

Role of Solar Energy in Nigeria's Energy Transition: Pathways and Strategies for Accelerated Decarbonization

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The authors declare that no funding was received for this work.



Received: 02-January-2025

Accepted: 10-February-2026

Published: 19-February-2026

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This article is published in the **MSI Journal of Multidisciplinary Research (MSIJMR)** ISSN 3049-0669 (Online)

The journal is managed and published by MSI Publishers.

Volume: 3, Issue: 2 (February-2026)

ABSTRACT: The global push for decarbonization has positioned solar energy as a cornerstone of sustainable energy transitions, particularly in developing economies with abundant solar resources. Nigeria, despite experiencing average daily solar irradiation of 3.5–7.0 kWh/m², continues to derive less than 5% of its electricity from solar power, relying predominantly on fossil fuels. This study examines the role of solar energy in Nigeria's decarbonization pathway by assessing its technical viability, socio-economic potential, and policy barriers. Using a mixed-methods approach, data were gathered from 150 staff of the Energy Commission of Nigeria through structured questionnaires, interviews, and focus group discussions, supplemented with secondary reports. Descriptive and inferential statistics, supported by thematic analysis, were employed for interpretation. Results reveal that while solar technologies are widely perceived as technically feasible for large-scale deployment, weak fiscal incentives, grid integration challenges, and regulatory inconsistencies significantly constrain adoption. Hypothesis testing confirmed a significant relationship between solar adoption and carbon emission reduction ($F = 2.414$; $p < 0.05$), underscoring its potential to drive national decarbonization. The study concludes that scaling solar deployment offers Nigeria a dual advantage of

mitigating energy poverty and reducing greenhouse gas emissions, thereby advancing Sustainable Development Goals 7 and 13. It recommends the establishment of coherent policy frameworks, investment in grid modernization and storage technologies, and targeted incentives to attract private investment.

Keywords: *Solar energy, Energy transition, Decarbonization, Renewable energy, Policy Frameworks, Grid Integration, Sustainable Development Goals and Carbon Emissions.*

Introduction

The global pursuit of decarbonization has placed renewable energy at the center of sustainable development strategies, with solar energy emerging as one of the most promising solutions (Korczak et al 2022; Saleh & Hassan, 2024; Suleiman et al., 2025). Solar power, derived from abundant and inexhaustible radiation, has witnessed unprecedented global expansion. Installed solar photovoltaic (PV) capacity grew from just 40 GW in 2010 to over 843 GW in 2021, emphasizing its technical maturity and cost competitiveness (Abdalla, 2024). For developing countries like Nigeria, solar energy presents a unique opportunity to simultaneously tackle energy poverty, diversify the energy mix, and reduce greenhouse gas emissions in line with the Paris Agreement (Mutezo & Mulopo, 2021; Al-Amin et al., 2025).

Nigeria's renewable energy potential is vast, with solar irradiation levels ranging from 3.5 kWh/m²/day in the southern regions to over 7 kWh/m²/day in the northern states (ECN, 2021).

This makes solar one of the most geographically widespread and technically feasible renewable options for the country. However, despite this enormous potential, solar energy currently contributes less than 5% to Nigeria's electricity generation mix, with total installed capacity of just 118 MW as of 2022 (NERC, 2022). This lag in adoption is attributed to systemic barriers, including inadequate infrastructure, weak regulatory enforcement, financing challenges, and the dominance of fossil fuels in national energy policy (Adewuyi, 2022; Sadiq et al., 2025).

The integration of solar energy into Nigeria's energy mix is not merely an environmental necessity but also a socioeconomic imperative. Expanding solar

deployment could create thousands of new jobs, expand electricity access to rural communities, and reduce air pollution-related health risks, which claim over 114,000 lives annually (WHO, 2020; IRENA, 2022).

Moreover, decentralized solar solutions such as mini-grids and standalone systems offer a cost-effective pathway to universal energy access, especially in rural areas where grid extension is economically unviable (World Bank, 2022). Against this backdrop, the present study examines the role of solar energy in decarbonizing Nigeria's energy sector. It explores the extent of solar's contribution to reducing carbon emissions and identifies strategies that can accelerate its adoption. By analyzing both the technical opportunities and the systemic barriers, this research seeks to highlight how solar energy can serve as a cornerstone in Nigeria's broader transition to a sustainable and resilient low-carbon economy.

