IKR Publishers

IKR Journal of Engineering and Technology (IKRJET)
Journal homepage: https://ikrpublishers.com/ikrjet/
Volume-1, Issue-2 (September-October) 2025

OPEN ACCESS
ISSN: 3107-7331 (Online)

# Comparison of Functionalities of Solar Photovoltaic System under Different Climatic and Environmental Parameters

[1]Sa'adu G.*, [2]Bello B.A, & [3]Sule T.K
[1, 2, 3,] Department of Electrical & Electronic Engineering, Institute Of Technology, Kwara State Polytechnic, Ilorin.

***DOI:****10.5281/zenodo.17264150*

**ARTICLE INFO**

***Article history:***
***Received : 20-09-2025***
***Accepted : 28-09-2025***
***Available online : 04-10-2025***



**Citation:** Sa'ad G., Bello B.A, & Sule T.K (2025). Comparison of Functionalities of Solar Photovoltaic System under Different Climatic and Environmental Parameters. *IKR Journal of Engineering and Technology (IKRJET)*, 1(2), 60-67.

**ABSTRACT** **Original research paper**

This paper presents a comparative simulation analysis of the performance of photovoltaic (PV) systems in two climatically distinct regions: Cardiff, Wales (United Kingdom) and Ilorin, Nigeria (West Africa). Using PV*SOL software, identical monocrystalline silicon (m-Si) modules were modeled to assess performance under differing environmental conditions. Key performance indicators including specific yield, performance ratio (PR), and solar fraction were evaluated. The research was carried out through both simulations and calculations. The results were then found to fall within agreeable limits, following thorough analysis.

Results show that Cardiff, situated in a temperate climate, produced a stable annual specific yield of 846.8 kWh/kWp and a high PR of 86.7%, aided by moderate ambient temperatures and minimal soiling. In contrast, Ilorin, located in a tropical savanna, yielded 1102.3 kWh/kWp due to higher solar irradiance but experienced a lower PR of 65% caused by high module temperatures and soiling losses. Seasonal variations also highlighted the advantages of stable temperate climates for PV efficiency versus the high yield but challenging conditions in tropical zones. This study demonstrates the importance of site-specific adaptation in PV system planning. It concludes that while tropical climates offer higher potential yields, cooling strategies and regular maintenance are essential to sustain performance. Meanwhile, temperate regions ensure more consistent and efficient operation. The findings provide guidance for policymakers, engineers, and investors in selecting PV technology suitable to regional climatic realities.

**Keywords:** Photovoltaic systems, Solar irradiance, Monocrystalline silicon, Climate adaptation, Performance ratio, System design, Tropical zones, Temperate zones, PV*SOL software.

**Corresponding author:* *Sa'adu G.*
*Department of Electrical & Electronic Engineering, Institute Of Technology, Kwara State Polytechnic, Ilorin.*

## 1. Introduction

As global energy demand continues to rise, driven by population growth and increased industrialization, there is an urgent need to pivot from fossil fuels toward renewable energy sources. Solar photovoltaic (PV) technology has emerged as a key solution due to its scalability, low operating costs, and capability for decentralized deployment making it well-suited for both urban infrastructure and rural electrification [2]. However, PV system performance is highly sensitive to local environmental conditions. Climatic variables such as solar irradiance, ambient temperature, humidity, wind speed, and particulate load significantly influence both system efficiency and longevity [12].

While regions closer to the equator can experience higher irradiance improving specific energy output they often suffer from elevated operating temperatures and soiling losses, which degrade performance [8]. Temperature-induced voltage reductions in monocrystalline silicon modules, typically on the order of 0.4–0.5% per °C, can lead to substantial performance losses during peak heat [12].

This study investigates the performance differences of monocrystalline silicon PV systems deployed in two climatically diverse regions: Cardiff, UK a temperate maritime environment and Ilorin, Nigeria a tropical savanna climate. By employing PV*SOL simulation with laboratory validation, the paper isolates how environmental factors shape energy yield, efficiency, and economic performance when identical technology is used. This addresses a gap in the literature regarding cross-continental PV comparisons with experimental corroboration a critical area for informed policy-making and technology deployment [17][14].

