

Assessment of the Effects of Environmental Factors on Solar Energy Performance in the Niger Delta: A Case Study Ozoro Delta State

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Abstract

The study analyzes a direct relationship between solar radiation, temperature and an inverse relationship with rainfall and relative humidity and also sunshine. The study scrutinizes the reliability and validity of existing analysis that focus on the various environment factors on photovoltaic (PV) system's performance for the first time four environmental factors (temperature, relative humidity, rainfall and sunshine). Affecting the system performance are investigated simultaneously. The study area is Southern Delta University, Ozoro. Ozoro is the Headquarters of Isoko North Local Government Area of Delta State, Nigeria. During the dry season (October -March), the average temperature in Rainfall in Delta State Polytechnic Ozoro ranged between 26.48 - 27.79⁰C and in rainy season (April - September), the average monthly temperature ranged 25.01 27.15⁰. Temperature in Ozoro is low at night and high in the day as a result of the external heat supply by the sun.

Keywords: Solar Radiation, Photovoltaic (PV) System Performance, Temperature, Relative Humidity, Rainfall, Sunshine Duration, Environmental Factors, Solar Energy.

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INTRODUCTION

Energy is the motivating force behind the sustainable technological development of any nation. Solar energy is the most promising renewable power source because of its free usage, clean, eco-friendly and silent operation when it is utilized to generate electricity by means of photovoltaic panels. Solar energy is now considered to be the most effective and economical of the alternative energy source (Sheer, 2002). The knowledge of the patterns of solar radiation is very vital in our contemporary world since the use of solar energy has become an integral part of energy source. Different researchers have explored variability region of solar radiation with weather parameters such as temperature, humidity, rainfall, sunshine etc. and also its variation with latitudes. Yazdani, *et al.*, (2014) in their investigation of effect of weather conditions on solar radiation in Brunei Darusaalam found that solar radiation is directly proportional to atmospheric temperature while it is inversely proportional to relative humidity. Also, Trabea and Mosalam (2010) confirmed that there is correlation of global solar radiation with weather

conditions. Low relative humidity leads to increase in solar flux, thus enhancing output current and improving the solar system efficiency in Ozoro of Nigeria Delta (Omubo-Pepple *et al.*, 2013).

In our research we investigated the influence of weather conditions of temperature relative humidity, rainfall and sunshine on the amount of solar energy received in the study area Ozoro. Precise knowledge of the global solar radiation at a location of study is required for the design and estimation of the performance of any solar energy system (Ibeh *et al.*, 2012). Therefore, the result of this work can be used in the design and construction of solar energy for the Ozoro community at large. Moreover, the results possibly can also offer input for climate risk information for 10 local and national planning and decision-making for sustainable development in agriculture, aviation, health, weather forecasting (NDES, 2019).

Nigeria is blessed with an abundance of non-depleting and environment friendly renewable energy resources such as solar, wind, biomass and hydro. The

northern part of Nigeria, where solar energy and wind energy are profusely available throughout the year in comparison to the rest of Nigeria, has higher potential to exploit renewable energies for domestic and industrial applications (Olorunmaiye *et al.*, 2012). Increasing rate of energy consumption is essential for progress of our civilization and therefore main problem is how we produce energy. Extensive use of fossil fuels and nuclear energy has created bad impact on environmental, social, and sustainability problems (Babatunde, 2012). The fill factor represents the ratio of the maximum power output to the product of open-circuit voltage and short-circuit current, serving as a key measure of solar cell performance. Most commercial solar cells in 2009 exhibited fill factors exceeding 0.70, while "Grade B" cells maintained a range of 0.4 to 0.7. Higher fill factor values indicate lower equivalent series resistance and enhanced equivalent shunt resistance, resulting in minimal current loss due to internal inefficiencies. Single p-n junction crystalline silicon solar cells are approaching the theoretical maximum power efficiency limit of 33.7%, known as the Shockley-Queisser limit established in 1961; theoretically, with infinite layers and concentrated sunlight, efficiencies can reach 86% (Ulanoff *et al.*, 2015). As of September 2013, a solar cell set a record of 44.7% efficiency according to the German Fraunhofer Institute for Solar Energy Systems (Ulanoff *et al.*, 2015).

