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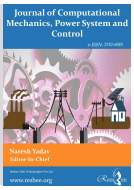

The Significance of Renewable Energy Integration into Nigeria's Power Stations: An Awareness-Based Perspective

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Abstract: Nigeria's power sector faces persistent challenges, including low generation capacity, high transmission losses, and over-reliance on fossil fuels, despite abundant renewable resources such as solar, wind, hydro, and biomass. The integration of these renewable resources into existing power stations can diversify the national energy mix while reducing dependence on conventional thermal generation. Integrating renewable energy sources into existing power stations presents a sustainable pathway to improving energy security, reducing environmental degradation, and supporting socio-economic development. Such integration can also improve the resilience of electricity supply by enabling power systems to utilize locally available and complementary energy resources. This study examines the importance of Renewable Energy Sources (RES) integration into power stations, identifies key methods of integration, and analyses the challenges associated with poor integration within electricity power systems. Furthermore, particular emphasis is placed on Nigeria's power sector. Using secondary data from sources like the Nigerian Electricity Regulatory Commission (NERC), the World Bank, and market analyses, we analysed current penetration levels, and findings revealed that renewables accounted for approximately 23% of generation in 2025, primarily hydropower, with solar and wind showing rapid growth projections. However, the effective utilization of these resources remains constrained by inadequate grid infrastructure, intermittency, limited energy-storage capacity, financing constraints, regulatory uncertainty, and insufficient technical expertise. This study also highlights the role of public awareness, policy support, and technical capacity building in achieving effective renewable energy integration. Strengthening regulatory frameworks, encouraging private-sector investment, upgrading grid infrastructure, and developing skilled human resources are therefore essential for accelerating RES deployment. The paper concludes by proposing strategic recommendations tailored to Nigeria's infrastructural, economic, and institutional realities to enhance sustainable power generation and grid stability.

Keywords: Renewable Energy Integration, Power Grid Stability, Hybrid Power Systems, Energy Storage Systems, Renewable Energy Sources (RES).

1. Introduction

Nigeria's electricity sector remains characterized by persistent supply deficits despite an installed generation capacity of approximately 13,000 MW. Actual average generation, however, remains below 5,000 MW as of 2026, resulting in frequent grid failures and significant economic losses estimated at USD 29 billion annually [1]. The national grid, operated by the Transmission Company of Nigeria (TCN), is further constrained by aging infrastructure, with transmission losses exceeding 10% and over 200 recorded system collapses since 2013 [2] [3]. These conditions demonstrate that increasing electricity-generation capacity alone is insufficient to address Nigeria's energy challenges. Improvements in generation diversity, transmission infrastructure, system flexibility, and grid management are also required to ensure reliable and sustainable electricity supply.

Paradoxically, Nigeria is endowed with substantial renewable energy resources, including solar irradiation ranging between 3.5–7.0 kWh/m²/day, wind speeds of up to 7 m/s in northern regions, and hydropower potential exceeding 14,000 MW. The integration of Renewable Energy Sources (RES) into existing power systems has therefore emerged as a strategic pathway for addressing energy deficits while advancing sustainability goals [4][5]. The availability of diverse renewable resources provides Nigeria with an opportunity to reduce its dependence on conventional fossil-fuel-based generation while improving the geographical and technological diversity of electricity production. However, the effective utilization of these resources depends on the ability of the existing power infrastructure to accommodate variable renewable generation.

Beyond improving electricity supply, renewable energy integration contributes to broader socio-economic development, including agricultural productivity, rural electrification, and climate change

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mitigation [6]. Renewable-energy deployment can also support industrial development, reduce exposure to fossil-fuel price fluctuations, and improve electricity access in underserved and remote communities. Consequently, renewable-energy integration should be considered not only as an electricity-generation strategy but also as an important component of Nigeria's broader economic and sustainable-development agenda.

1.1 Significance of Renewable Energy Integration

The integration of RES into Nigeria's power stations represents a multidimensional strategy for enhancing energy system performance and sustainability. Recent studies indicate a growth in renewable capacity from 4.51 GW in 2026 to approximately 14.07 GW by 2031, driven by declining solar photovoltaic costs and supportive policy mechanisms such as Feed-in Tariffs and fiscal incentives [7]. This projected increase demonstrates the growing importance of renewable energy in Nigeria's future electricity mix and indicates a gradual transition toward a more diversified generation structure.

