact

The performance of the grid-connected solar PV system was assessed by analyzing its contribution to electricity supply improvement in Umuezerokam. The percentage improvement in power supply after integrating the solar system was calculated using:

$$\%\ Power\ supply\ improvement = \frac{Final\ duration - Initial\ duration}{initial\ duration} \times 100 \quad (8)$$

where the initial duration represents the existing daily electricity supply hours from the national grid, and the final duration accounts for the additional electricity provided by the solar PV system.

2.6. SolarGIS-PV System Simulation

Th SolarGIS-pvPlanner is an advanced online simulation tool used to assess the performance of photovoltaic (PV) systems by leveraging high-resolution solar radiation and meteorological data. The platform perovides site-specific assessments based on aggregated climate data processed at 15-minute intervals, ensuring accurate modeling of solar energy availability. It incorporates key PV system parameters such as location coordinates, module geometry, inverter efficiency, mounting type, and system losses, allowing for detailed performance predictions.

To conduct a SolarGIS simulation, the geographic coordinates of Umuezerokam were entered into the system, and historical Global Horizontal Irradiance (GHI), Direct Normal Irradiance (DNI), and Diffuse Horizontal Irradiance (DHI) data were obtained. The PV system was configured with monocrystalline solar modules**,** a three-phase inverter**,** and fixed-tilt mounting for optimal energy capture. System losses due to cabling, shading, temperature variations, and soiling were defined to refine the simulation results.

The simulation process involved calculating the monthly and annual energy yield, evaluating power generation efficiency, and determining grid integration parameters such as voltage stability and frequency synchronization. The expected energy output was compared to the community's estimated energy demand to assess whether the 750 kW PV system could adequately supplement existing grid electricity.

Certain assumptions were made during the modeling process, including consistent six-hour daily grid electricity supply, a 300-household community, and the accuracy of energy consumption data from EEDC utility bills. These assumptions ensured that the simulation aligned with real-world conditions while accounting for potential limitations in system performance and energy availability.

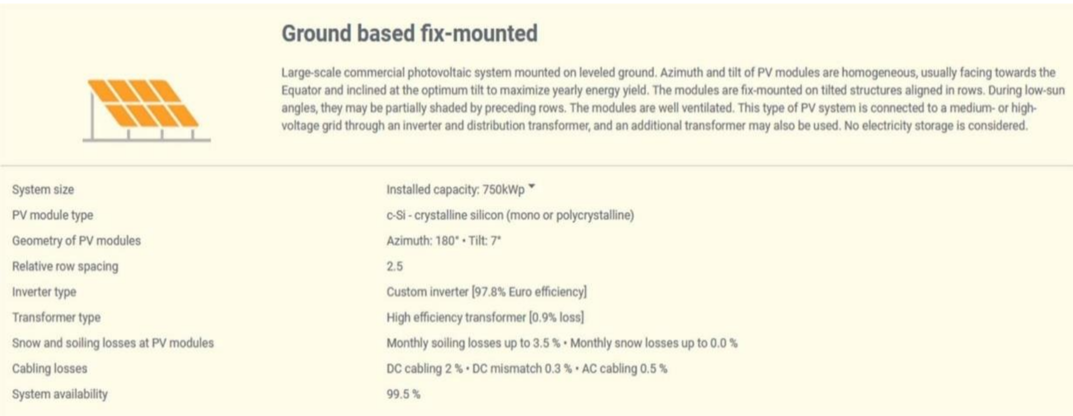

Figure 3*. 750kW model setup in Solargis simulator.*

3. Results and Discussions

This section presents the results of modeling the solar power plant capacity required to meet the community's monthly energy demand. The SolarGIS-pvPlanner simulator was used to evaluate the feasibility of integrating solar energy into the national grid. The study analyzes various parameters, including solar radiation, meteorological conditions, monthly power output, and PV electricity hourly profiles.

The section also assesses the solar power plant's performance in terms of energy losses, conversion efficiency, and lifetime performance. Graphical representations such as diagrams and plots are included to illustrate key findings. Additionally, the mathematical models developed in Chapter Three were applied to generate the desired results, providing insights into the system's reliability and stability improvements.

3.1. Data Collected

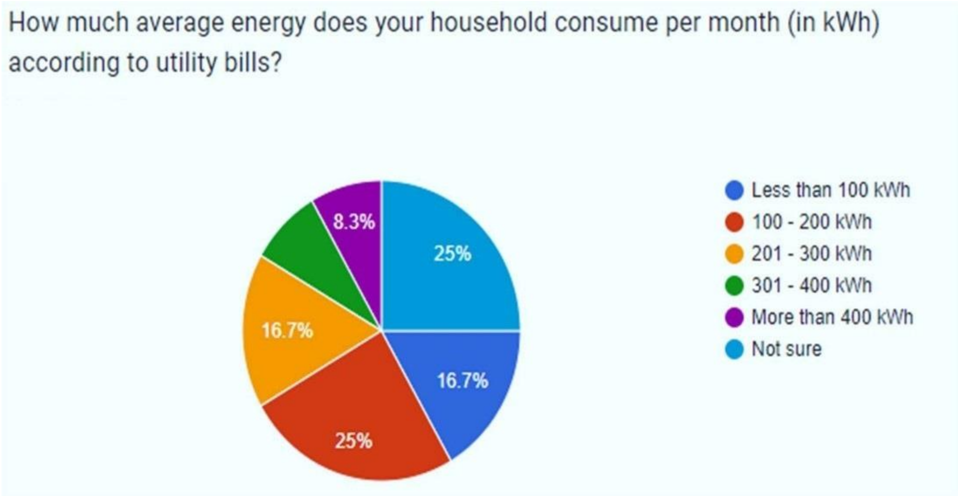

Figure 4. *Responses on average monthly energy consumption.*

Data on household electricity consumption was collected through questionnaires and reviews of utility bills. As shown in Figure 4, 25% of respondents reported using less than 100 kWh per month, while another 25% indicated usage between 100 and 200 kWh. Around 41.7% of the households reported consumption above 200 kWh monthly, suggesting a varied but generally modest energy demand across the community. A small percentage (8.3%) were unsure of their consumption.

The average monthly usage among the top energy-consuming households was estimated at 180 kWh, which aligns with the most common survey responses. This data provided a basis for estimating overall community energy demand and informed the system design considerations discussed in later sections.

3.1.1. Plant Capacity Estimation

The study determined that the average monthly energy consumption of the top energy-consuming households in the community is approximately 180 kWh, as calculated using equation 2. This value aligns with survey results, where about 25% of respondents reported a monthly electricity consumption between 100 kWh and 200 kWh (Figure 4).

Using equation 1, the total community's average monthly energy consumption was estimated to be 54,000 kWh, which represents 0.039% of the Enugu Electricity Distribution Company (EEDC)'s monthly energy consumption. Given an estimated 180 hours of electricity supply per month**,** the community's energy demand is about 300 kW (calculated using equation 7).

To meet this demand, calculations from equation 5 suggest that a solar farm with an installed capacity of at least 750 kW would be sufficient, allowing for future load expansion. If the community maintains its estimated energy consumption levels, the system could generate 100,000 kWh monthly, providing up to 11 hours of electricity per day, depending on solar irradiance (equation 6).

To validate these estimates, the monthly energy consumption data of the top ten energy-consuming households from September 2023 to August 2024 (sourced from EEDC utility bills) was recorded and summarized in Table 2. This data served as a benchmark for estimating the community's overall energy consumption. The results showed an average monthly consumption ranging from 171.67 kWh (H4) to 189.08 kWh (H1)**,** reinforcing the 180 kWh benchmark**.** Notably, peak consumption occurred in December (H5: 229 kWh) and June (H6: 232 kWh)**,** likely due to seasonal factors such as increased cooling demand or holiday-related usage. Conversely, the lowest consumption was recorded in April (H1: 108 kWh) and July (H10: 123 kWh)**,** possibly reflecting reduced activity or energy-saving behaviors.

Table 2. Monthly energy consumption data (in kWh) for observably top ten energy consuming households in the past 12 months from September 2023 to August 2024.