# 2. Literature Review

## 2.1 Solar Irradiance and Location

Solar irradiance varies with latitude, atmospheric composition, and seasonal weather patterns. High-latitude regions like the UK benefit from diffuse radiation, whereas tropical zones enjoy consistent high irradiance but contend with haze and dust [11][5]. Data from Meteonorm show that Cardiff averages 982 kWh/m² annually, compared to Ilorin's 1721 kWh/m².

## 2.2 Thermal Effects on Module Performance

Ambient temperature is a critical determinant of PV efficiency. Monocrystalline silicon modules typically lose 0.4–0.5% power per °C increase above 25 °C [12][8]. A 2024 study confirms that temperature remains the dominant environmental factor influencing output and long-term degradation in tropical PV deployments [15]. Modules operating above 60 °C are particularly vulnerable unless active or passive cooling mechanisms are employed.

## 2.3 Environmental Soiling and Maintenance

Dust and environmental particulates degrade PV performance by blocking cell surfaces, leading to reduced transmittance and electrical output. Soiling has been shown to reduce power generation by 5–20% when maintenance is infrequent [10]. A recent 2023 review emphasized the need for region-specific cleaning schedules, finding that scheduled maintenance in dusty zones can boost net output by up to 15% [14].

## 2.4 Cooling Technologies and Mitigation

To counter high temperature losses, cooling techniques are increasingly integrated into PV system design. A 2024 study demonstrated that combining phase-change materials (PCMs) with forced convection enhanced electrical efficiency by up to 15% under tropical conditions [16]. Similarly, mist-based cooling has shown energy gains between 4–11% in field studies conducted in Southeast Asia and West Africa.

## 2.5 Climate-Specific PV System Configurations

Optimal system configurations vary significantly with location. In temperate zones, south-facing orientations and moderate tilt angles improve winter gain. In tropical climates, flatter tilt angles and low-temperature-coefficient technologies like HIT or CdTe outperform traditional crystalline silicon [5][11]. Proper configuration improves not only energy yield but also system longevity.

## 2.6 Future Research Prospects

Despite extensive modeling and simulation studies, few research efforts compare identical PV technologies across distinctly different climates using both simulations and experimental validation. Likewise, economic viability studies especially in relation to grid availability, energy pricing, and ROI remain underexplored [13][7].

# 3. Methodology

## 3.1 Study Locations

Cardiff is located in South Wales, United Kingdom (Latitude 51.4816°N, Longitude 3.1791°W), and experiences a temperate maritime climate. The average annual solar irradiance in Cardiff is about 982 kWh/m². Ilorin, the capital of Kwara State in Nigeria (Latitude 8.4966°N, Longitude 4.5421°E), experiences a tropical savanna climate with average annual irradiance levels of approximately 1721 kWh/m². These two regions were selected for their climatic contrasts and represent ideal candidates for comparative performance studies. The simulations were done, utilizing monocrystalline silicon module (m-Si) to compare the solar PV performance parameters based on the two geographical and climatic locations.

## 3.2 PV System Design and Configuration

Identical PV system technologies were modeled using PV*SOL Premium simulation software. Both systems used SHARP NUE-245-J5 monocrystalline silicon modules with a nominal capacity of 245W. Inverters used in both cases were SMA Sunny Boy models selected to match the system configurations.