Since the existence of man on earth, man has greatly relied on the use of fossil fuel for electricity and power generation. On a world scale, environmental problems including global warming due to extensive use of fossil fuels for electricity production and combustion engines have become increasingly serious in recent years. One of the viable solutions to tackling these environmental problems is by turning our attention to the use of renewable sources of energy to replace the use of fossil fuel for electricity and power generation. Solar energy which is clean, noiseless and pollution free is considered one of the most important sources among the renewable sources of energy. Intensive efforts are being made to reduce the cost of photovoltaic cell production, improve efficiency and narrow the gap between photovoltaic and conventional power generation methods such as steam and gas turbine power generators. In order to decrease the cost of PV array production, different efforts have been made towards improving the efficiency of the system and collecting more energy per unit surface area, such effort is by considering environmental factors that has great impact on the performance of photovoltaic cell. This study was carried out to discuss those environmental factors. The main aim of the study is to investigate the effect of environmental factors such as Sunlight, humidity, temperature, rainfall on photovoltaic installed at Ozoro.

MATERIALS AND METHODS

The Area of Study

The study area is Rivers Delta State Polytechnic which is located at Ozoro. Ozoro is the headquarters of the Isoko North Local Government Area of Delta State, Nigeria. The monthly rainfall in Ozoro follows a sequence of increase from March to October before decreasing in the dry season months of November to February. Rainfall in Ozoro exhibits double maxima regime with peaks in July and September. Ozoro does experience mostly two weeks window of little or no rain within July and August otherwise described as "August break" though the time of occurrence varies each year. Temperature in Ozoro is low at night and high in the day due to the external sun heat supply.

Material Used

The entire setup contains rain gauge, barometer, wind vane/speedometer, peak and least thermometer, solar panel, Pyranometer, and hygrometer. The Decoder houses the power backup, the measurement control device, sensor interfacing and data logging units, the pressure sensor and the wireless telemetry device.

Method of Obtaining Data

- i. Automatic Meteorological weather station was applied in Ozoro to measure the temperature for a period of three months
- ii. Automatic Meteorological weather station was assessed in Ozoro to measure the rainfall for a period of three months
- iii. Automatic Meteorological weather station was in Ozoro to measure the relative humidity for a period of three months
- iv. Automatic Meteorological weather station was used in Ozoro to measure sunshine intensity for three months period.

Rainfall and Solar Energy

Rainfall in Ozoro exhibits a pattern of increase from March through October, followed by a decrease during the dry months from November to February (illustrated in Figure 5). The area's annual average rainfall recorded is 203.03 mm (as shown in Figure 4), reflecting notable peaks in July and September. The region typically experiences a two-week period of minimal rainfall termed the "August break," with the exact timing varying annually. In 2021, an upswing in daily rainfall was noted. Solar energy levels range between 47.07 and 113.99 mJ/m² monthly, with an average of 87.87 mJ/m² monthly. During the rainy months from April to September, the average solar energy is 86.69 mJ/m² monthly, and during the dry months, it is slightly higher at 89.05 mJ/m² monthly. The Pearson product-moment correlation coefficient indicates $r = -0.460$, revealing a negative correlation between solar radiation and rainfall, consistent with reduced sunshine durations in rainy seasons.

Temperature and Solar Energy

Monthly and annual average temperature variations are illustrated in Figure 3. In the dry season (October to March), temperatures range from 26.48°C to 27.79°C at Delta State Polytechnic Ozoro, whereas during the rainy season (April to September), averages range between 25.01°C and 27.15°C. Nighttime temperatures remain cooler while daytime temperatures increase due to solar heating. Average solar energy levels during the rainy season are recorded at 83.75 mJ/m² per month, with the dry season registering higher energy levels at 102.86 mJ/m² per month. Peak solar energy levels are observed in May at 113.35 mJ/m², contrasting with the lowest in September at 47.07 mJ/m². These findings align with previous studies by Olatona and Adegoke in 2015, indicating that the highest solar radiation occurs in May at 16.1 mJ/m² per day and the lowest in August at 10.7 mJ/m² per day. A correlation coefficient of $r = 0.48$ suggests a positive relationship with solar radiation.