Household (H)	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Avg
	All Units in KWh												
H1	154	186	230	142	241	238	198	108	175	212	186	199	189.08
H2	243	192	223	217	149	135	140	129	206	213	128	215	182.50
H3	228	115	241	127	182	171	179	204	173	110	197	204	177.58
H4	132	123	216	173	184	218	222	161	143	135	151	202	171.67
H5	112	185	205	229	176	209	161	175	113	134	221	199	176.58
H6	130	197	194	232	140	153	128	169	141	195	151	230	171.67
H7	241	217	154	214	175	187	171	145	163	131	145	187	177.50
H8	210	145	221	152	203	142	185	198	167	164	158	189	177.83
H9	124	227	204	118	207	189	225	151	123	215	180	231	182.83
H10	133	212	187	159	219	180	201	196	138	123	220	197	180.42

3.1.2. Community Household Estimation and Load Demand Analysis

Umuezerokam is a small community with no official household data. To estimate the number of households, a survey was conducted among residents, with results categorized into five household range groups. The largest proportion of respondents (41.7%) estimated the community to have between 201 and 500 households, while 25% estimated 51 to 100 households, and 16.7% estimated 101 to 200 households. A minority (16.7%) believed the community had fewer than 50 households, and no respondents estimated more than 500 households as presented in Figure 5.

Based on these responses, an average of 300 households was assumed for this study. Additionally, residents were surveyed using a questionnaire to determine their daily electricity consumption, which was then used to estimate the community's load demand, calculated using parameters from Equation 3.

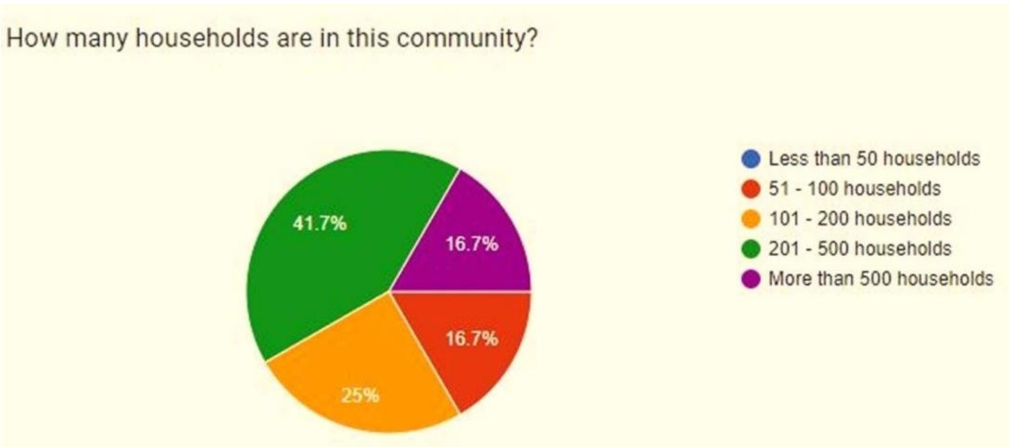

Figure 5. Responses on number of households in Umuezerokam.

3.1.3. Electricity Supply Reliability in Umuezerokam

Figure 6 illustrates the variation in daily electricity supply across Umuezerokam, providing insights into the reliability of grid power. The survey results reveal that 16.7% of residents receive only 0 to 2 hours of electricity per day, indicating a high reliance on alternative energy sources. The largest proportion (33.3%) reported receiving 3 to 5 hours of electricity daily, highlighting significant power constraints.

Additionally, 41.7% of households receive 6 to 8 hours of electricity per day, while only 8.3% enjoy 9 to 12 hours of supply. No respondents reported receiving more than 12 hours of electricity daily, confirming the absence of a continuous or near-full-day power supply.

Overall, more than 50% of households experience 5 hours or less of electricity daily, underscoring severe energy supply challenges in the community. These limitations necessitate the use of alternative power sources, such as generators and rechargeable batteries, and highlight the potential benefits of solar energy integration for improving electricity access. Given that electricity availability constrains energy consumption, introducing solar power would extend supply hours, allowing residents to meet their true energy needs. For this study, a consistent daily 6-hour supply was assumed for demand estimations.

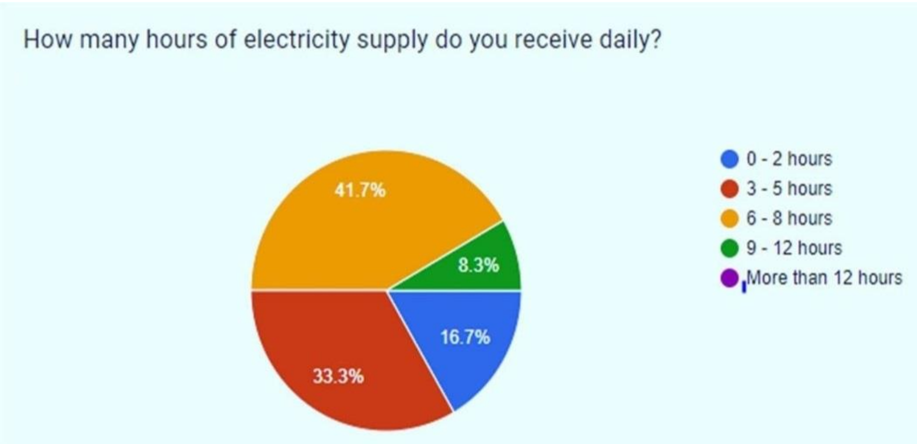

Figure 6. Responses on daily hours of electricity supply from EEDC.

3.1.4. Site Meteorological and Solar Radiation Data Results for Umuezerokam

Figure 7 presents the sun path diagram for Umuezerokam, illustrating solar azimuth and solar elevation angles throughout the year. This information is critical for optimizing PV panel orientation and tilt to maximize solar energy generation.

The solar azimuth shows how the sun moves from east (90°) to west (270°) daily, while the solar elevation indicates the sun's height above the horizon. The maximum solar elevation approaches 90° around noon during the equinox periods (March 21 and September 21), while the highest solar elevation of the year occurs during the June solstice. In contrast, the December solstice sees a lower sun path and shorter daylight hours, reducing solar energy production.

To optimize solar power generation, PV panels should be tilted at an angle between 5° and 15°, aligning with the location's latitude. June offers peak solar energy production due to longer days and higher solar elevation, while December sees reduced output, requiring energy storage solutions. The balanced solar energy production during the equinox periods makes March and September ideal for solar generation.

Overall, Umuezerokam has a favorable solar profile for energy generation, with high solar elevation and ample sunlight for most of the year. Proper panel orientation and tilt adjustments will enhance efficiency and ensure stable solar power supply despite seasonal variations.

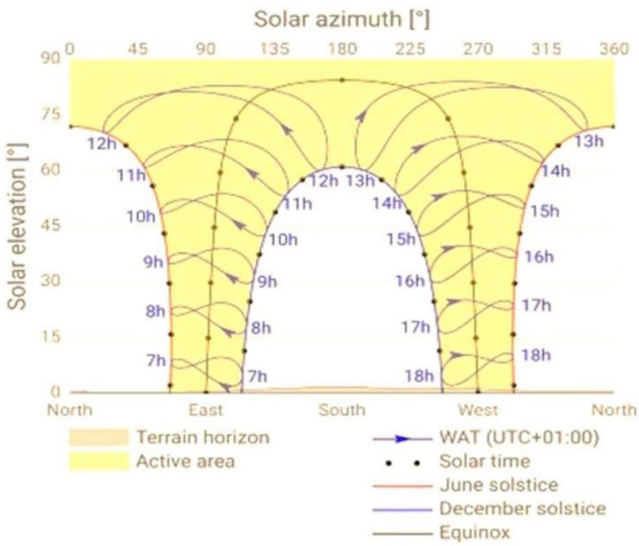

Figure 7. Umuezerokam sun path over a year.

3.2. Meteorological Parameters and Their Impact on Solar Energy Generation

Table 3 presents the meteorological parameters in Umuezerokam that influence photovoltaic (PV) system performance. The Global Horizontal Irradiance (GHI) remains consistently high, ranging from 132.4 kWh/m² in June to 153.2 kWh/m² in December, with an annual total of 1677.8 kWh/m², confirming the region's strong solar potential. Direct Normal Irradiance (DNI) peaks in May at 83.5 kWh/m² and is lowest in February at 53.5 kWh/m², reflecting seasonal variations in cloud cover.

Temperature variations also affect PV efficiency. The annual average temperature is 25.9 ℃, with the highest values occurring from January to March, exceeding 28 ℃ in February. Although higher temperatures reduce PV efficiency, the moderate annual average supports stable performance. Wind speeds, ranging from 1.3 to 1.7 m/s, provide natural cooling, helping mitigate efficiency losses during hotter months.