Given the increasing demand for electricity driven by population growth, industrialization, and agricultural modernization, reliance on conventional fossil fuel–based power systems has proven insufficient and environmentally unsustainable. Integrating renewable energy sources such as solar, wind, hydropower, and biomass into the power stations offers numerous technical, economic, environmental, and social benefits. The benefits of integration are particularly relevant to Nigeria because the country must simultaneously increase electricity supply, improve energy security, reduce environmental impacts, and expand electricity access. Fig. 1 shows the electricity production by sources in Nigeria where fossil fuels still takes a major contribution compared to other sources. Fig. 2 illustrates the trend in electricity production by source in Nigeria and shows the continued dominance of conventional energy sources compared with renewable sources.

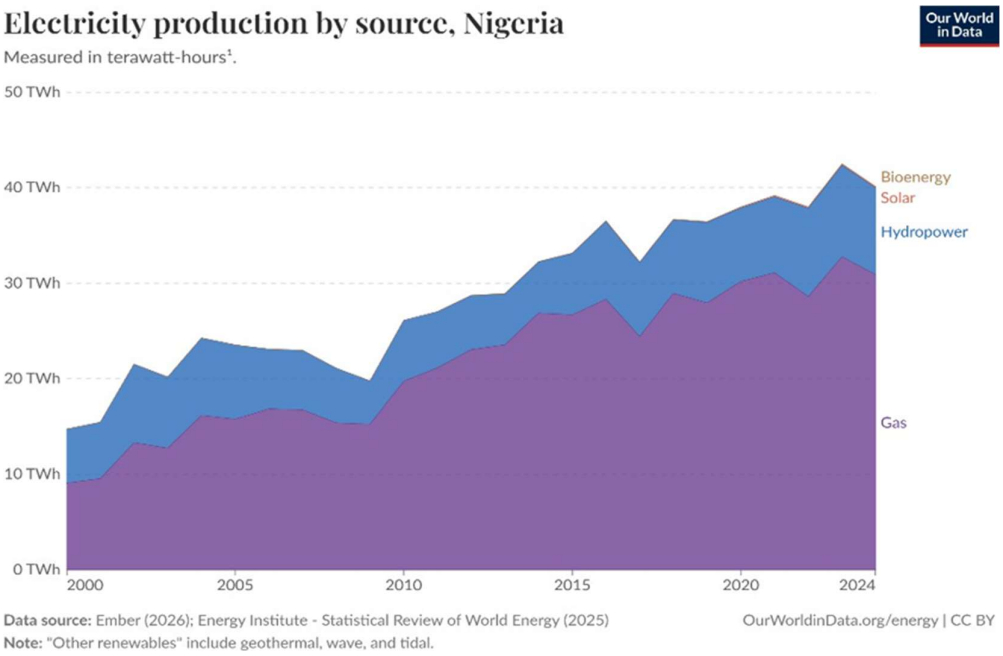

Fig. 1. *Electricity production by source, Nigeria*

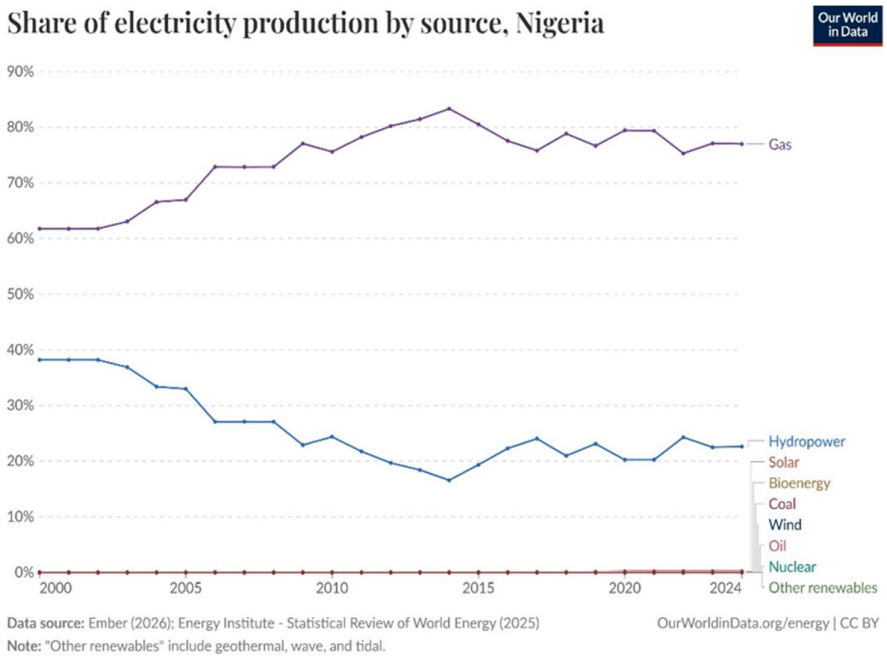

Fig. 2. *Electricity production by source (line graph), Nigeria*

1.1.1 Energy Security and System Reliability

Renewable energy integration enhances energy security by diversifying the generation mix and reducing reliance on fossil fuels, particularly natural gas. Given Nigeria's exposure to gas supply disruptions, pipeline vandalism, and price volatility, locally available renewable resources offer a more resilient alternative. Hybridization of renewable and conventional systems improves supply stability and reduces vulnerability to fuel-related uncertainties. The geographical distribution of renewable resources can further support decentralized electricity generation and reduce excessive dependence on centralized power stations.