Humidity and Solar Energy

The average monthly temperature of 26.02°C contributes to significant water evaporation (averaging 93.30 mm), which saturates the atmosphere with water vapor (max monthly humidity at 93.30%). This vapor eventually precipitates as monthly rainfall (203.03 mm). Evaporation tends to exceed precipitation during the dry season (refer to Figure 5). High humidity correlates with lower temperatures and reduced solar radiation levels (refer to Figure 5). These observations align with Ettah *et al.*, (2015), who reported that lower relative humidity correlates with increased solar energy. Humidity averages during the rainy season fluctuate between 73.66% and 82.48%, with an average of 78.06%. Conversely, during the dry season, humidity spans from 68.06% to 79.46%, averaging 73.25%. These humidity levels closely relate to solar energy readings throughout both periods. Solar energy levels in the area range from 47.07 to 113.99 mJ/m² daily, with an annual average of 87.87 mJ/m². Monthly averages indicate 86.69 mJ/m² during the rainy season, while in the dry season, it averages 89.05 mJ/m². Increased humidity levels result in diminished solar energy accessibility.

Sunlight and Solar Power

Figure 6 outlines sunlight intensity variations throughout a day, monitored from 7:00 AM to 4:00 PM in November 2015. Notably, sunlight intensity rises, peaking at 12:00 PM with maximum strength of 106.25 klux, followed by a gradual decline post-noon due to changes in sun position and angles impacting panel surface. Fluctuations in sunlight intensity directly correlate with estimates of electrical energy production from the panels. Figure 7 illustrates the impact of sunlight intensity on crucial electrical parameters of the solar panels, showing that short-circuit current (I_{sc}) increases with enhanced sunlight strength, while open-circuit voltage (V_{oc}) remains relatively stable. This behavior is attributable to the readiness of charge carriers

(free electrons and holes) to acquire energy and effectively navigate towards electrodes prior to recombination. Although increased temperature can influence the energy gap, this was not noticeably reflected in our findings due to the ambient temperature stability and the consistent nature of silicon-based solar panels.

Solar Power Output Formulas

This section elaborates on installing solar panels, presenting step-by-step calculations and examples addressing the required number of solar panels, battery specifications, inverter ratings, load requirements, and Watts needed, alongside circuit diagrams. Individuals following the provided instructions can successfully establish and connect solar panels for home utilization by learning how to:

- i. Determine the quantity of required solar panels and their specifications.
- ii. Calculate solar panel ratings.
- iii. Ascertain battery ratings within the solar system.
- iv. Estimate battery backup duration.
- v. Compute required charging current for batteries.
- vi. Evaluate battery charging time.
- vii. Identify charge controller ratings.
- viii. Determine total wattage needed for solar panels.
- ix. Select between series or parallel connections for solar panels.
- x. Choose suitable solar panels for home applications.
- xi. Calculate UPS/Inverter ratings based on loading requirements.

Solar Panel Installation

A comprehensive guide will unfold the processes associated with choosing appropriate solar panels for residential and business applications, elucidating how to connect and deploy a solar energy system via correct calculations and power assessments.

Assuming a desired battery backup for a total load of 800W lasting for three hours, calculations establish that the inverter or UPS should exceed 25% of the total load:

Total Load + 25% Power = 800 + 200 = 1000 Watts, necessitating a 1000W inverter/UPS rating.

Required Number of Batteries

To achieve a three-hour backup time, utilizing 100Ah, 12V batteries, calculations imply:

12V x 100Ah = 1200 Wh per battery, translating to 1.5 hours runtime per battery at 800W load.

Thus, 3 hours / 1.5 hours = 2 batteries required, each rated at 100Ah and 12V.

Backup Duration of Batteries

To determine how long the batteries will last based on the number of batteries:

$$1200 \text{ Wh} \times 2 \text{ Batteries} = 2400 \text{ Wh}$$

$$2400 \text{ Wh} / 800 \text{ W} = 3 \text{ hours.}$$

Using a 12V inverter system dictate connecting the two batteries (each 12V, 100Ah) in parallel.