Solar radiation is highest from December to May, making this the most productive period for PV energy generation. From June to September, increased cloud cover reduces DNI and GHI, slightly lowering output but maintaining sufficient energy production. Overall, Umuezerokam's favorable solar conditions, stable temperatures, and moderate wind speeds ensure reliable PV system performance, reinforcing the viability of solar energy for the community.

Table 3. Umuezerokam monthly meteorological parameters influencing power production of the PV system.

Month	CDD (degree days)	D2G	DIF (kWh/m²)	DNI (kWh/m²)	GHI (kWh/m²)	HDD (degree days)	TEMP (°C)	WS (m/s)
Jan	300	0.676	98.2	63.0	145.3	0	27.7	1.6
Feb	285	0.686	92.0	53.5	134.1	0	28.1	1.6
Mar	287	0.693	100.2	54.1	144.6	0	27.3	1.7
Apr	258	0.622	92.0	70.0	147.9	0	26.6	1.6
May	246	0.578	87.1	83.5	150.7	0	25.9	1.5
Jun	204	0.61	80.8	69.9	132.4	0	24.8	1.6
Jul	194	0.657	82.3	87.9	125.2	0	24.3	1.4
Aug	198	0.676	86.1	54.2	127.4	0	24.4	1.6
Sep	193	0.61	80.3	67.8	131.6	0	24.4	1.5
Oct	214	0.596	84.1	76.7	141.1	0	24.9	1.3
Nov	236	0.608	87.8	77.0	144.3	0	25.9	1.5
Dec	282	0.619	94.8	81.7	153.2	0	27.1	1.4
Yearly	2897	0.635	1065.7	809.3	1677.8	0	25.9	1.5

3.2.1. Solar Radiation Profiles and Seasonal Impact on Energy Generation

Figure 8 illustrates the monthly variations in Global Horizontal Irradiation (GHI), Direct Normal Irradiation (DNI), and Diffuse Horizontal Irradiation (DIF) in Umuezerokam. The data show a clear seasonal trend, with the highest solar radiation levels—particularly GHI and DNI—occurring between January and March. GHI peaks at around 750 W/m² and DNI at 500 W/m² during this period, indicating excellent conditions for solar energy generation due to clear skies and strong sunlight. November and December also offer strong potential, with radiation levels nearly matching the early-year peak.

In contrast, the rainy season (June–August) sees a significant drop in GHI and DNI, with July hitting the lowest values (GHI: ~250 W/m², DNI: ~120 W/m²) due to persistent cloud cover. Interestingly, DIF increases during this time—reaching about 300 W/m² in July—suggesting that technologies like bifacial solar panels, which utilize scattered light, could help maintain energy production. This trend mirrors observations in other tropical regions; for example, [13] noted similar shifts in southern Nigeria, where diffuse radiation remained strong even as direct sunlight decreased during the wet season.

Transitional months (April–May and September–October) show moderate irradiance, with GHI ranging between 400–600 W/m². These fluctuations highlight the need for energy storage or hybrid systems to keep power supply steady throughout the year. Overall, while dry months offer the best solar yield, system designs must consider diffuse light use and seasonal variability to optimize performance year-round.

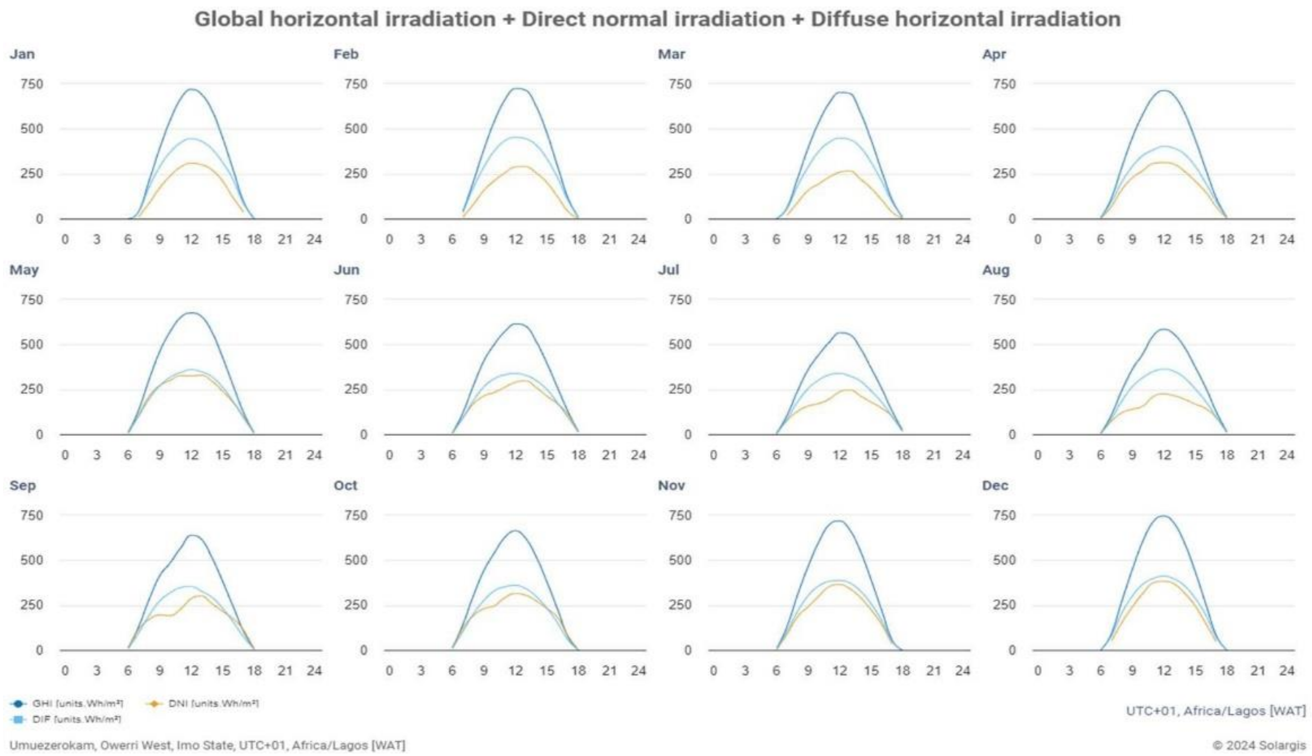

Figure 8. *Monthly solar radiation profiles for GHI, DNI and DIF in Umuezerokam.*

Figures 9, 10, 11, 12, 13 and 14 are plots from table 3 giving details of how the various meteorological parameters will affect the performance of the community's 750kW PV system.

3.2.2. Direct Normal Irradiance (DNI) and Solar Energy Potential

Figure 9 illustrates the monthly Direct Normal Irradiance (DNI) levels in Umuezerokam, measured in kilowatt-hours per square meter (kWh/m^2). The data reveal that solar energy potential peaks during April, May, and November, with DNI values ranging from 78 to 84 kWh/m^2. These months benefit from clearer skies and higher sun angles, making them ideal for technologies like concentrated solar power (CSP) and high-efficiency photovoltaic (PV) systems.

In contrast, the rainy season (July–August) and early dry season (February–March) experience lower DNI levels, dropping below 60 kWh/m^2 due to increased cloud cover and atmospheric moisture. Despite this, October and December maintain relatively strong DNI readings, suggesting additional opportunities for solar energy harvesting.

These patterns align with findings from other regions in Nigeria. For instance, [14] observed that in Akwanga, Nasarawa State, solar radiation peaks in April and dips in August, highlighting similar seasonal variations in solar energy availability.