1.1.2 Environmental Sustainability and Climate Mitigation

The integration of renewable energy significantly reduces greenhouse gas emissions and environmental degradation associated with conventional thermal power generation. This is particularly critical in the Nigerian context, where climate-related challenges such as flooding, desertification, and erratic rainfall patterns are intensifying. Transitioning toward low-carbon energy systems aligns with both national and global climate objectives [8]. Greater utilization of renewable resources can therefore contribute to reducing the environmental footprint of the electricity sector while supporting Nigeria's transition toward a lower-carbon energy system.

1.1.3 Alignment with Sustainable Development Goals

Renewable energy integration directly supports multiple Sustainable Development Goals (SDGs), notably SDG 7 (Affordable and Clean Energy) [9], SDG 9 (Industry, Innovation, and Infrastructure) [10], SDG 13 (Climate Action) [11], and SDG 2 (Zero Hunger) [12]. Reliable electricity supply enables agricultural mechanization, industrial productivity, and sustainable resource management, thereby reinforcing national development priorities. In addition, improved electricity availability can support essential services such as healthcare, education, water supply, telecommunications, and food processing, particularly in rural and underserved areas.

1.2 Integration Pathways for Renewable Energy Systems

The effective integration of renewable energy into power stations necessitates coordinated technical and infrastructural strategies tailored to Nigeria's energy landscape. Different integration pathways can be adopted depending on the characteristics of the renewable resource, electricity demand, grid strength, geographical location, and availability of supporting infrastructure. In this study, three major pathways are considered: grid-connected renewable systems, hybrid power systems, and energy-storage-integrated systems.

1.2.1 Grid-Connected Renewable Systems

Utility-scale renewable installations, including solar farms, wind farms, and hydropower plants, can be

integrated into the national grid to enhance centralized generation capacity. However, grid integration requires robust transmission infrastructure and advanced grid codes capable of managing variability and intermittency [13]. Effective integration also requires renewable-generation forecasting, appropriate protection systems, voltage and frequency control, and coordinated power-flow management. Fig. 3 shows an illustration of a grid-connected Solar PV system [14].