Series or Parallel Battery Configuration

For a 12V inverter system, parallel connections are favored as series connections would aggregate voltages to 24V while maintaining a current of 100Ah, which is not optimal for this case.

In parallel, battery voltage remains at 12V, while capacity increases, providing 200Ah.

Charging Current for Batteries

Charging current should equal one-tenth of the battery's amp-hour rating:

$$200 \text{ Ah} \times (1/10) = 20 \text{ A.}$$

Charging Time Needed for Batteries

Charging time is calculated with:

$$T = \text{Ah} / \text{A} \text{ (for lead-acid batteries).}$$

Using a single 12V, 100Ah battery, $T = 100 \text{ Ah} / 10 \text{ A} = 10 \text{ hours}$ (ideal condition).

Factoring in a 40% loss during charging means adjusting the initial calculations to:

$$\text{-Total Battery Capacity} = 100 \text{ Ah} + 40 \text{ Ah} = 140 \text{ Ah.}$$

Thus, required charging time becomes $140 \text{ Ah} / 12 \text{ A} = 11.6 \text{ hours}$.

Required Number of Solar Panels (Series or Parallel)

To ascertain solar panel requirements, consider two scenarios:

1. DC Load Not Connected (Battery Charging Only):
Power needed for charging is determined as follows:
 $P = 12\text{V} \times 20 \text{ A} = 240 \text{ Watts}$, resulting in $240\text{W}/60\text{W} = 4$ Solar Panels needed in parallel.
2. DC Load Connected Along with Battery Charging:

If connected to a 10A load simultaneously, total current is:

$$20 \text{ A (for battery charging)} + 10 \text{ A (for load)} = 30 \text{ A.}$$

Therefore,

$$\text{Power} = 12\text{V} \times 30 \text{ A} = 360 \text{ Watts, necessitating } 360\text{W}/60\text{W} = 6 \text{ Solar Panels in parallel.}$$

Charge Controller Specifications

Considering the charging current needed for a 200Ah battery falls between 20 and 22 Amperes, a charge controller rated at about 30 to 32 Amps should be employed to account for losses.

How Many Watts of Solar Panels Are Required?

The following addresses how to calculate wattage for solar systems influenced by available sunlight and required device wattage.

For facilitating the establishment of solar energy solutions for household appliances, several topical discussions have been provided.

The solar panel installation guide emphasizes various technical aspects essential for effective solar energy deployment.

The suit of the data was recorded continuously every 5 minutes daily throughout the years. The data was downloaded into the laptop computer for analysis. The weather data values used in this study are rainfall, humidity, temperature, solar energy, and evaporation. Daily averages are computed into monthly averages from which yearly patterns are derived.

Two small silicon based solar panels (Leybold Didactic GMBH) with dimension of $25 \times 25\text{cm}^2$ arranged series were installed on the roof of a home building specified for the investigations. The panels were inclined 36 degrees due south and a light meter was deployed to note the light intensity, accordingly. Two digital multimeters were utilized to display the current and voltage produced by the panels, while a variable resistor (1Ω to $100 \text{ K}\Omega$) was connected as a load and a thermometer was deployed to display the ambient temperature. Figure 1 shows the experimental set up used in the investigations.

The maximum power ($P_{\max}$) delivered from cell panels while the fill factor (FF) were calculated by the following equations:

$$P_{\max} = V_{\text{mp}} \times I_{\text{mp}} \quad (1)$$

$$\text{FF} = P_{\max} / (V_{\text{oc}} \times I_{\text{sc}}) \quad (2)$$

Where, I_{sc} and V_{oc} are short-circuiting current and open-circuit voltage of the cell panels, respectively.