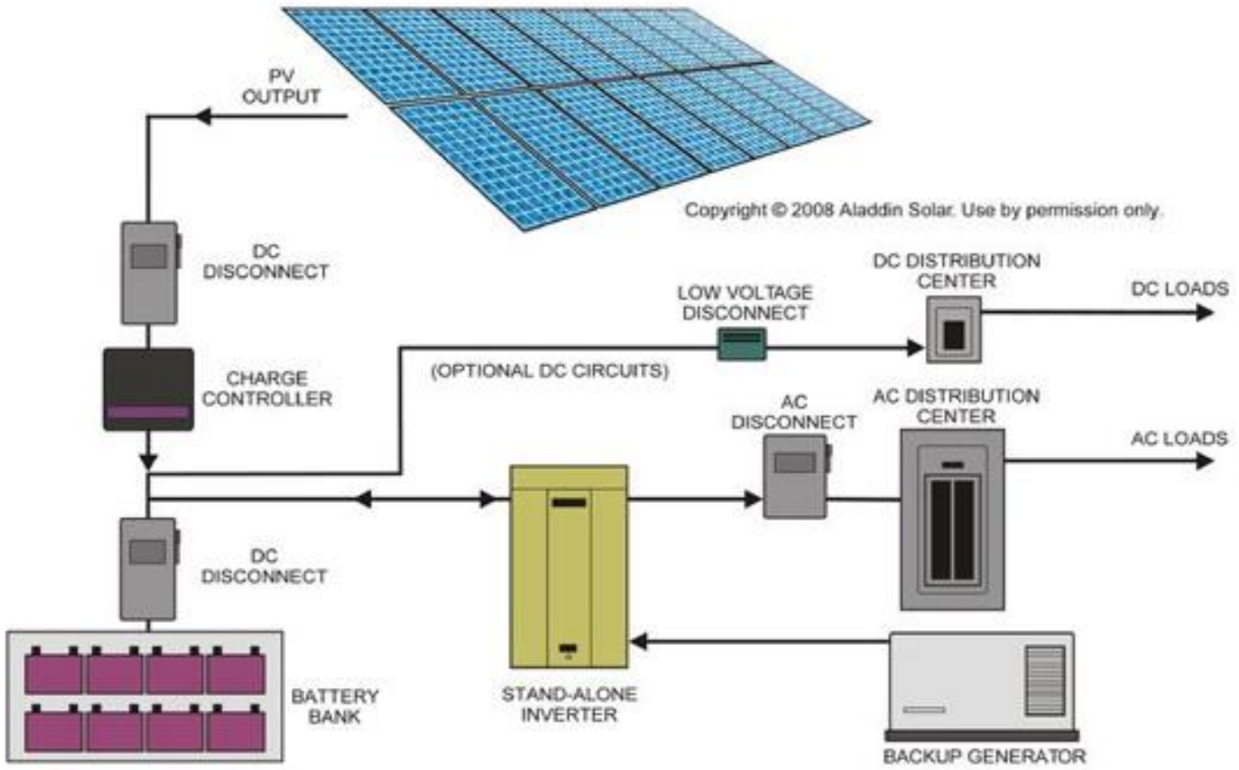


**Fig. 3.1: Standalone PV system (www.arsolar.com)**

A standalone PV system (also called an off-grid system) works independently without connection to the national electricity grid. It uses solar panels to generate electricity, which is stored in batteries for use during the night or cloudy periods. This makes it suitable for rural areas or regions with unreliable grid supply, such as many communities in Nigeria, including Ilorin. In contrast, a grid-tied solar system is connected to the main electricity grid and usually does not require batteries, as excess power can be fed back to the grid and electricity can be drawn when solar energy is insufficient. While grid-tied systems are common in developed countries like the UK (Cardiff) due to their stable grid infrastructure and favorable feed-in tariff policies, standalone systems are more practical in Nigeria, where frequent outages and weak grid coverage make energy independence a necessity.

