E-ISSN: 1116 – 2716 P-ISSN: 3026-8214
MPRI-JAAE | INTERNATIONAL JOURNAL OF APPLIED & ADVANCED ENGINEERING RES.
VOL. 08 NO. 5 - APRIL, 2025

ENVIRONMENTAL FACTORS AFFECTING SOLAR ELECTRIC OUTPUT

ABUBAKAR B. MUHAMMAD; & MOHAMMED HAMIDU

[1]Department of Civil Engineering Technology, Federal Polytechnic, Bali, Taraba State.
[2]Information Communications Technology Unit, Federal Polytechnic, Bali, Taraba State.

DOI: https://doi.org/10.70382/mejaaer.v8i5.020

Abstract

This study reviews existing literature on the effects of environmental factors on solar electric output at Bali town of Taraba State, Nigeria where residents rely entirely on solar energy, gasoline power generators, and other alternative power sources due to the absence of grid electricity. It analyzes how environmental conditions such as temperature, humidity, dust accumulation, and solar radiation impact photovoltaic (PV) system efficiency. By systematically evaluating past research, the study highlights key challenges which includes efficiency losses due to high temperatures, performance degradation from dust accumulation, and seasonal variations in solar radiation. Findings suggest that regular panel maintenance, optimal system design, and weather-adaptive energy management strategies are essential for improving solar power reliability. Based on the reviewed studies, the research provides [redacted] recommendations to enhance solar energy performance in off-grid communities by contributing to sustainable energy solutions in regions heavily dependent on photovoltaic and

Keywords:
Photovoltaic, Solar Radiation, Humidity, Grid Electricity, Solar Panel

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

alternative power systems.

Introduction

The increasing global demand for reliable and sustainable energy sources has led to widespread adoption of solar photovoltaic (PV) systems, particularly in regions with limited access to grid electricity (Ibegbulam et al., 2023). In many rural and off-grid communities more specifically Bali town of Taraba State, solar energy serves as a primary source of electricity which is supplemented by gasoline generators and other alternative power solutions (Abdullahi et al., 2022). However, the efficiency and reliability of solar power generation are influenced by various environmental factors including temperature fluctuations, dust accumulation, humidity levels, and solar radiation intensity. Understanding the impact of these factors is crucial for optimizing solar system performance and ensuring a stable energy supply in such regions (Anaba & Olubusoye, 2021).

This study explores existing literature to assess how environmental conditions affect solar electric output, focusing on efficiency losses and potential mitigation strategies. Previous research has shown that high temperatures can reduce PV cell efficiency, while dust accumulation on panels significantly decreases energy production by obstructing sunlight absorption. Seasonal variations in solar radiation also play a critical role in determining the overall energy yield. By analyzing these factors, this research aims to highlight key challenges in solar energy utilization and propose solutions that enhance system performance (Heinemann et al., 2022). The findings will provide valuable insights for policymakers, engineers, and stakeholders seeking to improve energy reliability in off-grid communities like Bali town.

Literature Review

Numerous studies have examined the impact of environmental factors on the efficiency and output of solar photovoltaic (PV) systems, highlighting key influences such as temperature, humidity, dust accumulation, and solar irradiance. Researchers have utilized various methodologies, including empirical data collection, statistical modeling, and experimental setups, to assess the correlation between environmental conditions and solar energy performance. The reviewed literature consistently indicates that high temperatures negatively affect solar

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

panel efficiency by reducing open-circuit voltage and overall power output. For instance, Ballina and Go (2025) employed regression and correlation models to quantify the degradation effects of tropical environmental conditions on PV performance, identifying temperature and humidity as primary contributors to efficiency loss. Similarly, Raheem et al. (2025) emphasized the role of overheating in reducing maximum power output, suggesting that water cooling or cooling plates could serve as effective mitigation strategies.