Statement of the Problem

Despite Nigeria's vast solar potential, the contribution of solar energy to the national electricity supply remains marginal, accounting for less than 5% of total generation capacity (NERC, 2022). This underutilization contrasts sharply with the country's abundant solar irradiation levels, ranging from 3.5 kWh/m²/day in the south to over 7 kWh/m²/day in the north (ECN, 2021). While solar technologies are globally recognized as key instruments for decarbonization and universal energy access, Nigeria continues to rely heavily on fossil fuels, with petroleum subsidies alone amounting to \$4.5 billion annually resources that could otherwise accelerate solar deployment (IMF, 2022).

Existing studies have acknowledged Nigeria's solar potential (Ohunakin et al., 2019; Adewuyi, 2020), but gaps persist in understanding how to design and implement optimal system configurations for grid-scale integration. Research has also overlooked the financing mechanisms, investor incentives, and policy enforcement strategies required to scale solar adoption. As a result, Nigeria's energy sector struggles to align with SDG 7's targets of universal access, renewable energy expansion, and energy efficiency improvement (United Nations, 2015).

Furthermore, there is limited empirical work analyzing how solar energy can address the dual challenges of energy poverty and carbon emissions simultaneously. The absence of localized, evidence-based strategies that reflect Nigeria's socioeconomic and political realities hampers progress toward both SDG 7 and SDG 13 (Climate Action). This knowledge gap constrains the ability of policymakers, investors, and communities to adopt solar energy as a transformative pathway for decarbonization. This study addresses these gaps by examining the specific role of solar energy in Nigeria's transition to a low-carbon energy system. It seeks to provide actionable insights into how solar can be strategically deployed to achieve affordable, reliable, and sustainable energy while contributing to broader environmental and developmental goals.

Conceptual Review

Decarbonization

Decarbonization is a strategic and systemic process that involves the significant reduction or complete elimination of carbon dioxide (CO₂) and other greenhouse gas emissions (GHGs) from various sectors of the economy, especially the energy sector. It is a crucial component of global efforts to mitigate the adverse impacts of climate change and achieve a sustainable, low-carbon future (Ibrahim et al., 2025; Abiola et al., 2025). Decarbonization primarily targets fossil fuel-intensive sectors, including power generation, transportation, manufacturing, and buildings, to replace them with cleaner, renewable, and energy-efficient alternatives (International Energy Agency [IEA], 2021).

As noted by Sachs (2016), decarbonization is not merely a technological shift but a transformation of energy systems, societal behaviour, institutional governance, and economic structures. The process involves both supply-side measures, such as adopting renewable energy sources and enhancing grid infrastructure, and demand-side interventions, including energy efficiency improvements, behavioural changes, and promoting low-carbon consumption patterns (Olusola et al., 2025; Yakubu et al., 2025). The energy sector is the largest contributor to global greenhouse gas emissions, accounting for approximately 73% of all emissions, with electricity and

heat production alone responsible for about 42% (IEA, 2020). Therefore, decarbonising the energy sector is fundamental to any climate action strategy. It involves transitioning from fossil fuel-based electricity generation to clean energy sources, modernising power grids, deploying storage technologies, phasing out coal plants, and implementing carbon pricing mechanisms.

The Role of Solar Energy in Decarbonising Nigeria's Energy Sector

Solar energy refers to the radiant light and heat from the sun that is harnessed using various technologies for electricity generation, thermal heating, and other energy needs. It is the most abundant and readily available renewable energy resource on Earth. According to the International Energy Agency (IEA, 2021), solar energy has the potential to become the dominant source of global electricity generation by mid-century, driven by its vast potential and declining technology costs. Solar power can be captured through two primary technologies: photovoltaic (PV) systems, which directly convert sunlight into electricity, and solar thermal systems, which utilise mirrors or lenses to concentrate sunlight and produce heat that can then be used to generate power.

The sun emits more energy in one hour than humanity consumes in an entire year (International Renewable Energy Agency [IRENA], 2020). This incredible energy source can be utilised in multiple ways, including solar home systems, solar-powered water pumps, solar streetlights, industrial-scale solar farms, and hybrid mini-grid systems (Abubakar et al., 2025). Technological innovations have significantly increased the efficiency and cost-effectiveness of solar installations, making them viable even in remote and off-grid communities. The versatility, sustainability, and environmental benefits of solar energy make it a crucial component in the global transition to low-carbon energy systems.