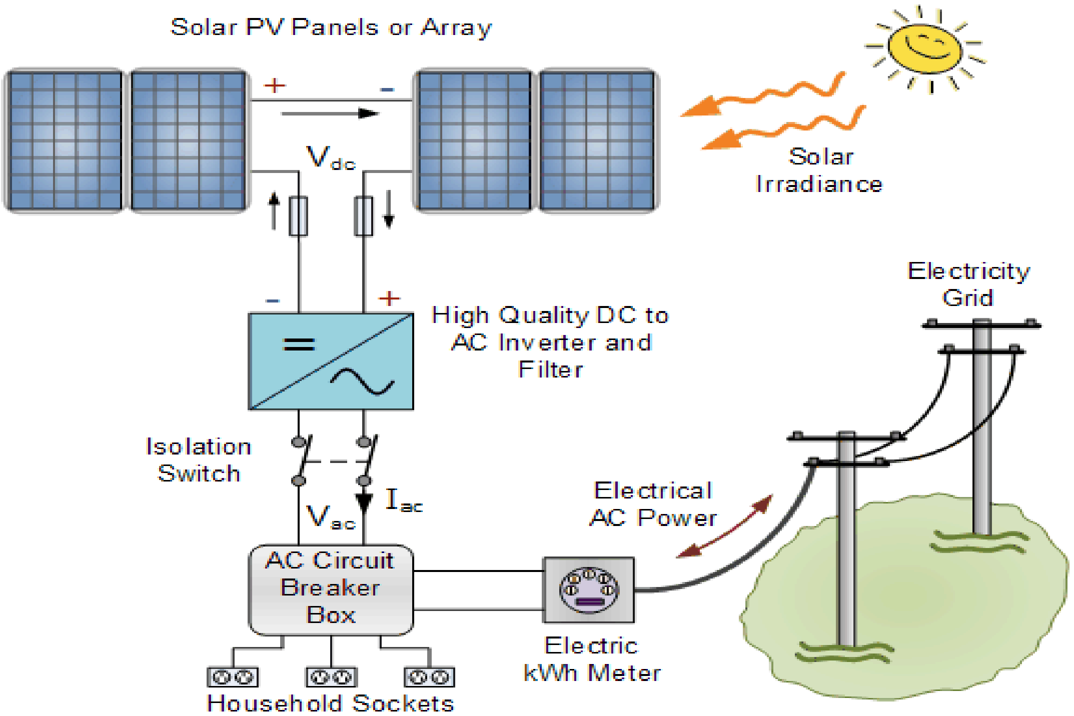


**Fig 3.2: Grid connected PV system (enwikipedia.org/wiki/)**

A grid-tied photovoltaic (PV) system works alongside the public electricity network. Power from the solar panels is used in the home or business first, while any extra energy is automatically sent to the grid and can earn credits through net-metering. When solar output is low, electricity is taken from the grid instead of batteries. This setup is best suited to locations with dependable grid supply and incentive programs such as the United Kingdom where surplus solar power can be sold back to the utility.

**Table; 3.2.1 Comparison of Standalone and Grid-Tied Solar PV Systems**

| S/N | Factor | Standalone (Off-Grid) | Grid-Tied |
|---|---|---|---|
| 1 | Grid Reliability | National grid is unreliable, with frequent outages and low coverage. Standalone systems ensure energy independence. | Grid is highly reliable, making grid-tied systems practical with minimal need for backup. |
| 2 | System Design | Requires batteries for storage to supply power at night and during cloudy periods. | Usually does not need batteries since the grid supplies power when solar is insufficient. |
| 3 | Energy Security | Offers reliable supply for homes and small businesses in areas with poor grid access. | Relies on stable grid and policy incentives; less focus on energy independence. |
| 4 | Climate Suitability | High solar radiation levels in Ilorin make standalone systems highly effective for off-grid communities. | Moderate solar potential in Cardiff; grid-tied systems maximize use of available solar while relying on grid stability. |
| 5 | Cost Implication | Higher initial cost due to batteries and charge controllers, but provides long-term independence from unreliable grid. | Lower upfront cost without batteries, but savings depend on feed-in tariffs and electricity prices. |

a). Cardiff System: 333 modules totaling 81.6 kWp installed on the south-facing roof of the Eastern Leisure Centre at a tilt angle of 38°.
b). Ilorin System: 161 modules totaling 39.45 kWp installed on the east-facing roof of Royal Shekinah Suites with a tilt angle of 31.3°.

### 3.3 Data Collection and Simulation Inputs

Simulation data included solar irradiation, temperature, system losses (wiring, inverter, soiling), building load profile, roof geometry, and shading effects. Climatic data were sourced from Meteonorm and embedded within PV*SOL's global database. Load profiles for the two buildings were created based on operational schedules and appliance audits. The simulation timeframe spanned one calendar year for both systems, and outputs such as annual energy production, specific yield (kWh/kWp), and performance ratio (PR) were extracted.

## 4. Results and Discussion

### 4.1 Simulated Energy Outputs of the Buildings

The energy output generated, following the simulation exercises on both buildings were given in kWh on monthly basis. Then, all these energies were aggregated to obtain the annual simulated energy output for each of the buildings. The table below shows the monthly energies generated for Cardiff building.

**Table 4.1 Monthly kilowatt- hour for Cardiff building**

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Generation (kWh) | 2450 | 3150 | 5850 | 6950 | 9000 | 8750 | 9350 | 7850 | 6650 | 4700 | 2400 | 2000 |

The total energy produced during the year (annual energy output) equals the summation of all monthly energies;

$\sum_1^{12} Xi$=2450+3150+5850+6950+9000+8750+9350+7850+6650+4700+2400+2000

= 69100kWh/year,

*X* is the energy generation per month in kWh

i =1, 2, 3…..12, the number of months

**Table 4.2 Simulated monthly energy output for Nigeria building**

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Generation (kWh) | 3150 | 3200 | 4100 | 4450 | 4650 | 4000 | 3350 | 3300 | 3450 | 3600 | 3260 | 2975 |

From the table above, the total energy produced during the year (annual energy output) equals the summation of all monthly energies given by;

$\sum_1^{12}$ ***Xi***=3150+3200+4100+4450+4650+4000+3350+3300+3450+3600+3260+2975= 43,485kWh/year,

*X* is the energy generation per month in kWh

i = 1, 2, 3…..12 The number of month.