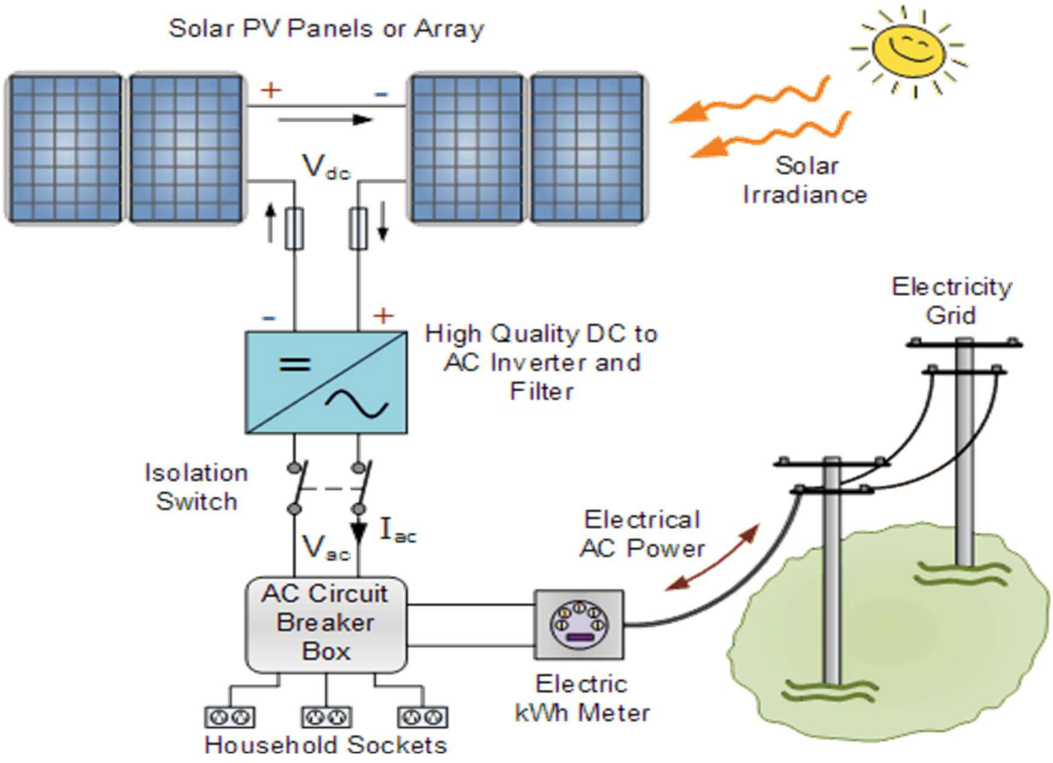

Fig. 3. *Grid-Connected Solar Photovoltaic (PV) System.*

1.2.2 Hybrid Power Systems

Hybrid systems, which combine renewable and conventional generation technologies (e.g., solar–gas, wind–diesel), provide a practical solution for enhancing reliability. These systems enable conventional generators to compensate for renewable intermittency while reducing fuel consumption and emissions. In Nigeria, hybrid configurations are particularly suitable for industrial clusters, agro-processing zones, and off-grid communities.

Hybridizing renewable and conventional generation systems is quite beneficial in power systems. In a situation when renewable energy is available, the system generates most or all of the required power to meet the load demand, thus reducing the load on the conventional generator systems. This reduces the generator runtime, lowers the fuel consumption, and significantly cuts down CO^2 emissions. Similarly, when there is lower supply of renewable energy, the conventional generator kicks in to maintain or cover the load demand. This tends to boost the output of the power supply. The model of a hybrid power system configuration utilizing a solar PV system and a Diesel Engine Generator (DEG) system is illustrated in Fig. 4 [15].

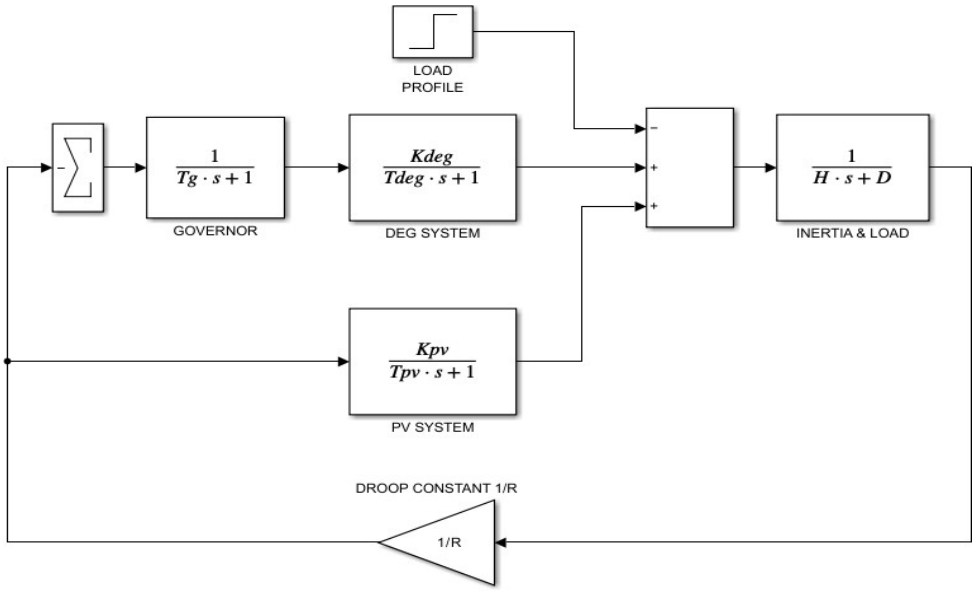

Fig. 4. *Simple model of the hybrid power generation system*

1.2.3 Energy Storage Integration

Energy storage technologies, including Battery Energy Storage Systems (BESS), pumped hydro storage, and thermal storage, play a critical role in stabilizing renewable-integrated power systems. Storage systems enable load balancing, frequency regulation, and improved power quality. In Nigeria, battery storage is especially relevant for solar-based mini-grids and distributed energy systems, enhancing reliability and reducing energy curtailment. Energy storage can also shift excess renewable generation from periods of high resource availability to periods of increased electricity demand, thereby reducing the operational effects of renewable intermittency. Fig. 5 shows an illustration of the integration of an energy storage system with the grid [16].