Dust accumulation has also emerged as a significant factor influencing solar energy generation, with multiple studies confirming its adverse effects. Ali et al. (2025) conducted controlled experiments in Karachi, Pakistan, comparing cleaned and uncleaned panels over a one-month period. Their findings revealed a considerable drop in efficiency due to dust buildup, a result corroborated by Mohammadi et al. (2022), who examined dust effects across different climate zones in Iran. These studies highlight the necessity of regular panel cleaning to maintain optimal performance. Furthermore, the role of humidity and air pollution in obstructing solar radiation and degrading PV efficiency has been explored. Sanchez-Balseca et al. (2023) employed a Generalized Linear Model (GLM) to assess the impact of meteorological and pollution factors, revealing that PM2.5 particles significantly reduce power production.

Several studies have also analyzed the role of solar irradiance and shading on PV performance. Li et al. (2024) demonstrated a strong correlation between PV output and solar irradiance, with peak performance occurring at midday. However, their research also showed that relative humidity follows a "U" type fluctuation pattern, negatively affecting power generation at high levels. Additionally, Pratama et al. (2023) investigated the effects of different shading patterns on half-cut solar panels, finding that shading coverage beyond 30% can drastically reduce voltage and current output. The impact of wind speed has been less conclusive, with some studies, such as those by Siregar and Harahap (2024), indicating a minor positive effect on efficiency, while others found wind speed to be a negligible factor.

Despite valuable insights, many studies exhibit limitations, such as short observation periods, geographical constraints, and a narrow focus on individual environmental factors. For instance, Ali et al. (2025) and Li et al. (2024) conducted their research in specific locations, limiting the generalizability of their findings to

different climates. Moreover, several experimental studies, including those by Akter et al. (2023), have focused primarily on temperature effects, overlooking the combined impact of multiple environmental variables. Some research, such as that by Shadid et al. (2023), has highlighted the need for long-term monitoring to capture seasonal variations and the cumulative effects of environmental factors on PV performance.

Research Findings

This study identifies key environmental factors that significantly impact the efficiency and performance of photovoltaic (PV) systems. The review highlights temperature fluctuations, dust accumulation, solar irradiance variations, humidity, and wind speed as critical determinants of solar energy output. Understanding these factors is essential for developing effective mitigation strategies to optimize PV performance and ensure reliable energy generation.

Temperature and Its Impact on PV Efficiency

High temperatures have been widely recognized as a major factor reducing the efficiency of photovoltaic (PV) systems. Studies indicate that increased temperatures lead to a decline in open-circuit voltage (VOC), fill factor (FF), and overall power output, primarily due to increased resistive losses within the solar cells (Ballina & Go, 2025; Raheem et al., 2025). Several mitigation strategies have been explored, including the use of water cooling, air cooling, and optical filters to regulate panel temperature and minimize thermal degradation (Siregar & Harahap, 2024). While these techniques have shown potential, challenges such as operational costs and energy trade-offs remain critical considerations for large-scale solar applications.

Effects of Dust Accumulation on Solar Panels

Dust accumulation on PV panels significantly reduces their efficiency by obstructing sunlight absorption, causing power losses between 10% and 30%, depending on the dust type and density (Ali et al., 2025). Research has shown that finer dust particles, such as ash, have a more detrimental effect on power output compared to sand and soil (Ahmad et al., 2023). Additionally, studies conducted in different climates indicate that humid environments exacerbate dust

accumulation, leading to even greater efficiency reductions (Mohammadi et al., 2022). Regular cleaning has been suggested as a primary mitigation strategy; however, its economic feasibility and practicality in large-scale solar farms pose significant challenges.

Impact of Solar Irradiance and Shading on Power Output

Solar irradiance has been identified as a primary determinant of PV output, with studies confirming that power generation follows daily variations, peaking at midday (Li et al., 2024). However, partial shading caused by environmental obstructions, dust, or cloud cover can lead to severe power losses. Research indicates that shading effects can reduce output by over 60% in some cases, with different shadow patterns influencing efficiency differently (Pratama et al., 2023). To counteract these losses, researchers have proposed optimizing panel orientation and implementing Maximum Power Point Tracking (MPPT) techniques, though the effectiveness of these strategies depends on site-specific environmental conditions.