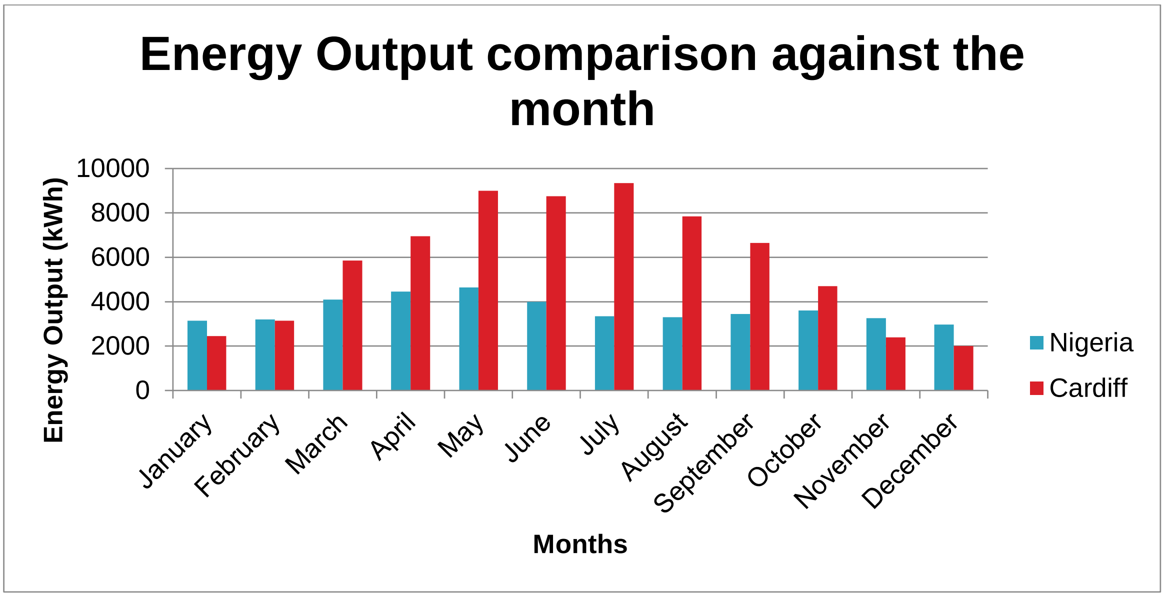


**Fig 4.1: Bar-chart representation of monthly Energy generation (kWh)**

## 4.2 Performance ratios (PR)

This is the ratio of the actual reading of plant output in kWh/year, to the calculated nominal plant output in kWh/year, expressed in percent (%). It indicates the percentage of the incident beams of solar energy in the period under consideration that were converted to useable electrical energy. The existence of thermal loss, conduction loss or other defects in the system, accounts for the value of PR being less than 100% oftentimes (sma solar technology)**.** The simulated monthly performance ratios of both buildings are as shown in the tables below;

**Table 4.3: Monthly performance ratio (PR) for Cardiff building**

| Months | Performance ratio (PR) % |
|---|---|
| January | 77 |
| February | 77 |
| March | 79.5 |
| April | 78.5 |
| May | 78 |

| | |
|---|---|
| June | 77 |
| July | 76 |
| August | 76.5 |
| September | 77 |
| October | 77.5 |
| November | 75.5 |
| December | 75.5 |

**Table 4.4: Monthly performance ratio (PR) for Nigeria building**

| Months | Performance ratio (PR) % |
|---|---|
| January | 73 |
| February | 74 |
| March | 74.5 |
| April | 75.5 |
| May | 75 |
| June | 75.5 |
| July | 74.5 |
| August | 74.5 |
| September | 74.5 |
| October | 74 |
| November | 73 |
| December | 71 |