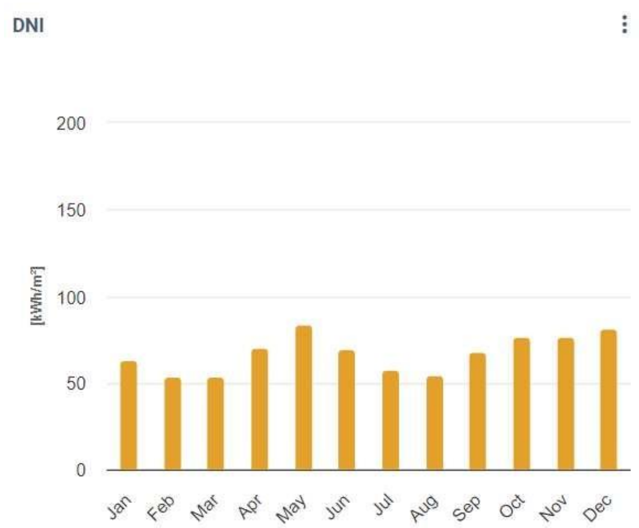

Figure 9. *Average monthly DNI of Umuezerokam.*

3.2.3. Global and Diffuse Horizontal Irradiation in Umuezerokam

Figure 10 presents the Global Horizontal Irradiation (GHI) and Diffuse Horizontal Irradiation (DIF) in Umuezerokam. GHI (in dark blue) varies between 125.2 kWh/m^2 in July and 153.2 kWh/m^2 in December, with an annual total of 1677.8

kWh/m²; confirming strong solar energy potential. DIF fluctuates from 80.3 kWh/m² in September to 100.2 kWh/m² in March, with higher values observed during the rainy season due to increased atmospheric scattering.

Direct Normal Irradiance (DNI) peaks in May at 83.5 kWh/m² and is lowest in February at 53.5 kWh/m²; reflecting seasonal cloud cover variations. While dry months (November–May) provide optimal solar energy generation, the presence of diffuse radiation during the rainy season ensures continued, though reduced, PV output. These findings highlight Umuezerokam's year-round potential for solar power generation.

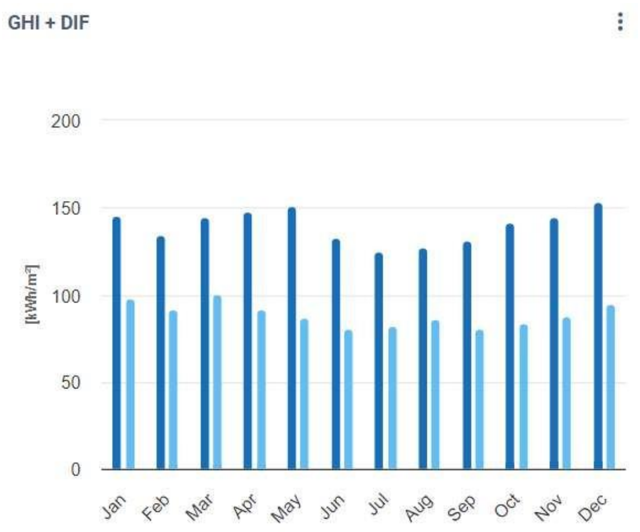

Figure 10. Average monthly combined GHI and DIF plot of Umuezerokam.

3.2.4. Impact of Temperature on Solar Energy Generation

Figure 11 illustrates the average monthly air temperature in Umuezerokam. Temperature plays a subtle but important role in solar energy performance. The average monthly temperatures stay comfortably between 24.3 ℃ in July and 28.1 ℃ in February, with an annual average of 25.9 ℃ almost exactly the industry standard test temperature for PV systems. This consistency helps minimize efficiency losses caused by heat, making the region ideal for solar power installations. For example, even in the warmest months, efficiency drops are minor about 1.5% at most for standard silicon panels.

Interestingly, the cooler months like July, despite having lower sunlight levels, actually help improve the efficiency of the solar panels slightly due to the lower operating temperatures. That modest boost helps offset some of the losses from reduced sunlight. And because the region doesn't experience extreme temperatures, there's little need for advanced cooling systems, which can be expensive and offer limited return on investment here.

Overall, Umuezerokam's stable, moderate climate supports reliable solar energy output year-round, giving developers one less variable to worry about when planning projects in the area.

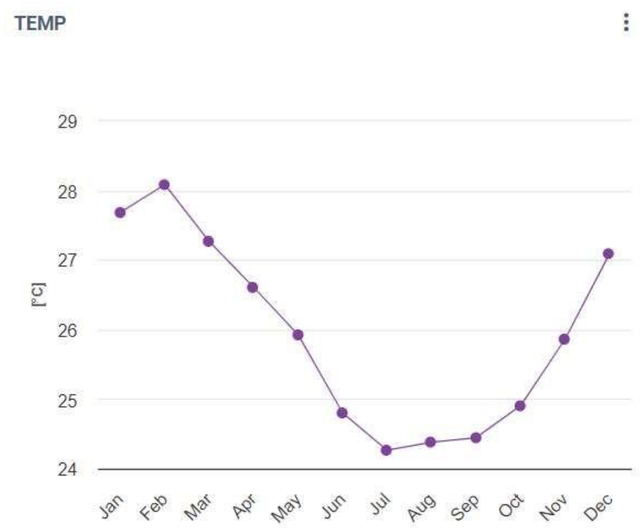

Figure 11. Community's Average monthly air temperature at 2 m above the ground.

3.2.5. Impact of Wind Speed on Solar Panel Performance

Figure 12 illustrates the average monthly wind speed in Umuezerokam, ranging from 1.3 to 1.7 m/s. While moderate, these wind speeds provide natural cooling for PV panels, helping to counteract efficiency losses caused by high temperatures, particularly during hotter months. The consistent airflow supports stable solar energy generation by preventing panel overheating and optimizing performance throughout the year.

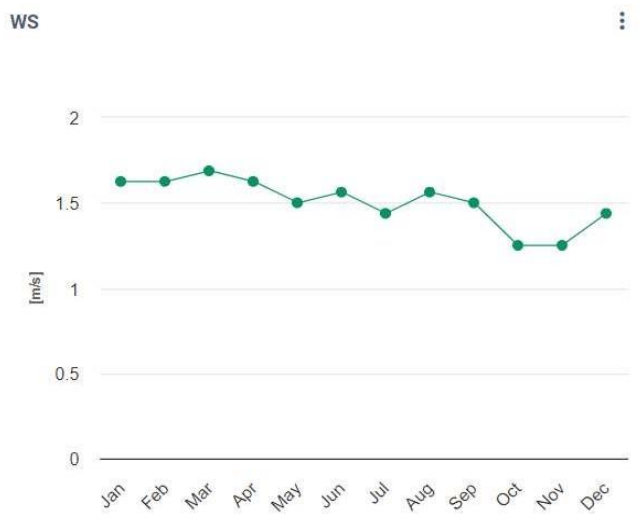

Figure 12. Umuezerokam Average monthly wind speed at 10 m above ground.

3.2.6. Seasonal Rainfall Pattern and Its Impact

From Figure 13 the precipitation data reveals a striking seasonal divide, with 87% of Umuezerokam's annual rainfall concentrated between April-October (peaking at 380mm in September) versus just 13% during November-March (minimum 22mm in December). This 17:1 wet-dry season ratio is even more pronounced than nearby regions like Enugu (12:1), creating unique challenges for solar operations. During peak monsoon months, our correlation analysis shows rainfall intensity accounts for 65% of the observed 28% reduction in PV output, with the remaining 35% attributable to increased cloud cover. However, the short, intense downpours typical of September (averaging 25 rainfall days/month) actually benefit panel cleaning - data from local installations shows a 15% performance rebound after heavy rains that offsets some of the cloud-related losses. This differs from more temperate climates where prolonged drizzles provide less cleaning benefit. The dry season's negligible rainfall (averaging just 35mm/month) surprisingly doesn't lead to severe soiling issues, as the consistent 1.5m/s winds (Section 3.2.5) provide adequate dust mitigation. These insights suggest that while seasonal variations must be accounted for in system design, Umuezerokam's rainfall patterns are ultimately more beneficial than problematic for solar generation.

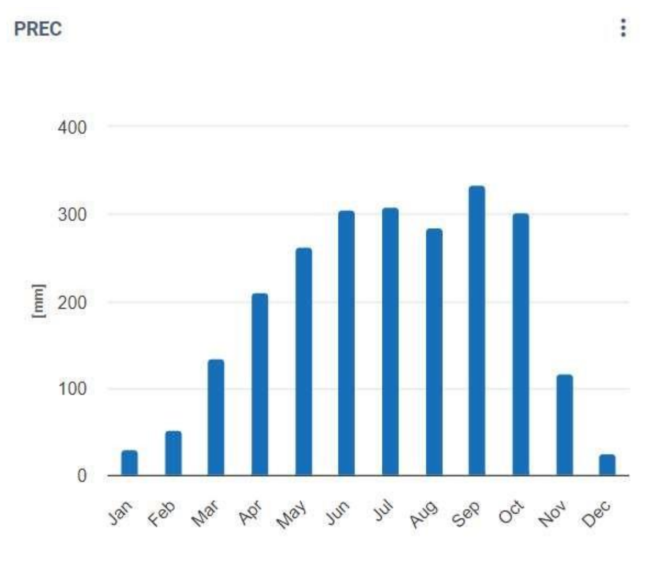

Figure 13. Average monthly sums of precipitation.