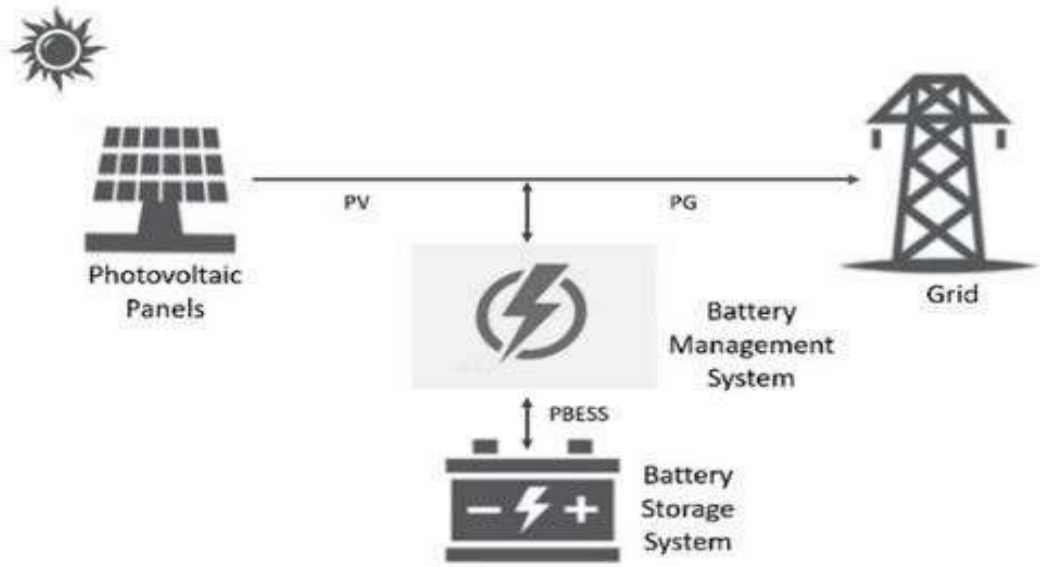

Fig. 5. *Integration of energy storage system with the grid.*

1.3 Problem Statement

Despite Nigeria's substantial renewable-energy potential, the country continues to experience electricity shortages, frequent grid disturbances, inadequate transmission capacity, and high dependence on fossil-fuel-based generation. The gap between available renewable-energy resources and their effective contribution to the national electricity system indicates that resource availability alone does not guarantee successful renewable-energy deployment. Furthermore, the intermittent nature of solar and wind resources, inadequate grid infrastructure, limited energy-storage deployment, shortage of specialized technical skills, financing constraints, and policy and institutional challenges can restrict the effective

integration of renewable energy into existing power stations. Consequently, there is a need for an integrated assessment of renewable-energy capacity, available integration pathways, and the technical, infrastructural, economic, and institutional barriers affecting their implementation in Nigeria.

The remainder of this paper is organized as follows. Section 2 reviews previous studies on renewable-energy development and integration in Nigeria and identifies the major research gaps. Section 3 presents the research methodology, including the secondary-data sources and analytical procedures adopted in the study. Section 4 presents the current status and capacity of renewable-energy systems in Nigeria. Section 5 discusses the results, integration challenges, and implications for Nigeria's electricity sector. Section 6 presents strategic recommendations, while Section 7 concludes the study.

2. Literature Review

Renewable energy integration has received increasing attention as countries seek to improve energy security, reduce greenhouse gas emissions, and address the limitations of conventional electricity-generation systems. In the Nigerian context, previous studies have examined renewable-energy potential, hybrid energy systems, tariff regulation, grid integration, energy storage, and sustainable development. These studies provide an important foundation for understanding the opportunities and limitations associated with increasing renewable-energy penetration in Nigeria. However, the literature remains distributed across different technological, regulatory, and application-specific areas, creating a need for an integrated assessment of renewable-energy integration into Nigeria's power system.

2.1 Renewable Energy Development in Nigeria

Nigeria possesses substantial renewable-energy resources, including solar, wind, hydropower, and biomass, which provide opportunities for diversifying the country's electricity-generation mix. Sambo et al. [6] emphasized the importance of strategic renewable-energy development in Nigeria and identified renewable resources as an important component of the country's long-term energy-development pathway. The availability of these resources is particularly significant given Nigeria's persistent electricity-supply challenges and its continued dependence on conventional generation.

IRENA's assessments of renewable-energy development in Africa have further highlighted the opportunities for renewable-energy expansion across the continent, including the potential for solar, wind, hydropower, and other renewable technologies to contribute to electricity access and sustainable development [4], [5]. These assessments indicate that Africa possesses substantial renewable resources, although infrastructure, financing, institutional capacity, and policy conditions strongly influence the extent to which this potential can be converted into operational generation capacity.