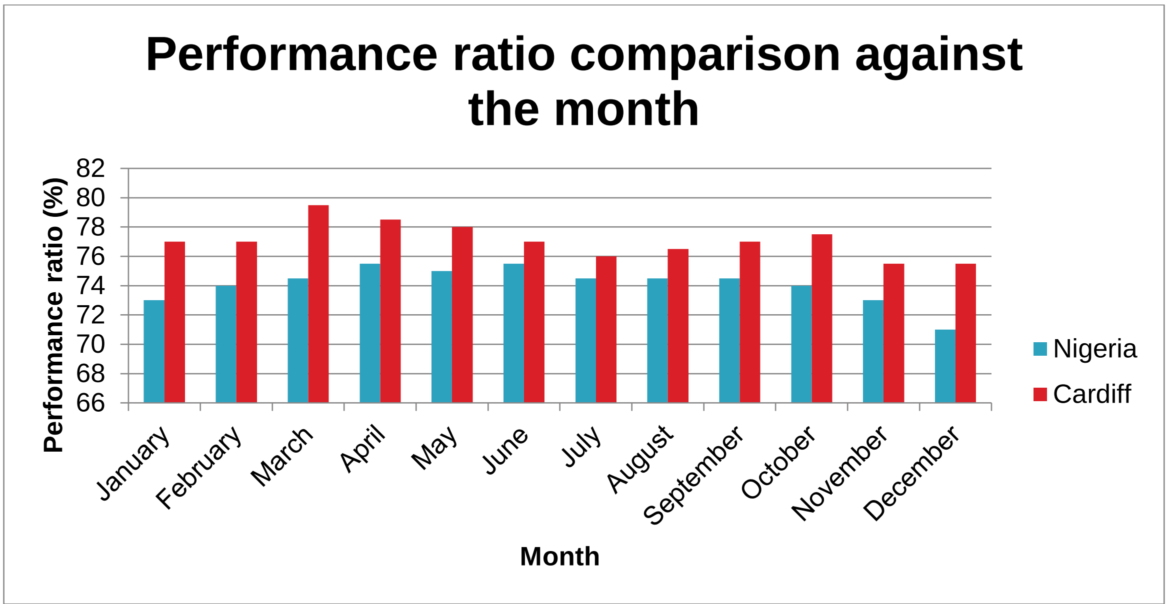


**Fig. 4.2: Bar chart representation of monthly % PR in the buildings.**

From the data shown, the average annual performance ratios for Cardiff and Nigeria building are respectively 77.1% and 74.1%.

### 4.2.1 Performance Ratio for Cardiff building

The average annual solar irradiation for Cardiff $=982kWh/m^2$**;**

Solar array area (plant area) Cardiff building = $540.8m^2$,

Efficiency factor of PV modules is taken as 15% **(sma solar technology)**;

Electrical energy exported to the grid annually = 69100kWh = 69.1MWh;

The irradiation value $kWh/m^2$ Xplant area in $m^2$ = 982 X540.8 = 531066kWh = 531.1MWh.

The nominal plant output = the above value Xefficiency factor = 531066kWh X0.15= 79659.8kWh = 79.66MWh;

Hence, performance ratio (PR) $=\frac{G.91\ X10^7}{7.966\ X10^7} = \frac{69100}{79659.8} = 86.7\%$

The findings revealed that the simulation gave the value of performance ratio as 77.1% whilst the calculation presented 86.7% for the same parameter. This implies that the array could be categorized as 'average' by simulation standard, whereas calculation classified it as 'good'. Bearing in mind that a system with a performance ratio of 0.65-0.8 is described as 'average' and 0.8 upwards is referred to as 'good' (Bristow 2015).

### 4.2.2 Performance Ratio for Nigeria building

The average annual solar irradiation for Nigeria=1721kWh/m$^2$**;**
Solar array area (plant area) for Nigeria building = 261.36m$^2$
Efficiency factor of PV modules is taken as 15%
Electrical energy exported to the grid annually = 43485kWh = 43.49MWh;
The irradiation value kWh/m$^2$ Xplant area in m$^2$ = 1721 X 261.36= 449800.6kWh = 449.8MWh.
The nominal plant output = the above value Xefficiency factor = 449800.6kWh x 0.15= 67470.1kWh = 67.47MWh;
Then, performance ratio (PR) = energy output in kWh/calculated nominal plant output kWh

$$= \frac{43485}{67470.1} = 65\%.$$

The simulation produced a Performance ratio (PR) of 74.1% for Nigeria building, there by classifying it as an 'average' system, whilst the calculation gave the same parameter to be 65%which still falls under the same 'average**'** system category.