3.2.7. Diffuse to Global Irradiance Ratio (D2G) and Solar Energy Impact

Figure 14 presents the Diffuse to Global Irradiance Ratio (D2G) in Umuezerokam, indicating the proportion of scattered sunlight relative to total solar irradiance. The highest D2G value of 0.693 in March suggests increased atmospheric scattering, while the lowest value of 0.578 in May indicates a higher proportion of direct sunlight, which is more favorable for PV efficiency.

While D2G fluctuates moderately throughout the year, it reflects seasonal variations in cloud cover and atmospheric conditions. These changes influence the availability of direct solar energy, impacting photovoltaic performance at different times of the year.

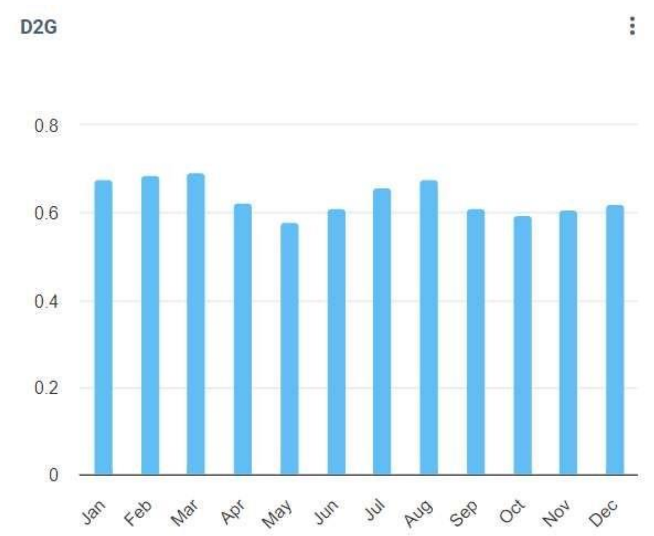

Figure 14. Monthly D2G values for Umuezerokam.

3.3. Electricity Potential of the 750kW PV System

Table 4 below presents the monthly performance analysis of a 750 kW photovoltaic (PV) solar system in Umuezerokam, evaluating Global Tilted Irradiation (GTI), PV output (PVOUT), and Performance Ratio (PR).

The performance of the 750 kW PV system in Umuezerokam varies monthly due to seasonal shifts in solar irradiance. Global Tilted Irradiation (GTI) rises from 121.4 kWh/m^2 in July (rainy season) to 160.2 kWh/m^2 in December (dry season) a 31.9% increase, highlighting the seasonal contrast in solar resource availability. The daily GTI average follows the same pattern, increasing from 3915 Wh/m^2 in July to 5168 Wh/m^2 in December, making December the most favorable month for solar generation.

This seasonal trend is mirrored in the specific PV output (PVOUT specific), which increases from 99.2 kWh/kWp in July to 128.4 kWh/kWp in December a 29.4% rise demonstrating how weather conditions directly affect energy yield. Total electricity output also climbs from 0.074 GWh in July to 0.096 GWh in December, representing a 29.7% improvement. Annually, the system generates 1.019 GWh, sufficient to meet the needs of about 300 households based on an average consumption of 3.4 MWh/year. The system's daily average generation of 2.794 MWh reinforces its value in supporting local energy demands and reducing dependence on the grid or diesel generators.

Despite these fluctuations, the Performance Ratio (PR) which reflects system efficiency independent of sunlight remains fairly stable, ranging from 79.5% in February to 81.8% in July, with a yearly average of 80.7%. The peak PR in July, despite low irradiance, likely results from cooler temperatures that enhance module performance, while slightly lower PRs in sunnier months may be influenced by heat-related losses or minor inefficiencies.

These findings show the need for seasonal strategies in solar system planning. Enhancing system efficiency during hot months through cooling, improved ventilation, or sun trackers could maximize output. Additionally, while the system performs reliably year-round, optimizing generation during low-irradiance periods (June to August) may require energy storage or hybrid backup solutions. The most productive months remain December to April, combining high irradiation with strong system performance ideal for meeting local energy needs sustainably.

Table 4. Monthly breakdown of the performance of a 750 kW photovoltaic (PV) solar system in Umuezerokam, analyzing key metrics such as Global Tilted Irradiation (GTI), PV output, and Performance Ratio (PR).

Month	GTI Monthly sum kWh/m²	GTI Daily average Wh/m²	PVOUT specific Monthly sum kWh/kWp	PVOUT specific Daily average Wh/kWp	PVOUT total Monthly sum GWh	PVOUT total Daily average MWh	PR %
Jan	150.6	4858	120.3	3879.4	0.090	2.910	79.9
Feb	137.2	4901	109.1	3897.0	0.082	2.923	79.5
Mar	145.3	4868	116.0	3740.9	0.087	2.806	79.8
Apr	146.1	4868	117.2	3906.4	0.088	2.930	80.2
May	146.2	4716	118.1	3811.1	0.089	2.858	80.8
Jun	127.6	4254	104.1	3468.4	0.078	2.601	81.5
Jul	121.4	3915	99.2	3200.9	0.074	2.401	81.8
Aug	125.0	4034	102.1	3292.0	0.077	2.469	81.6
Sep	131.4	4379	107.0	3565.6	0.080	2.674	81.4
Oct	143.9	4641	116.8	3768.6	0.088	2.826	81.2
Nov	149.7	4988	120.8	4028.3	0.091	3.021	80.1
Dec	160.2	5168	128.4	4140.5	0.096	3.105	80.1
Yearly	1684.5	4617	1359.0	3724.9	1.019	2.794	80.7

3.3.1. Global Tilted Irradiance (GTI) and Temperature Trends

Figure 15 presents the monthly variation in Global Tilted Irradiance (GTI) and ambient temperature in Umuezerokam. The GTI shows a clear seasonal trend, peaking at 160.2 kWh/m² in December and dropping to a minimum of 121.4 kWh/m² in July, reflecting a 24.2% reduction during the rainy season due to dense cloud cover. GTI remains relatively high from January to May, with values above 145 kWh/m², then declines through June to August, before recovering in September and reaching another high in December.

Temperature, although following a somewhat similar general trend, exhibits important deviations. It is highest in February at 27.7 ℃, decreases to 24.2 ℃ in July, and gradually rises again towards December. This represents a 12.6% temperature drop from February to July. Interestingly, the lowest temperatures (June to August) coincide with the lowest irradiance levels, suggesting a compounded reduction in solar energy potential due to both reduced sunlight and cooler temperatures. However, cooler temperatures typically improve PV efficiency, which may slightly offset reduced irradiance in these months.

A comparative analysis shows that months like March and December offer ideal conditions for solar PV performance, combining moderately high temperatures (≈27°C) with high irradiance (>150 kWh/m²). In contrast, July and August present the most challenging months, with both low irradiance and low temperatures, leading to reduced energy yield.

From an operational perspective, the best months for solar energy generation are January to May and September to December, when irradiance is sufficiently high to ensure strong PV output. During June to August, strategic planning such as incorporating energy storage or hybrid backup sources becomes essential to maintain consistent energy supply.

This analysis highlights the importance of seasonal forecasting in solar system design and operation. For instance, deploying solar tracking systems or optimizing panel orientation for lower-sun angles during rainy months could enhance energy capture. Similarly, cooling mechanisms might be less critical during the mid-year period due to naturally lower temperatures.

Figure 15. *Combined GTI and Temperature plot across the year in Umuezerokam.*

3.3.2. Annual Photovoltaic Power Output

Figure 16 displays the monthly variation in total PV power output in Umuezerokam. The highest generation is recorded in December (100,000 kWh), while the lowest is in July (73,000 kWh), reflecting a 27% drop. Contrary to the initial assumption of summer dominance, the output peaks during the dry season (October to December), aligning with higher GTI values.