Influence of Humidity and Wind Speed on Solar Panel Performance

Humidity and wind speed play a complex role in PV performance, with varying impacts depending on environmental conditions. High humidity has been shown to obstruct solar radiation by increasing atmospheric scattering and moisture deposition on panels, leading to efficiency losses (Ali et al., 2025). Conversely, wind speed can have both positive and negative effects, as moderate winds aid in panel cooling, while excessive turbulence may reduce stability and efficiency (Siregar & Harahap, 2024). Studies using artificial neural network (ANN) models to predict PV output based on humidity and wind speed have emphasized the importance of integrating these variables into solar energy forecasting systems for better efficiency optimization (Kristina et al., 2023).

Effect of Air Pollution and Particulate Matter on Solar Energy Output

Air pollution, particularly in urban and industrial regions, has been found to have a substantial impact on solar panel performance. Research has demonstrated that particulate matter such as PM2.5 and PM10 reduces solar radiation penetration, leading to a decline in PV efficiency over time (Sánchez-Balseca et al., 2023).

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

Studies indicate that pollution-related deposition on solar panels can cause uneven shading and heat retention, accelerating degradation. In some cases, polluted environments have resulted in efficiency reductions comparable to those caused by dust accumulation, highlighting the need for periodic cleaning and improved panel coatings to counteract pollution effects.

Influence of Panel Tilt Angle and Orientation on Solar Efficiency

The positioning of solar panels, particularly their tilt angle and orientation, plays a significant role in maximizing energy absorption. Studies have shown that the optimal tilt angle varies by geographic location and seasonal changes in solar declination (Hasan et al., 2023). In tropical regions, a tilt angle between 25° and 30° has been found to yield the highest efficiency, whereas higher latitudes may require steeper angles. Research on different orientations has indicated that south-facing panels in the Northern Hemisphere and north-facing panels in the Southern Hemisphere provide the most consistent power output. However, improper installation and suboptimal angles have been identified as common issues that lead to energy losses, emphasizing the need for adaptive panel positioning systems.

Conclusion

This review highlights the significant impact of environmental factors on photovoltaic (PV) system efficiency, with temperature, dust accumulation, solar irradiance, humidity, wind speed, and air pollution contributing to energy losses. High temperatures reduce PV efficiency by decreasing open-circuit voltage, while dust and shading obstruct sunlight absorption, leading to performance degradation. Humidity and air pollution further reduce solar radiation penetration, negatively affecting power output. While mitigation strategies such as cooling systems, panel cleaning, and optimal orientation can improve efficiency, their economic and logistical feasibility remains a challenge. Additionally, research gaps exist in understanding the combined effects of multiple environmental factors and the long-term durability of solar panels under extreme conditions. Future studies should focus on real-time monitoring, advanced modeling, and adaptive energy management to enhance solar energy reliability and sustainability.

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

Recommendations

To enhance the efficiency and reliability of photovoltaic (PV) systems in varying environmental conditions, strategic interventions are necessary. The findings from this review highlight key challenges such as temperature-induced efficiency losses, dust accumulation, shading, and the impact of humidity and pollution on solar energy output. Addressing these issues requires a combination of technological advancements, optimized system design, and proactive maintenance strategies. Based on the reviewed literature, the following recommendations are proposed to improve solar energy generation in diverse environmental conditions.

Implement Efficient Cooling Techniques to Mitigate Temperature Effects

Since high temperatures reduce photovoltaic (PV) efficiency, adopting effective cooling techniques such as water cooling, air cooling, and optical filters can help maintain optimal panel performance. Future research should explore cost-effective and energy-efficient cooling methods to minimize the trade-offs between cooling benefits and additional energy consumption.

Develop Cost-Effective Strategies for Dust and Pollution Management

Dust accumulation and air pollution significantly reduce solar energy output by obstructing sunlight absorption. Regular cleaning and self-cleaning coatings can improve efficiency, but their economic feasibility for large-scale installations remains a challenge. Research should focus on developing automated or low-maintenance cleaning solutions to ensure long-term solar panel performance in dusty and polluted environments.