Awodiji [3] examined the integration of renewable energy into Nigerian power systems and highlighted the importance of addressing system-level considerations when increasing renewable penetration. This perspective is particularly relevant to Nigeria because renewable-energy deployment must occur within an electricity network that continues to experience transmission limitations, reliability problems, and generation constraints.

More recent research has also examined hybrid energy systems as a pathway for addressing Nigeria's energy-access and reliability challenges. Adeyeye and Mbohwa [1] assessed trends, deployment, and future pathways for hybrid energy microgrids in Nigeria, demonstrating the growing relevance of hybrid configurations for decentralized and distributed electricity supply. Hybrid microgrids can be particularly valuable in locations where conventional grid extension is difficult or where renewable resources need to be complemented by storage or conventional generation.

2.2 Solar Energy Integration

Solar photovoltaic energy represents one of the most promising renewable-energy options for Nigeria because of the country's substantial solar-resource availability. The modularity of photovoltaic technology enables deployment at household, commercial, institutional, mini-grid, and utility scales, making solar energy suitable for both centralized and decentralized electricity-generation applications.

Haque et al. [14] provided detailed treatment of the design and control of grid-connected photovoltaic systems, emphasizing the importance of appropriate control strategies for integrating PV generation with electrical networks. Grid-connected PV systems require coordinated control of power conversion, voltage, current, synchronization, and power quality to ensure reliable interaction with the electricity grid.

The integration of solar PV into Nigeria's electricity system therefore requires more than the installation of additional PV capacity. Transmission and distribution capacity, power-electronic interfaces, protection systems, forecasting, voltage regulation, and appropriate grid codes are necessary to accommodate increasing levels of variable solar generation.

The potential of solar generation can also be enhanced through integration with battery storage. Atif et al. [16] investigated battery-integrated optimal power smoothing of solar PV output using meta-heuristic optimization, demonstrating the importance of storage and intelligent control in reducing fluctuations in PV output. Such approaches are particularly relevant to Nigeria because solar-based generation can experience significant short-term variability, while battery systems can provide additional flexibility for balancing and smoothing power output.

2.3 Wind Energy Integration

Wind energy represents another renewable resource that can contribute to Nigeria's future electricity mix, particularly in regions with suitable wind conditions. Although wind deployment remains comparatively limited, its development could contribute to generation diversification and reduce dependence on individual renewable or conventional resources.

The integration of wind generation introduces technical requirements associated with variable power output, forecasting, voltage regulation, frequency management, and transmission capacity. These requirements become increasingly important as the penetration of variable renewable-energy resources increases.

Kroposki et al. [18] examined the operation of electric power systems with extremely high levels of variable renewable energy and emphasized the importance of system flexibility, advanced operational practices, forecasting, transmission, storage, and coordinated control. Although the study considers renewable-rich power systems more broadly, its findings are relevant to Nigeria because increasing solar and wind penetration will require improvements in the flexibility and operational capability of the national grid.

2.4 Hydropower Integration

Hydropower remains an important renewable-energy resource in Nigeria and has historically contributed substantially to renewable electricity generation. Unlike solar and wind generation, hydropower can provide relatively controllable generation and can therefore contribute to balancing and system reliability when adequate water resources and operational infrastructure are available.

Osho [17] examined hydropower, climate change, and the green-energy transition in Nigeria, emphasizing the economic and policy dimensions associated with hydropower development. The continued importance of hydropower demonstrates that Nigeria's renewable-energy transition does not require replacement of existing renewable technologies but rather diversification and complementary development across multiple renewable resources.

At the same time, hydropower development can be influenced by changes in rainfall patterns, water availability, environmental considerations, and infrastructure requirements. Therefore, hydropower should be integrated into a broader renewable-energy strategy that also considers solar, wind, biomass, and energy storage.

2.5 Biomass Energy Integration

Biomass represents an additional renewable-energy resource with potential applications in Nigeria because of the country's agricultural activities and availability of organic residues. Agricultural residues, animal waste, and other biomass resources can potentially be converted into useful energy while also contributing to waste-management objectives.

Biomass-based electricity generation has the potential to complement intermittent renewable resources because appropriately designed biomass systems can provide more controllable generation. However, their deployment requires reliable feedstock availability, appropriate conversion technologies, transportation systems, and sustainable resource-management practices.

Compared with solar and hydropower, the literature and current deployment evidence for large-scale biomass electricity generation in Nigeria remain relatively limited. This indicates an area requiring further technical and economic assessment.