RESULTS AND DISCUSSION

Temperature and Solar Energy

Monthly and annual average temperatures are illustrated in Figure 1. In the dry season (October - March), Delta State Polytechnic Ozoro records temperature ranges between 26.48°C and 27.79°C , while during the rainy season (April - September), temperatures span from 25.01°C to 27.15°C . Nighttime temperatures are cooler, with daytime temperatures rising due to solar activity. Average solar energy for the rainy season is documented at 83.75 MJ/m^2 , compared to the dry season's higher 102.86 MJ/m^2 average. Peak solar energy is attained in May at 113.35 MJ/m^2 and the minimum in September at 47.07 MJ/m^2 , corroborating Olatona and Adegoke's (2015) findings of solar radiation peaks at 16.1 MJ/m^2 daily in May and a dip to 10.7 MJ/m^2 daily in August. The positive correlation coefficient ($r = 0.48$) reflects a direct relationship between solar radiation levels and temperatures.

Rainfall and Solar Energy

Rainfall in Ozoro exhibits an increasing trend from March to October, declining in the dry months of

November through February, as represented in Figure 3. The average yearly rainfall is recorded at 203.03mm in Figure 2, revealing dual peaks in July and September. The area typically experiences a short dry period termed the "August break," which varies from year to year. An upward trend in daily rainfall was noted in 2021. Solar energy readings fluctuate from 47.07 mJ/m² to 113.99 mJ/m², averaging 87.87 mJ/m²; during the rainy months (April - September), the mean stands at 86.69 mJ/m², while the dry season averages slightly higher at 89.05 mJ/m². The Pearson correlation coefficient ($r = -0.460$) indicates a negative relationship between solar radiation and rainfall, consistent with diminished sunshine during the rainy period.

Humidity and Solar Energy

The region's average monthly temperature of 26.02°C prompts considerable evaporation (averaging 93.30 mm), saturating the atmosphere with water vapor,

which condenses into rainfall (203.03 mm monthly). Evaporation surpasses rainfall during the dry season (refer to Figure 5). High humidity correlates with reduced temperatures and lower solar radiation levels (illustrated in Figures 3). These observations align with findings from Ettah *et al.*, (2015), suggesting that decreased relative humidity corresponds with increased solar irradiance. Humidity averages during the rainy season oscillate between 73.66% and 82.48%, averaging 78.06%, whereas dry season humidity spans from 68.06% to 79.46%, averaging 73.25%. These humidity percentages correlate closely with solar energy values during the same periods. Solar energy levels in the area range from 47.07 to 113.99 mJ/m², yielding an annual average of 87.87 mJ/m². Monthly evaluations show 86.69 mJ/m² during rainy months against 89.05 mJ/m² during dry months. Higher humidity translates to a decline in solar energy reaching the surface.