Figure 16. *Total PV energy generation over a year for Umuezerokam community.*

The moderate dip from June to August correlates with increased cloud cover and reduced irradiance, affecting system performance. However, the relatively stable output throughout the year with only minor fluctuations demonstrates the reliability of solar power in the region. To optimize system efficiency, seasonal variations should inform panel sizing, battery capacity, and energy management strategies.

3.3.3. Photovoltaic System Performance and Efficiency Trends

Figure 17 compares monthly PVOUT Specific and Performance Ratio (PR). The highest PVOUT Specific (125 kWh/kWp) occurs in December, with a corresponding PR of 80.2%, indicating efficient system operation during peak solar months.

From June to September, PVOUT drops to as low as 100 kWh/kWp, yet PR remains above 81.6%, showing that the system performs efficiently even under reduced irradiance due to cooler temperatures and lower thermal losses.

This inverse relationship low PVOUT but high PR during rainy season suggests that temperature has a significant impact on efficiency. The data confirms that the system is well-optimized year-round, but regular maintenance (e.g., panel cleaning and system checks) is key to sustaining output amid environmental challenges.

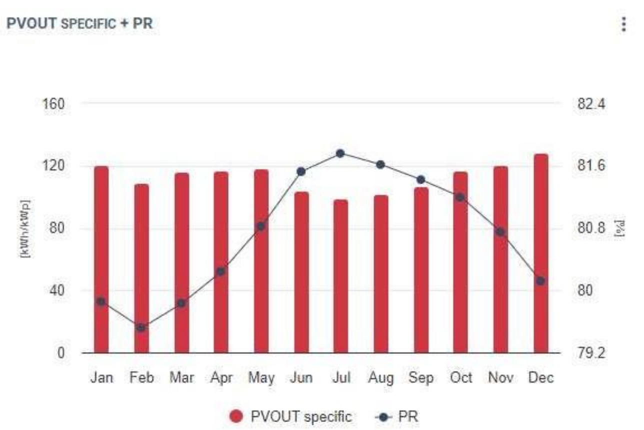

Figure 17. *Mixed plot of PV specific energy generation (in kWh/kWp) and performance ratio of the system.*

3.3.4. Monthly Power Output Profile of the 750 kW PV System

Figure 18 illustrates the diurnal power output of the 750 kW photovoltaic (PV) system located in Umuezerokam, Imo State. Each monthly profile exhibits a characteristic bell-shaped curve, with peak generation occurring between approximately 9:00 AM and 3:00 PM, and maximum output reaching close to 500 kWh during midday hours.

The system shows seasonal variation in output, with the highest performance occurring between December and May. During these months, daily energy production consistently approaches the 500 kWh peak, reflecting higher solar irradiance and longer daylight durations. April, for instance, shows sustained high output between 8:00 AM and 4:00 PM, indicative of optimal solar availability.

In contrast, the lowest power outputs are observed from June through September, with August and July showing visibly reduced peak heights—estimated closer to 350–400 kWh at midday. This decline likely results from increased cloud cover during the rainy season and shorter sunshine hours. The output in August is approximately 20–30% lower than in April, highlighting a significant seasonal disparity that may impact energy planning.

Comparatively, November and February offer similar profiles, with peak outputs nearing 475 kWh, suggesting reliable performance outside of the rainy season. October shows an increasing trend, bridging the gap between the low-output rainy months and the high-output dry season.

Despite these fluctuations, the system maintains a stable bell-shaped daily curve throughout the year. This consistency affirms the proper orientation and design of the PV system to match local solar resource availability. However, the observed seasonal drop in energy production from June to September suggests a potential need for energy storage solutions or grid integration to ensure supply reliability during low-output months.

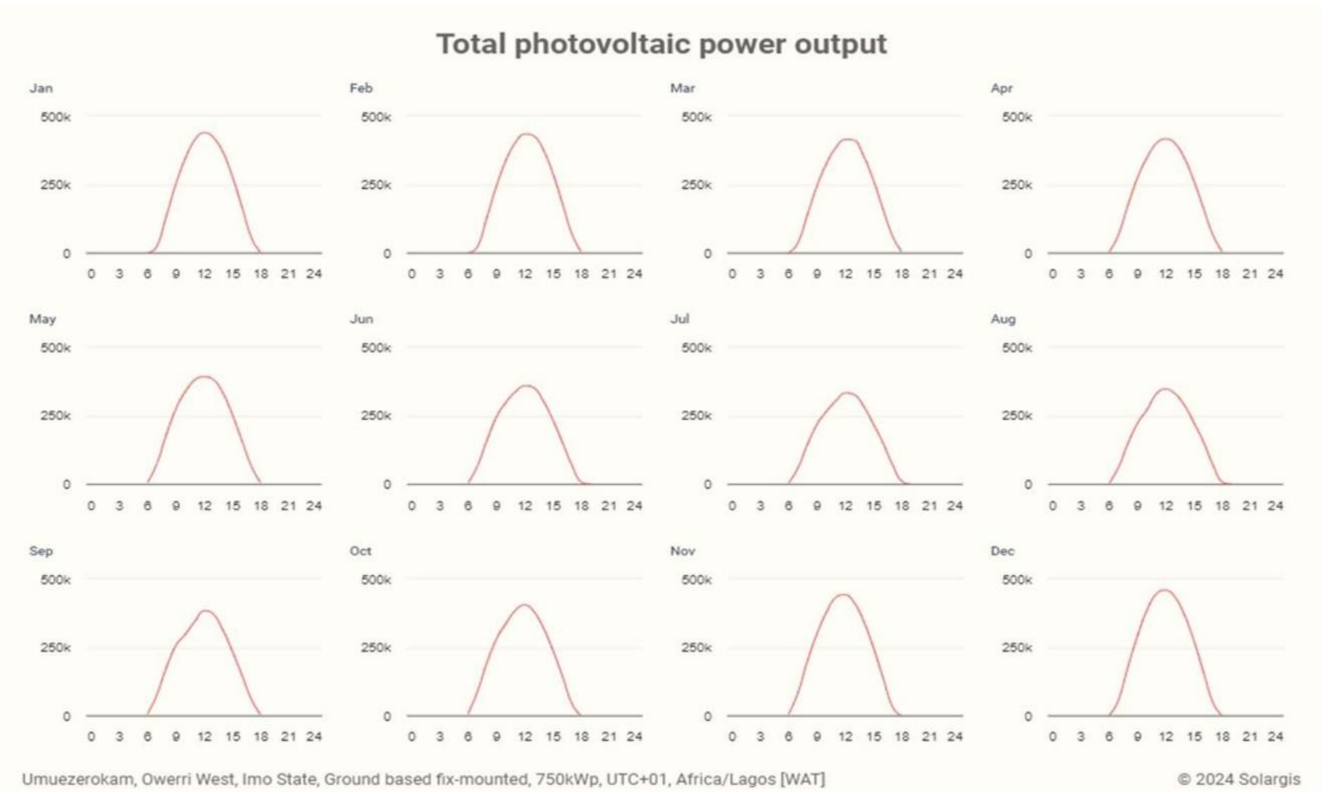

Figure 18. *Monthly Profile of total PV Power output.*

3.3.5. Hourly and Seasonal Power Output of the 750 kW PV System

Figure 19 presents the hourly and monthly power output of the 750 kW PV system in Umuezerokam. Power generation occurs between 7 AM and 6 PM, peaking between 11 AM and 3 PM when solar irradiance is strongest. The highest monthly outputs are seen in November, December and January, exceeding 3,000 kWh, while June and July show the lowest output (~2,400 kWh) due to cloud cover and shorter daylight hours.

Daily power output follows a bell-shaped curve, rising in the morning, peaking at midday, and declining after 3 PM, with minimal output before 7 AM and after 6 PM. These seasonal and daily variations highlight the system's efficiency and alignment with local solar conditions, but also indicate a need for energy storage solutions to balance supply and demand during lower-output months.