2.6 Hybrid Renewable Energy Systems

Hybrid renewable-energy systems combine multiple generation technologies or integrate renewable generation with conventional generation and/or energy storage. Adeyeye and Mbohwa [1] examined hybrid energy microgrids in Nigeria and highlighted their relevance to the country's evolving energy landscape. Hybrid systems can improve reliability by allowing different energy resources to compensate for one another when individual sources are unavailable or insufficient.

Achilihu et al. [15] investigated a load-frequency controller for a hybrid power system using fuzzy logic tuned by the Bees Algorithm. The study demonstrates the importance of advanced control approaches for

maintaining frequency stability in hybrid generation systems. Such control strategies are particularly relevant when renewable and conventional generation sources operate together and must respond dynamically to changing load and generation conditions.

For Nigeria, hybrid configurations such as solar–diesel, solar–gas, solar–battery, and renewable-based mini-grids may provide practical pathways for improving electricity reliability while progressively reducing conventional-fuel consumption. The effectiveness of these systems, however, depends on appropriate sizing, control, energy management, resource availability, and lifecycle economic assessment.

2.7 Energy Storage and Grid Integration

Energy storage is increasingly recognized as an enabling technology for integrating variable renewable-energy resources. Battery Energy Storage Systems (BESS), pumped hydro storage, and other storage technologies can provide frequency regulation, load balancing, power smoothing, peak-load management, and energy shifting.

Atif et al. [16] demonstrated the application of battery storage for smoothing solar PV output, highlighting the role of optimization-based energy management in improving the quality and reliability of renewable generation. Similarly, Gevorgian et al. [13] examined the provision of grid services by PV plants equipped with integrated battery energy storage systems, demonstrating that storage can enable renewable plants to provide services beyond simple energy generation.

These findings are relevant to Nigeria because battery storage could support renewable integration in weak-grid locations, solar mini-grids, industrial facilities, and utility-scale renewable projects. Storage can also reduce renewable-energy curtailment and provide additional flexibility during periods of low renewable generation.

Nevertheless, the adoption of energy storage in Nigeria may be constrained by high initial investment costs, battery replacement requirements, degradation, limited local manufacturing capacity, and shortages of specialized technical expertise. These factors should therefore be considered when assessing the economic feasibility of storage-based renewable integration.

2.8 Grid Integration Challenges

The successful integration of renewable energy depends on the ability of the electricity network to accommodate variable power flows while maintaining voltage, frequency, and power-quality requirements. Awodiji [3] emphasized the importance of system-level considerations in integrating renewable energy into Nigerian power systems. The challenges associated with grid integration become more significant when renewable generation is connected to networks with limited transmission capacity, inadequate monitoring systems, and weak operational flexibility.

Kroposki et al. [18] demonstrated that high renewable penetration requires enhanced system flexibility, improved forecasting, advanced operational practices, and appropriate balancing resources. These requirements indicate that renewable-energy expansion must be accompanied by modernization of electricity-system infrastructure and operational capabilities.

The World Bank's assessment of Nigeria's public finances also highlights broader structural and investment challenges affecting sustainable infrastructure development [19]. Although the reference is not exclusively focused on renewable-energy integration, its findings provide relevant context for understanding the financial and institutional environment within which large-scale energy infrastructure must be developed.

Oyedepo [20] discussed the relationship between energy and sustainable development in Nigeria and emphasized the importance of addressing the country's energy challenges as part of its broader development pathway. This reinforces the argument that renewable-energy integration should be evaluated not only in terms of electricity generation but also in relation to economic development, energy access, environmental sustainability, and long-term national planning.

2.9 Policy and Regulatory Considerations

The successful integration of renewable energy requires supportive regulatory and economic frameworks. Akpodiete [2] examined the regulation of renewable-energy tariffs within the Nigerian electricity supply industry, highlighting the importance of tariff mechanisms in supporting renewable-energy development. Appropriate tariff structures can influence the financial viability of renewable-energy projects by providing greater certainty regarding revenue generation and investment returns.

Policy mechanisms such as feed-in tariffs, fiscal incentives, renewable-energy targets, competitive procurement, and public–private partnerships can therefore influence the pace of renewable-energy deployment. However, policy consistency and transparent implementation are essential because uncertainty can increase investment risk and delay project development.

2.10 Research Gap

The literature review identifies three major gaps. First, limited studies simultaneously evaluate multiple renewable-energy integration pathways within the context of Nigeria's existing power infrastructure. Second, the relationship between renewable-capacity expansion and the technical ability of the national grid to accommodate additional renewable generation requires further integrated assessment. Third, technical, infrastructural, financial, regulatory, and human-capacity barriers are often examined separately rather than as interconnected factors affecting renewable-energy deployment.