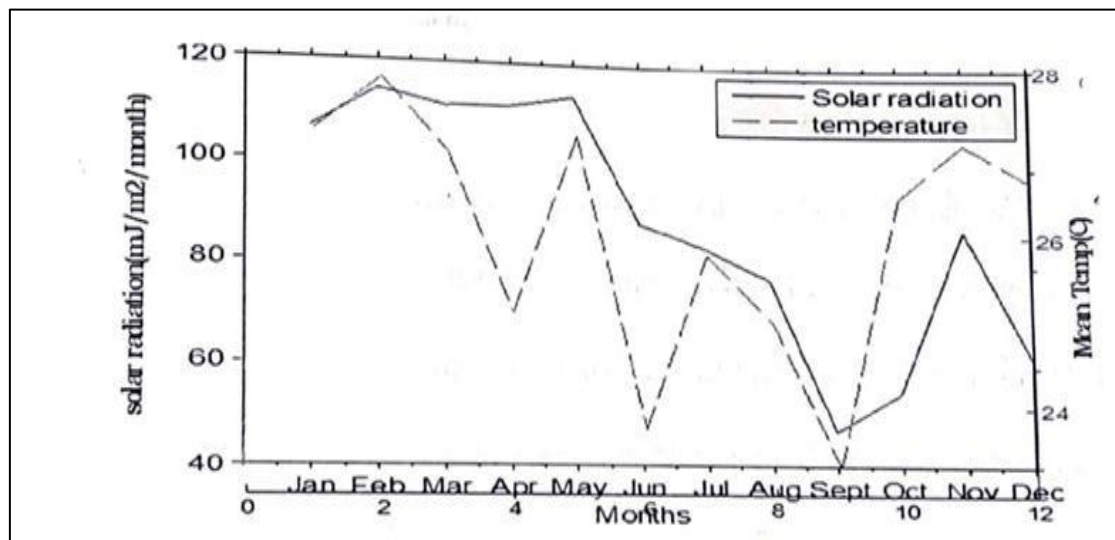


Figure 1: Solar Energy-Temperature profile

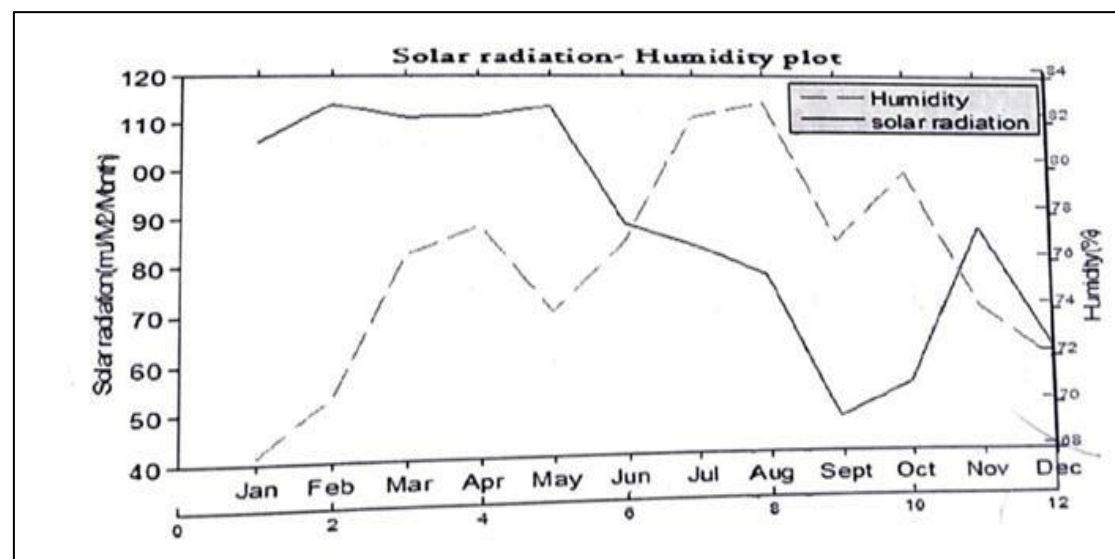


Figure 2: Solar Energy-Humidity profile

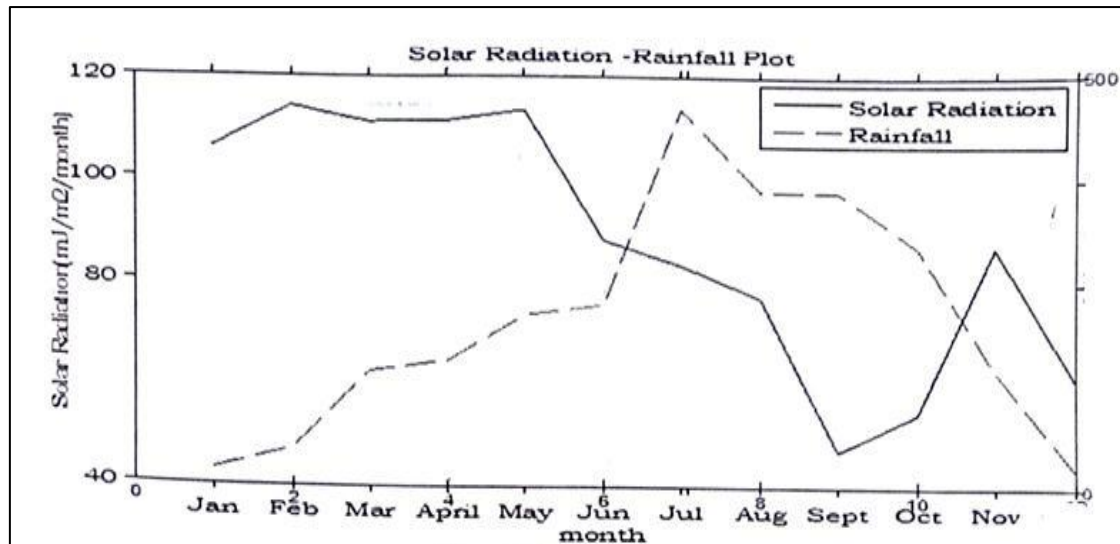


Figure 3: Solar Energy-Rainfall profile

Findings of the Study

The study revealed that various environmental factors in Ozoro significantly influence solar photovoltaic (PV) system performance and efficiency:

1. Increased ambient temperatures lower the efficiency of solar panels by decreasing voltage outputs during heat waves.
2. Elevated humidity levels prevalent in the Niger Delta result in corrosion of solar components and connections, adversely affecting performance and longevity.
3. Frequent rain and cloud cover restrict solar radiation, lowering energy output in the rainy season; however, rainfall also cleans panel surfaces, enhancing performance afterward.
4. Dust and pollutants accumulating on panel surfaces reduce light absorption, leading to decreased energy conversion efficiency, highlighting the importance of regular maintenance and cleaning.
5. Weather variability causes fluctuations in solar output, resulting in unpredictable energy generation without adequate backup systems or battery storage.
6. Regular maintenance such as cleaning and inspections is critical to enhance the performance and durability of solar energy systems.
7. Adequate installation practices—including optimal panel positioning and ventilation—maximize energy capture and improve system efficiency.

Overall, the research confirms that even amid environmental challenges, solar energy remains a reliable and sustainable renewable resource for Ozoro and the Niger Delta, particularly when coupled with effective maintenance strategies and appropriate technologies.

CONCLUSION AND RECOMMENDATION

This study establishes key findings regarding solar energy patterns within the Ozoro area, demonstrating that solar energy levels fluctuate between 47.07 and 113.99 mJ/m² monthly, with a mean of 87.87 mJ/m². The regular solar energy output during the rainy month's averages lower at 86.69 mJ/m², contrasted by a higher mean of 89.05 mJ/m² during the dry period. The average annual humidity is recorded at 75.65%, closely correlating with the