**4.3 Specific annual yield:** This is the ratio of the total annual energy output produced to the power input of the system. It is given by kWh produced in a year/ kWp input i.e. the amount of energy output a given kWp power can produce. It is attributable to the quality of the particular PV technology used for the array. It is also dependent on the level of solar insolation (sunlight energy absorption).

For Cardiff building, the specific yield = $\sum_1^{12} \boldsymbol{Xi}$**/kWp** = $\frac{69100}{81.6}$ = 846.8kWh/kWp.
The UK benchmark of annual specific yield is 800kWh/kWp **(Bristow 2015).** Therefore, the above value is in line with UK standard, thus the design is in consonance with UK expectation.

For Nigeria building, the specific yield is $\sum_1^{12} \boldsymbol{Xi}$/kWp. =$\frac{43485}{39.45}$ = 1102.3kWh/kWp.

**4.4 Solar fraction:** This is the ratio annual energy output (kWh) produced by the system to the total annual kWh required by the building expressed in percentage. It shows the amount of energy the system is not able to supply but needed by the building. So this amount must be provided by an alternative energy source in order to ascertain continuity in power supply.
Solar fraction for Cardiff building; the annual kWh requires by the building is given by 391248kWh = 391.2MWh;
The simulated annual energy output for the building is 69100kWh;
Then, the solar fraction =$\frac{69100}{391248}$ = 17.7%.
Similarly, the annual kWh requires by Nigeria building is 153997kWh=153.997MWh;
The simulated annual energy output for the building is 43485kWh.
Hence, its solar fraction is equal to$\frac{43485}{153997}$= 28.2%.

### 4.5 Comparison of PV performance indicators between the designs for Cardiff and Nigeria building.

It was discovered, that the total annual energy output for Cardiff building was more compared with Nigeria building. This is due to the larger size of the array for the Cardiff building. However, there is even distribution of solar resource in Nigeria than Cardiff i.e. the monthly distribution of energy outputs for Nigeria building is more consistent, due to more solar energy presence in Nigeria, almost all year round.
Nigeria is a tropical country very close to the equator (latitude N8.5$^o$) thereby enjoys more sunlight, unlike Cardiff that witnesses adequate sunlight only during the summer months as it is located very far away from the equator (latitude N51.4$^o$).

i. **Specific annual yield**; This is an indicator of the output energy capability (kWh) per unit kWp of the solar technology. Since the same technology was utilized for both arrays (m-Si), the level of insolation on the array would then determine the size of the specific annual yield. From section 4.3, it was observed that the specific yield was more for Nigeria building as the country experiences more sunlight which give way to more insolation than Cardiff.

ii. **Performance ratio;** The performance ratios, both monthly and annual average value, favors Cardiff building more than Nigeria building as could be seen from fig 4.2. This is because there is adequate cool breeze in Cardiff compares with Nigeria that lacks this. Besides, the chosen solar technology (m-Si) thrives very well under Cardiff weather (temperature) **(Jardine and Lane 2003)**. These go a long way in improving the performance ratio of Cardiff more.

iii. **Solar fraction;** The solar fraction is more for Nigeria building than Cardiff as could be seen from section 4.4. This shows that the ratio of the generated output energy to the needed energy by the Nigeria building is more than that of the Cardiff. So, the percentage of energy backup required from an alternative energy source (e.g. generator) to meet the energy requirement by Nigeria building is less compared with the Cardiff.

## 5. Conclusion and Recommendation

This research has demonstrated that photovoltaic system performance varies significantly with environmental and climatic conditions, even when identical technology is used.

While Ilorin benefits from abundant solar radiation, high ambient temperatures and environmental factors such as dust accumulation result in reduced module efficiency and performance ratio. Cardiff, despite lower irradiance levels, supports more stable and efficient system operation due to favorable thermal conditions and minimal soiling. The findings affirm that climatic specific design strategies are crucial for optimizing PV system performance. In tropical climates, technological alternatives with lower temperature coefficients such as HIT or CdTe may offer better returns. Moreover, maintenance protocols like regular cleaning and thermal regulation measures are necessary to sustain system output.