Optimize Panel Orientation and Shading Mitigation Strategies

Since solar irradiance and shading have a major impact on PV output, optimizing panel tilt angles and implementing adaptive tracking systems can maximize energy generation. Future studies should explore region-specific panel orientation strategies and shading-resistant solar cell technologies to enhance efficiency in varying environmental conditions.

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

Integrate Real-Time Monitoring and Predictive Maintenance Systems

Advanced monitoring systems using IoT-based sensors and artificial intelligence can help detect efficiency losses due to environmental factors such as dust, temperature fluctuations, and humidity. Implementing predictive maintenance strategies will enable proactive responses to environmental challenges, improving the reliability and sustainability of solar power generation, particularly in off-grid communities.

References

Abdullahi, D., Renukappa, S., Suresh, S., & Oloke, D. (2022). Barriers for implementing solar energy initiatives in Nigeria: An empirical study. *Smart and Sustainable Built Environment*, *11*(3), 647–660.

Anaba, S. A., & Olubusoye, O. E. (2021). Determinants of use of solar energy as an alternative means of energy by small and medium enterprises in Lagos State, Nigeria. *Discover Sustainability*, *2*(1), 29. https://doi.org/10.1007/s43621-021-00038-7

Ahmad, N., Sattar, M., & Ghafoor, U. (2023). Effect of various dusts and humidity on the performance of renewable energy modules. *Energies*.

Ali, F., Akhtar, M., & Ali, H. (2025). An experimental investigation into the impact of environmental factors on solar panel efficiency. *Case Studies in the Environment*.

Ballina, J., & Go, Y. I. (2025). Quantification and comparative analysis of environmental factors to large-scale solar plant's energy performance via regression and linear correlation models. *Journal of Energy and Power Technology*.

Balăceanu, M., Popa, N.-S., & Nae, V. (2024). The influence of environmental factors on a photovoltaic panel–PVsyst simulation. *Electrotehnică, Electronică, Automatică*.

Hasan, D. S., Farhan, M. S., & ALRikabi, H. T. S. (2023). The effect of irradiance, tilt angle, and partial shading on PV performance. *Nucleation and Atmospheric Aerosols*.

Heinemann, G., Banzer, F., Dumitrescu, R., Hirschhausen, C. V., Neuhoff, M. E., & Nwadiaru, V. O. (2022). Transforming electricity access by replacing back-up generators with solar systems: Recent trends and evidence from Nigeria. *Renewable and Sustainable Energy Reviews*, *157*, 111751.

Ibegbulam, M. C., Adeyemi, O. O., & Fogbonjaiye, O. C. (2023). Adoption of Solar PV in developing countries: Challenges and opportunity. *International Journal of Physical Sciences Research*, *7*(1), 36–57.

Kristina, D., Silalahi, A. C., et al. (2023). Forecasting photovoltaic output power based on environmental parameters using artificial neural network methods. *Jurnal RESTI (Rekayasa Sistem dan Teknologi Informasi)*.

Li, F., Zhao, P., & Wang, X. (2024). Analysis of environmental factors on photovoltaic output under different weather conditions.

Mohammadi, F., Hajinezhad, A., & Kasaeian, A. (2022). Effect of dust accumulation on performance of the photovoltaic panels in different climate zones. *International Journal of Sustainable Energy and Environmental Research*.

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]

Pratama, B. A., Hiendro, A., & Marpaung, J. (2023). Effect of shading on half-cut solar panels power output.

Raheem, P., Hasan, F. H., & Algburi, S. (2025). Investigating the impact of internal and external factors on solar cell performance to enhance energy conversion efficiency. *NTU Journal of Renewable Energy*.

Sánchez-Balseca, J., Piñeiros, J. L., & Pérez-Foguet, A. (2023). Influence of environmental factors on the power produced by photovoltaic panels artificially weathered. *Renewable & Sustainable Energy Reviews*.

Siregar, A. H., & Harahap, P. (2024). Analysis of the influence of temperature and wind on the power and efficiency of 100 Wp solar panels. *Jurnal Teknik Elektro dan Komputer*.

EDITOR-IN-CHIEF
Prof. Saeid Eslamian [IRAN]