rainfall-to-evaporation ratio of 2.17 and the temperature-related evaporation rate of 3.57 mm/°C. High humidity, along with the defined rainfall-to-evaporation ratios, influences the availability of solar energy, showing complex interactions between solar radiation, temperature, and moisture. The evaporation rates per degree vary from 2.92 mm/°C to 4.47 mm/°C, with annual averages sitting at 3.57 mm/°C (see Figure 8). The months of February and December—which experience minimal rainfall—exhibit the lowest rainfall-to-evaporation ratios of 1.61, 3.89, and 2.49, respectively. Annual ratios fluctuate from a low of 1.61 in January to a high of 5.71 in July. These findings, which indicate that double the amount of rainfall occurs compared to evaporation, align with high humidity observations. The results illustrate how varying weather conditions can have both positive and negative consequences on solar energy reception in Ozoro. The analyses indicate a positive correlation with temperature and rainfall, suggesting that as temperatures rise, solar radiation levels correspondingly increase—a reverse relationship exists with increased humidity and rainfall, diminishing solar energy output and reducing solar panel efficiency, while robust sunlight enhances solar energy yield.

The study's observations of November sunlight intensity revealed that strength peaks at midday (12 PM) with 106.25 klux, demonstrating non-linear declines post-noon due to changes in solar angle and panel exposure. The increment in sunlight strength correlates

directly with heightened photoelectron generation, enabling higher current outputs. Notably, the highest solar panel output was evaluated around midday, reaching about 2.3 W. Sunlight impacts I_{sc} positively while leaving V_{oc} relatively unchanged—this differential behavior confirms charge carriers gain sufficient kinetic energy to traverse electrodes effectively, despite energy gap alterations being less apparent due to the overall stable temperature conditions and reliability of silicon-based panels. Recommendations for developing solar panels for Ozoro and the Niger Delta region should consider these environmental factors to optimize performance.

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