Unlike fossil fuels, solar energy systems do not produce greenhouse gas emissions during operation. This characteristic is particularly crucial in the context of climate change mitigation, as the energy sector is the most significant contributor to global greenhouse gas emissions (United Nations Environment Programme [UNEP], 2019). As such, the adoption of solar energy is widely recognised as a key strategy in

reducing dependency on carbon-intensive fuels and promoting sustainable development.

Theoretical framework

Energy Transition Theory is a conceptual framework that explores the shift from one dominant energy system to another, often driven by technological advancements, socio-economic pressures, environmental concerns, and policy changes. It was influenced by the work of scholars such as Arie Rip and René Kemp, as well as other researchers involved in socio-technical systems thinking. This theory gained widespread recognition during the global push for cleaner energy following the oil crises of the 1970s and intensified due to increasing awareness of climate change in the 21st century. The theory encompasses not only replacing fossil fuels with renewable sources but also a profound transformation in the production, distribution, and consumption of energy across all sectors (Sovacool, 2016).

At its core, Energy Transition Theory outlines a staged process through which energy systems evolve. These stages typically include pre-development, where alternative energy options are explored; take-off, where interest in new technologies grows and initial policy frameworks are developed; acceleration, marked by large-scale implementation, falling costs, and public acceptance; and finally, stabilization, when renewable energy becomes dominant and the system enters a new regime (Rotmans et al., 2001; Cherp et al., 2018). Unlike traditional linear development theories, Energy Transition Theory acknowledges the non-linear, multi-actor, and dynamic nature of energy transitions, emphasising the roles of institutions, culture, technology, and governance in shaping outcomes.

Nigeria currently resides in the pre-development to take-off stages, characterised by fragmented but growing policy attention, pilot renewable energy projects, and the foundational work of national frameworks such as the Energy Transition Plan (ETP). However, challenges such as dependence on oil revenues, weak regulatory enforcement, and inadequate energy infrastructure hinder this progression. Energy Transition Theory emphasises the role of governance, financial incentives, and infrastructure planning in overcoming such barriers (IRENA, 2022). Applying this

theory helps identify policy gaps, investment opportunities, and strategies for aligning Nigeria's energy transition with global low-carbon pathways.

Empirical Reviews

Johnson, Hamisu, Umar, and Mwapwa (2025) examined Nigeria's energy mix in the context of achieving net-zero carbon emissions by 2060. Using a threshold analysis methodology, they found that Nigeria's energy mix has a critical threshold of 1.3397 percent, below which increased renewable energy adoption could counterintuitively lead to higher carbon emissions. This indicates that renewable energy must reach a certain scale before it yields emission-reducing benefits. The study also emphasized the high cost of renewable adoption, recommending the use of natural gas and LNG as transition fuels. Furthermore, the authors highlighted the need for joint efforts between fiscal and monetary authorities to lower Nigeria's carbon footprint.

In a related study, Akangbe and Sharifi (2025) focused on micro-level determinants of renewable energy adoption, particularly solar photovoltaic (PV) systems among Small and Medium-sized Enterprises (SMEs). Drawing on data from 412 SMEs through a randomized conjoint experiment and randomized control trial, they revealed that power supply reliability and setup cost are the most influential factors for adoption. Sectoral differences were observed, with manufacturing SMEs demonstrating stronger preferences for reliability and cost savings than service-oriented firms. The study further showed that SMEs were willing to commit up to 38 percent of their annual revenues to secure reliable renewable energy. Importantly, information treatments increased adoption likelihood by 2 percent and willingness to pay by 3.28 percent, underscoring the role of awareness and flexible financing in stimulating solar PV uptake.

On a broader sectoral level, Dioha and Kumar (2020) explored sustainable energy transition pathways for Nigeria's residential sector using a newly developed energy system model. Their results projected significant shifts in energy consumption by 2050, with rural household demand decreasing and urban household demand increasing. Cooking was identified as the most energy-intensive end-use, and a