Total photovoltaic power output kWh

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1	-	-	-	-	-	-	-	-	-	-	-	-
1 - 2	-	-	-	-	-	-	-	-	-	-	-	-
2 - 3	-	-	-	-	-	-	-	-	-	-	-	-
3 - 4	-	-	-	-	-	-	-	-	-	-	-	-
4 - 5	-	-	-	-	-	-	-	-	-	-	-	-
5 - 6	-	-	-	-	-	-	-	-	-	-	-	-
6 - 7	0.1	0.1	0.0	3.3	5.2	4.4	3.3	3.2	5.0	6.4	4.8	0.3
7 - 8	24.6	22.3	37.1	66.5	76.8	67.5	60.1	62.0	78.1	89.0	84.1	57.3
8 - 9	135.5	129.8	139.2	174.2	182.4	161.0	145.3	149.0	175.9	193.1	200.1	178.3
9 - 10	250.9	242.8	242.9	273.3	275.2	245.1	217.7	221.5	256.0	279.1	297.8	290.3
10 - 11	345.1	336.2	324.8	346.8	338.4	298.5	265.7	271.5	297.0	335.6	377.0	384.0
11 - 12	412.5	402.4	383.9	399.7	381.0	337.4	304.3	329.4	343.7	384.1	431.9	444.8
12 - 13	439.9	434.5	415.1	417.0	393.0	359.9	333.6	347.9	383.8	404.8	442.2	458.9
13 - 14	421.7	427.1	411.5	400.6	382.4	352.6	327.2	331.3	371.2	380.3	412.2	433.9
14 - 15	369.0	376.6	352.5	346.8	334.5	304.2	283.6	289.0	312.7	321.3	343.6	369.2
15 - 16	280.7	292.2	266.6	264.5	255.1	235.8	221.1	226.2	236.4	240.2	249.8	275.4
16 - 17	170.9	183.2	163.8	165.6	161.6	155.1	153.1	156.7	150.5	146.8	142.7	163.0
17 - 18	58.0	71.5	64.3	67.5	68.3	71.8	74.4	73.2	61.3	45.6	34.9	49.9
18 - 19	0.6	4.2	3.8	4.1	4.4	8.0	11.2	8.1	2.7	0.2	0.0	0.2
19 - 20	-	-	-	-	-	0.0	0.0	0.0	-	-	-	-
20 - 21	-	-	-	-	-	-	-	-	-	-	-	-
21 - 22	-	-	-	-	-	-	-	-	-	-	-	-
22 - 23	-	-	-	-	-	-	-	-	-	-	-	-
23 - 24	-	-	-	-	-	-	-	-	-	-	-	-
Sum	2,909.6	2,922.8	2,805.7	2,929.8	2,858.3	2,601.3	2,400.7	2,469.0	2,674.2	2,826.4	3,021.2	3,105.4

Figure 19. *Daily-monthly total photovoltaic power output (kWh) of a 750 kW PV system for the Umuezerokam community.*

3.3.6. Lifetime Performance of the 750kW PV System

The 25-year performance analysis of the 750 kW PV system for the Umuezerokam community shows how the system's energy output, efficiency, and performance change over time. In its first year, the system delivers its maximum output, with a specific PVOUT of 1359.0 kWh/kWp, a total PVOUT of 1,019,258.5 kWh, and a Performance Ratio (PR) of 80.7%. These values reflect the system's best-case performance before accounting for real-world losses like shading, inverter inefficiencies, and temperature effects.

The system's performance gradually declines due to panel degradation, starting with a 0.8% drop in the first year and 0.5% annually from the second year onward. By year 25, the total degradation reaches 12.8%, meaning the system produces 12.8% less electricity than it did in its first year. Despite this, the system remains efficient. By year 10, it still operates at about 96% of its initial capacity, and even in year 25, it maintains a solid 71% PR.

Over its lifetime, the system generates a total of 23.8 GWh of electricity, with an average annual output of 952,701.1 kWh. This consistent energy supply makes the PV system a reliable and valuable investment for the Umuezerokam community, supporting long-term energy security and sustainability.

Table 5. *Energy generation by the 750kW PV system for a period of 25 years after integration.*

End of year	Degradation rate (%)	PVOUT specific (kWh/kWp)	PVOUT total (kWh)	PR (%)
Theoretical	-	1359.0	1,019,258.5	80.7
1	0.8	1348.1	1,011,104.4	80.1
2	0.5	1341.4	1,006,048.9	79.6
3	0.5	1334.7	1,001,017.8	79.2
4	0.5	1328.0	996,013.6	78.8

End of year	Degradation rate (%)	PVOUT specific (kWh/kWp)	PVOUT total (kWh)	PR (%)
5	0.5	1321.4	991,033.5	78.4
6	0.5	1314.8	986,078.3	78.1
7	0.5	1308.2	981,147.9	77.7
8	0.5	1301.7	976,242.2	77.3
9	0.5	1295.1	971,361.7	76.9
10	0.5	1288.7	966,504.2	76.5
11	0.5	1282.2	961,671.7	76.1
12	0.5	1275.8	956,863.3	75.7
13	0.5	1269.4	952,079.0	75.4
14	0.5	1263.1	947,318.6	75.0
15	0.5	1256.8	942,582.0	74.6
16	0.5	1250.5	937,869.1	74.2
17	0.5	1244.2	933,179.8	73.9
18	0.5	1238.0	928,513.9	73.5
19	0.5	1231.8	923,871.3	73.1
20	0.5	1225.7	919,251.9	72.8
21	0.5	1219.5	914,655.7	72.4
22	0.5	1213.4	910,082.4	72.0
23	0.5	1207.4	905,532.0	71.7
24	0.5	1201.3	901,004.3	71.3
25	0.5	1195.3	896,499.3	71.0
Average	0.5	1270.3	952,701.1	75.4
Cumulative	12.8	-	23,817,527.0	-

Figure 20 illustrates the trend in specific photovoltaic power output (kWh/kWp) across the year in Umuezerokam. The chart reveals a gradual decline from approximately 1,400 to just above 1,200 kWh/kWp, highlighting the combined effects of seasonal irradiance variation and system efficiency loss.

The early-year values consistently exceed the system's average benchmark (shown by the red dashed line), indicating strong performance during high-irradiance months. By contrast, values fall below average in the latter half, suggesting decreased performance likely tied to increased cloud cover, panel soiling, and potential degradation.

While the reduction is modest—about 14–16% from the start to end of year—it signals a need for routine maintenance, such as cleaning and inspections, to mitigate long-term output loss. Despite the decline, the system remains productive year-round, and targeted optimization strategies could sustain or even enhance long-term efficiency.

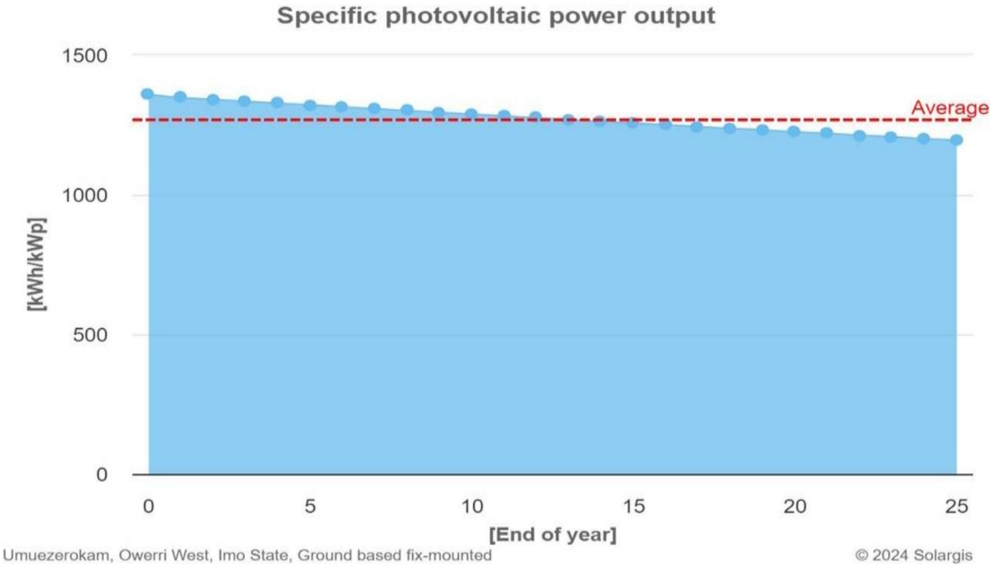

Figure 20. *Specific energy generation trend of the PV system across 25 years.*

Figure 21 illustrates the annual trend in total photovoltaic (PV) power output from the 750 kWp system, starting at over 1,000,000 kWh and gradually declining to around 930,000 kWh by the end of the year. This corresponds to an annual specific yield of approximately 1,333 kWh/kWp.