Future research should explore the long-term degradation patterns of PV modules under varied environmental stressors, including humidity, UV exposure, and real-time soiling accumulation. Furthermore, incorporating hybrid PV-battery systems may improve reliability in regions with unstable grid supply.

## 6. References


1. N. Bristow, Outdoor PV Performance Monitoring Seminar. Cardiff University, 2015.
2. International Energy Agency (IEA), World Energy Outlook 2022. Paris: IEA, 2022. [Online]. Available:https://www.iea.org/reports/world-energy-outlook-2022
3. Meteonorm, Solar Radiation and Climate Data Tool. Meteotest AG, 2023. [Online]. Available: https://meteonorm.com
4. C. O. Okoye and B. C. Oranekwu-Okoye, “Economic feasibility of solar PV systems for rural electrification in Sub-Saharan Africa,” Renewable Energy, vol. 119, pp. 262–273, 2018. doi: 10.1016/j.renene.2017.12.041.
5. Panasonic, HIT Solar Panel Technology, 2015. [Online]. Available: https://www.panasonic.com
6. S. Rehman and M. A. Bader, “Evaluation of solar radiation potential in Saudi Arabia,” Renewable and Sustainable Energy Reviews, vol. 11, no. 7, pp. 1488–1520, 2007. doi: 10.1016/j.rser.2005.11.007.
7. REN21, Renewables 2021 Global Status Report. Paris: REN21 Secretariat, 2021. [Online]. Available: https://www.ren21.net/reports/global-status-report/
8. E. Skoplaki and J. A. Palyvos, “On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations,” Solar Energy, vol. 83, no. 5, pp. 614–624, 2009. doi: 10.1016/j.solener.2008.10.008.
9. T. Sweet, Photovoltaic Systems Laboratory Manual. Cardiff University, 2015.
10. J. Tanesab, D. Parlevliet, S. Al Mahmud, and J. Whale, “The impact of outdoor exposure on PV module degradation under tropical conditions,” Solar Energy Materials and Solar Cells, vol. 155, pp. 301–312, 2016. doi: 10.1016/j.solmat.2016.06.031.
11. G. N. Tiwari and S. Dubey, Fundamentals of Photovoltaic Modules and Their Applications. RSC Publishing, 2010.
12. S. R. Wenham, M. A. Green, M. E. Watt, and R. Corkish, Applied Photovoltaics, 3rd ed. Earthscan, 2011.
13. M. Yamaguchi, T. Takamoto, K. Araki, and M. Kaneiwa, “Multi-junction solar cells: Current status and future potential,” Solar Energy, vol. 79, no. 1, pp. 78–85, 2005. doi: 10.1016/j.solener.2004.11.003.
14. “Effects of dust accumulation and cleaning protocols on PV performance in tropical climates,” Sustainable Energy Research, vol. 9, no. 2, pp. 113–120, 2023. [Online].Available:https://sustainenergyres.springeropen.com/articles/10.1186/s40807-023-00076-x
15. “Examining the influence of thermal effects on PV degradation in hot regions,” Sustainable Energy Research, vol. 10, no. 1, pp. 55–67, 2024. [Online]. Available: https://sustainenergyres.springeropen.com/articles/10.1186/s40807-024-00100-8
16. “Enhanced cooling of solar panels using PCM and forced convection: A field study,” International Journal of Heat and Technology, vol. 42, no. 5, pp. 192–198, 2024. doi: 10.18280/ijht.420524.
17. R. A. Messenger and J. Ventre, Photovoltaic Systems Engineering, 2nd ed. CRC Press, 2004.
18. M. Tahir, M. A. Qureshi, and M. Yousaf, “Comparative analysis of PV technologies under Pakistani climatic conditions,” Journal of Solar Energy Research, vol. 6, no. 3, pp. 201–210, 2022.
19. H. Khan, N. Akhtar, and M. Jamil, “Modeling of monocrystalline solar panels under varying irradiance and temperature,” Energy Reports, vol. 8, pp. 2209–2217, 2022. doi: 10.1016/j.egyr.2022.11.016.
20. A. Adeoye and D. Akinyele, “Assessment of economic viability and technical performance of solar PV in West Africa,” Renewable Energy Focus, vol. 47, pp. 48–59, 2023. doi: 10.1016/j.ref.2023.01.006.