transition from fuelwood to liquefied petroleum gas (LPG) was projected to reduce indoor air pollution but increase CO₂ emissions. However, incorporating externality costs into energy pricing made electricity and biogas more economically viable cooking alternatives. The authors concluded that robust and targeted policies are essential for achieving Sustainable Development Goal 7 and for ensuring sustainable energy transitions in the residential sector. Ajia (2025) conducted a systematic scoping review to examine the policy challenges and opportunities for advancing Nigeria's renewable energy system. Drawing on secondary data from peer-reviewed articles, books, and reputable online sources spanning the years 2000 to 2025, the study employed content and thematic analysis to identify key issues affecting the development of renewable energy. The findings revealed that, although Nigeria possesses abundant renewable energy resources, such as solar, wind, and hydro, existing policy frameworks, including the Renewable Energy Master Plan (REMP) and the National Renewable Energy and Energy Efficiency Policy (NREEEP), have failed to deliver the expected outcomes due to regulatory inconsistencies and institutional inefficiencies. The study recommended that Nigeria establish a coherent regulatory framework, enhance policy implementation mechanisms, and strengthen institutional coordination. Ajia concluded that Nigeria must reform its energy governance architecture to effectively harness its renewable energy resources and achieve long-term energy resilience.

The literature shows progress in understanding Nigeria's renewable transition, but key gaps remain in scaling solar adoption, sectoral applications, household integration, effective policy frameworks, long-term socio-economic impacts, financing strategies, and systemic integration with other energy sources. Addressing these gaps is essential for formulating pathways and strategies for accelerated solar-driven decarbonization in Nigeria.

Methodology

This study employs both qualitative and quantitative approaches to examine Nigeria's transition to renewable energy for decarbonization comprehensively. The rationale for this design stems from the need to capture both numerical trends and contextual

insights across technical, policy, and socio-economic dimensions of energy transition (Creswell & Creswell, 2018).

The study focuses particularly on three key geographical zones based on their renewable energy characteristics. Northern Nigeria, comprising states such as Kano, Kaduna, and Sokoto, serves as the focal point for solar energy analysis due to its high solar irradiation levels, averaging 5.5-7.0 kWh/m²/day (ECN, 2022).

A Krejcie & Morgan (1970) table (Appendix C) is used to determine the sample size from the population (N=285 staff in the first six departments). For a 95% confidence level and 5% margin of error, the required sample is 150 respondents, distributed proportionally across departments. To comprehensively address the research objectives, data will be collected through a mixed-methods approach that incorporates both quantitative and qualitative tools, ensuring robust and reliable findings. Primary data collection focuses on gathering firsthand information from the staff of the Energy Commission of Nigeria (ECN) through structured questionnaires, semi-structured interviews, and focus group discussions. Secondary data is obtained from official ECN documents, national energy reports, and international publications to provide contextual background and support primary findings (Creswell & Creswell, 2018).

This section outlines the statistical and analytical techniques to be used in examining both quantitative and qualitative data gathered during the study. For data obtained from the structured questionnaires, descriptive and inferential statistical techniques are applied. The responses are first cleaned and coded using IBM SPSS Statistics (Version 27) to ensure data integrity. Descriptive statistics, including frequencies, percentages, means, and standard deviations, are computed to summarise staff perceptions on renewable energy adoption, policy effectiveness, and institutional barriers (Pallant, 2020).

Data and analysis

This section presents the data collected and analysed using descriptive statistics. The data analysed was collected using the research instrument.

Results

One of the pivotal components of Nigeria’s energy transition strategy is the adoption of solar energy technologies as a viable means to reduce dependence on fossil fuels and achieve national decarbonization goals. Table 4.4 provides insight into the adoption of large-scale solar energy.

Table 1: Solar Energy Adoption in Nigeria

Item	STATEMENT	SD	D	N	A	SA	TOTAL
1.	Solar energy technologies are technically viable for large-scale deployment in Nigeria.	29 (19.73%)	15(10.20%)	-	44(29.3%)	63(42.86%)	147(100%)
2.	Current fiscal incentives (e.g., tax waivers) are sufficient to attract private solar investments.	51(47.68%)	49(60%)	-	32(6.46%)	15(10.30%)	147(100%)
3.	Grid integration challenges significantly hinder the adoption of solar energy in Nigeria.	19(12.92%)	21(14.29%)	-	55(37.41%)	52(35.37%)	147(100%)

Source: Field survey, 2025.

As revealed in Item 1, a combined total of 107 respondents (72.16%) agreed or strongly agreed that solar energy technologies are technically viable for large-scale deployment in Nigeria. This positive opinion, led by 63 respondents who strongly agreed (42.86%) and 44 who agreed (29.3%), reflects an acknowledgement of the maturity and feasibility of solar technologies under Nigeria’s climatic and geographical conditions. Additionally, 29 (19.73%) strongly disagreed, and 15

(10.20%) disagreed. This suggests that there is a strong potential for solar energy as a major contributor to Nigeria's renewable energy and decarbonization.