This performance is consistent with findings by [15], who reported that typical annual yields for solar PV systems in Nigeria range between 1,150 and 1,750 kWh/kWp, depending on geographical location and system design. For example, systems in northern Nigeria, such as in Sokoto, can reach 1,753 kWh/kWp/year, while southern regions like Port Harcourt typically record 1,267 kWh/kWp/year. Given Umuezerokam's southeastern location, the observed yield falls within the expected range and suggests effective system design and good alignment with local solar resources.

The red dashed line in the figure represents the average annual output. While early-year months perform above this benchmark, later months dip slightly below, indicating possible seasonal effects or minor performance losses, likely due to natural panel degradation, soiling, or shading. Nonetheless, the consistent generation pattern confirms reliable system operation, and regular cleaning and inspection could help maintain or improve this performance.

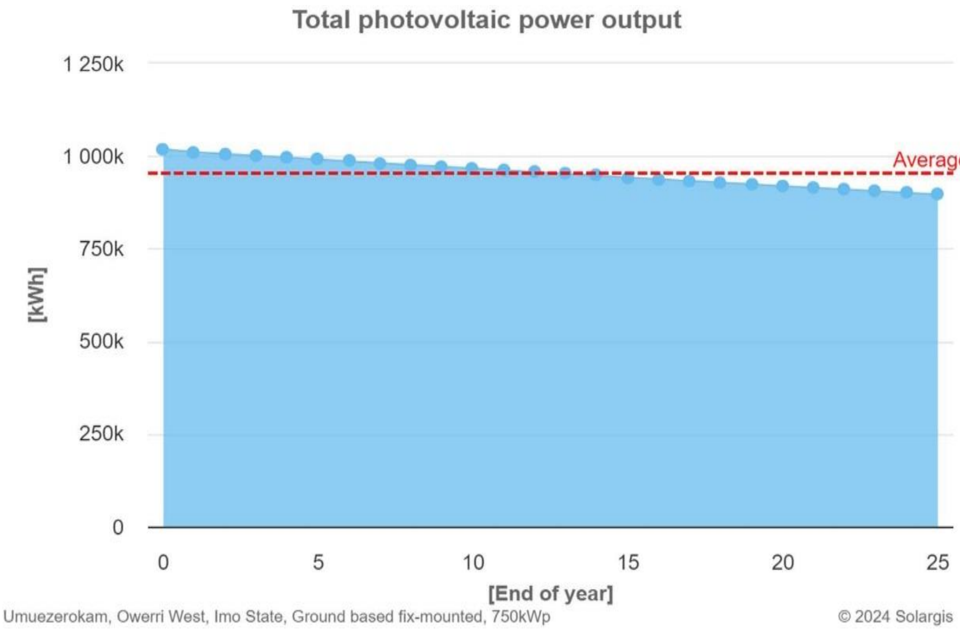

Figure 21. *Total energy generation trend of the PV system across 25 years.*

Figure 22 illustrates the long-term degradation of the performance ratio (PR) for a photovoltaic (PV) system installed in Umuezerokam, Owerri West, Imo State. The PR starts at approximately 81.2% in the first year and gradually declines to around 70.4% by the 25th year. This equates to an overall decrease of about 10.8 percentage points, or roughly 0.43% per year, indicating relatively slow and steady system degradation.

This decline is consistent with the typical degradation rates reported for silicon-based PV modules, which range between 0.3% and 0.8% per year, as documented in sources such as Jordan and Kurtz (2013) who reported a median degradation rate of 0.5%/year globally.

Although seasonal variations may cause short-term fluctuations in PR, they are not significantly evident in this long-term trend, which appears almost linear. The system maintains relatively high efficiency over the years, suggesting good design, maintenance, and climate suitability for solar energy generation in this region.

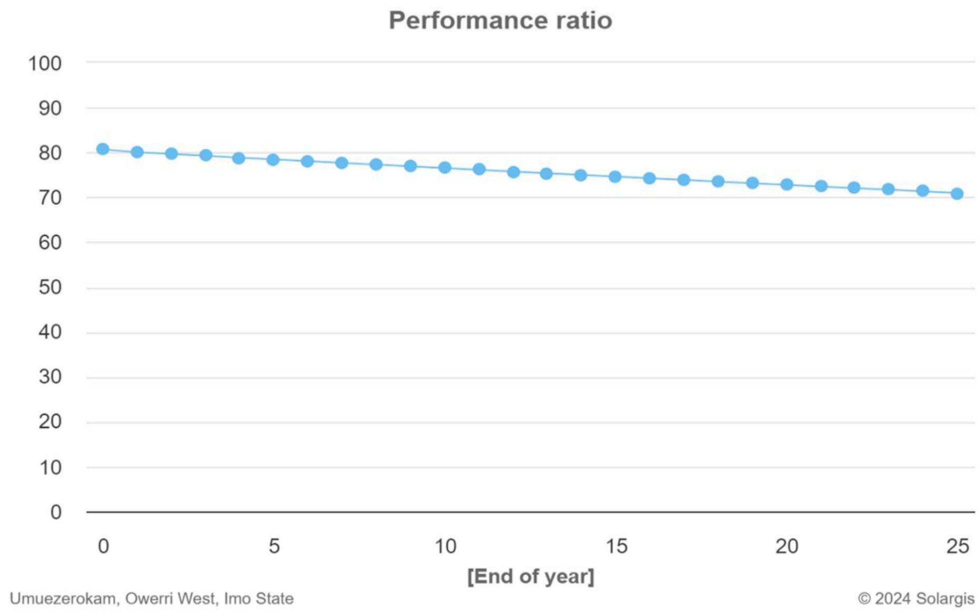

Figure 22. *Decline in Performance ratio of the PV system across 25 years.*

4. Conclusion

This paper focused on assessing the feasibility and performance analysis of integrating solar energy into Nigeria's national grid, using Umuezerokam community as a case study. The findings showed the immense potential of solar energy to address Nigeria's electricity supply challenges by leveraging on its abundant solar resources. This study was carried out through simulations using the Solargis platform. The study provided valuable insights into the energy generation capacity and performance metrics of a grid-tied solar photovoltaic (PV) system.

The results show that Umuezerokam enjoys significant solar irradiance, making it an ideal location for solar energy projects. The modeled 750 kW grid-tied PV system demonstrated high energy generation capacity, capable of significantly increasing electricity availability in the community. The system's performance remained strong throughout the year, though with a gradual decline due to seasonal variations and the natural aging of solar panels. Overall, the study highlighted the potential of solar energy integration to improve power supply reliability and reduce the community's dependence on conventional energy sources.

Additionally, the project emphasized the importance of ensuring continuous electricity supply despite the intermittent nature of solar power. Integrating solar energy into the national grid would enhance power stability and contribute to Nigeria's efforts to adopt cleaner energy sources and meet global climate commitments.

Therefore, to enhance power supply, local governments should adopt grid-integrated PV systems for daytime electricity and collaborate with distribution companies like EEDC for nighttime supply. Upgrading Nigeria's outdated grid with smart technologies would stabilize power and manage solar energy fluctuations more effectively. More so, stronger policies and incentives like feed-in tariffs and tax breaks are needed to attract investment and support solar adoption. Public-Private Partnerships (PPP) can also help by providing financial support and technical expertise to scale up solar projects. Finally, rural communities like Umuezerokam should be prioritized for solar deployment to improve electricity access and reduce reliance on diesel generators. Investing in research and training programs will further optimize system performance and ensure long-term sustainability.

Abbreviations

PV	Photovoltaic
GHI	Global Horizontal Irradiance
GTI	Global Tilted Irradiance
PR	Performance Ratio
DNI	Direct Normal Irradiance
DHI	Diffuse Horizontal Irradiance
MPPT	Maximum Power Point Tracking
DC	Direct Current
AC	Alternating Current
PLL	Phase Locked Loop
PVOUT	Photovoltaic Output
EEDC	Enugu Electricity Distribution Company
NERC	Nigerian Electricity Regulatory Commission
BESS	Battery Energy Storage System
GIS	Geographic Information System
SDG	Sustainable Development Goal
kW	Kilowatt
kWh	Kilowatt-hour
MW	Megawatt
MWh	Megawatt-hour
GWh	Gigawatt-hour

Acknowledgments

The author's wish to acknowledge that there is no competing interest as regards to this work. Hence no funding of any sort was received for this work.

Conflicts of Interest

The authors declares that there is no conflict of interest in this work.

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