In Item 2, the opinions regarding the sufficiency of fiscal incentives for private sector investment in solar energy were less favourable. A significant proportion of respondents (51, 47.68%) strongly disagreed, while 49 (60%) disagreed that existing fiscal incentives are adequate. In contrast, only 32(21.77%) agreed and 15(10.30%) strongly agreed. This reveals a critical gap in policy implementation, where technical readiness is not being matched with the necessary financial and regulatory support to attract significant private sector participation.

In item 3, regarding the issue of grid integration, a large segment of respondents (107, 72.78%) agreed and strongly agreed that grid challenges hinder the broader adoption of solar energy. This finding highlights the infrastructural bottlenecks in Nigeria's electricity transmission and distribution systems, which are primarily designed for centralised fossil fuel generation. The decentralisation and intermittency of solar power necessitate grid modernisation, smart metering, and robust energy storage solutions—areas in which Nigeria currently lags. The recognition of grid integration as a significant barrier underscores the need for technical reforms, alongside policy and financial innovations, in the renewable energy sector.

Analysis of Focus Group Interviews

To complement the quantitative survey, focus group interviews were conducted with key stakeholders, including senior officials from the Energy Commission of Nigeria (ECN), renewable energy experts, and departmental heads. The interviews explored diverse perspectives on technical, policy, and institutional challenges affecting Nigeria's transition to renewable energy. The analysis is structured around six thematic domains: solar energy, wind energy, transport electrification, green hydrogen, policy effectiveness, and stakeholder coordination.

Solar Energy Development

Stakeholders consistently identified three key technical barriers to large-scale solar deployment: intermittency and lack of storage infrastructure, poor grid infrastructure, and limited access to high-efficiency solar components. A senior ECN director noted:

“Our solar projects often suffer from inadequate energy storage systems and weak transmission networks. Until these are addressed, scalability will remain a challenge.”

Regarding fiscal policies, most respondents acknowledged the limited impact of current import waivers and tax incentives in attracting private capital. According to a renewable energy policy expert:

“While waivers exist on paper, the bureaucracy in accessing them deters investors. Moreover, there is no long-term policy consistency.”

This reveals a disconnect between policy design and implementation, undermining investor confidence in solar infrastructure development.

Test of Hypothesis

H₀₁: There is no significant relationship between solar energy adoption and the reduction of carbon emissions in Nigeria’s energy sector.

The hypothesis was tested using Analysis of Variance (ANOVA), which was selected because the data satisfied all necessary assumptions for this test. The results of the ANOVA are presented in Table 2.

Table 4.2 Analysis of Variance for Solar Energy Adoption

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F-Value	P-Value
Between Groups	8.581	5	1.716	2.414	.037
Within Groups	650.90	915	0.719		
Total	695.481	920			

(F-critical = 2.414, P < 0.05)

From Table 2, the calculated F-value is 2.414, and the P-value is 0.037. Since the P-value is less than the significance level of 0.05, the null hypothesis (H₀) is rejected.

This result indicates a significant relationship between solar energy adoption and the reduction of carbon emissions in Nigeria's energy sector. This finding suggests that the adoption and integration of solar energy in Nigeria's energy sector will reduce carbon emissions and enhance the country's renewable energy strategy.

Conclusion

This study examined the role of solar energy in Nigeria's energy transition and its contribution to decarbonization efforts. The results of the hypothesis tests confirmed that solar energy adoption significantly reduces carbon emissions and supports Nigeria's decarbonization goals. Furthermore, effective strategies exist that can accelerate the adoption of solar energy in the country.

The rejection of the hypothesis reinforces the potential of solar power as a viable alternative to fossil fuels in Nigeria's energy sector. By scaling up solar deployment, Nigeria can simultaneously address its chronic energy poverty, reduce reliance on hydrocarbons, and align with Sustainable Development Goal 7 (affordable and clean energy) and Goal 13 (climate action).

Recommendation

Based on the findings, it is recommended that the Nigerian government should enforce consistent and transparent renewable energy policies, particularly those that encourage large-scale solar deployment and provide long-term security for investors.

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