This study addresses these gaps by developing an integrated assessment of renewable-energy integration into Nigeria's power stations. It examines the current status of renewable-energy capacity, evaluates grid-connected, hybrid, and storage-based integration pathways, identifies major barriers, and develops strategic recommendations for improving renewable penetration while maintaining grid stability and supporting sustainable development.

3. Research Methodology

This study adopts a secondary-data-based descriptive and analytical research design to assess the integration of renewable energy sources (RES) into Nigeria's power stations. The methodology was designed to examine three interconnected dimensions: the current status of renewable-energy deployment, the available pathways for integrating renewable resources into the electricity system, and the technical, infrastructural, economic, and institutional barriers affecting effective integration. The approach combines quantitative analysis of renewable-energy capacity and electricity-generation data with qualitative analysis of published research, policy documents, and institutional reports.

3.1 Research Design

The study employs a descriptive and analytical research design based entirely on secondary information. The descriptive component is used to establish the current status of renewable-energy deployment in Nigeria, while the analytical component is used to examine trends, integration pathways, and barriers affecting renewable-energy penetration.

A secondary-data approach is appropriate for this study because information concerning electricity generation, installed capacity, renewable-energy projects, grid infrastructure, energy policies, and renewable-resource development is available through established institutional and scholarly sources. The study does not involve primary surveys, interviews, laboratory experiments, or field measurements.

4. Current Capacity of Renewable Energy Systems in Nigeria.

Nigeria has made incremental progress in renewable energy deployment, although integration into the grid remains limited. Table 1 summarizes current capacity trends and key projects. The renewable-energy portfolio consists primarily of hydropower, while solar photovoltaic (PV), wind, and biomass technologies are developing at different rates. This uneven distribution indicates that Nigeria's renewable-energy transition is still at an evolving stage, with considerable opportunities for diversification.

Table 1. *Renewable Energy Capacity and Key Projects in Nigeria*

Energy Source	2025 (GW)	2026 (GW)	Key Projects (2024–2025)
Hydropower	~2.5	~2.7	Zungeru (413 MW); Kainji solar hybrid
Solar PV	~0.8	~1.2	NDA 2.5 MW hybrid; DARES (1,265 MW)
Wind	~0.01	~0.05	Lamba Rimi 10 MW revival
Biomass	~0.1	~0.15	Rije biogas (100 kVA)
Total	**3.59**	**4.51**	**400 mini-grids planned**

The data in Table 1 indicate an increase in the reported renewable-energy capacity from approximately 3.59 GW in 2025 to 4.51 GW in 2026. This represents an overall increase of approximately 25.6%, although the figures should be interpreted with caution because project status, operational capacity, and planned capacity may be reported differently across sources.

Hydropower remains the largest contributor to the reported renewable-energy capacity. Its increase from approximately 2.5 GW to 2.7 GW indicates continued importance in Nigeria's electricity-generation structure. However, the relatively smaller contribution from solar, wind, and biomass demonstrates that diversification of the renewable portfolio remains necessary.

4.1 Hydropower Capacity

Hydropower remains the dominant renewable source, contributing approximately 23% of grid electricity in 2024 [17]. Its relatively large contribution reflects the established role of hydropower in Nigeria's electricity system compared with newer renewable technologies. Hydropower can also provide comparatively controllable generation, making it valuable for supporting electricity-system reliability. However, continued dependence on hydropower alone may expose the electricity system to seasonal variations in water availability and climate-related changes. Consequently, hydropower development should be complemented by solar, wind, biomass, and energy-storage technologies to create a more diversified and resilient renewable-energy portfolio.

4.2 Solar Photovoltaic Development

Solar PV capacity increased from approximately 0.8 GW in 2025 to approximately 1.2 GW in 2026 according to the data presented in Table 1. This represents an increase of approximately 50%, making solar PV one of the fastest-growing renewable technologies in the reported capacity portfolio. Solar and wind deployment are largely off-grid, highlighting limited grid integration capacity. The growth of solar PV is particularly important for Nigeria because solar resources are geographically widespread and can be deployed through both centralized utility-scale projects and decentralized systems such as mini-grids and rooftop installations. The development of projects such as DARES also indicates increasing attention toward large-scale expansion of distributed renewable electricity access. Nevertheless, increasing solar penetration will require improvements in transmission and distribution infrastructure, power-quality management, forecasting, and energy storage.

4.3 Wind Energy Development

The reported wind capacity increased from approximately 0.01 GW in 2025 to approximately 0.05 GW in 2026. Although this represents a substantial percentage increase, the absolute installed capacity remains small compared with hydropower and solar PV. The relatively limited contribution of wind energy indicates that the technology has not yet reached the same level of deployment as hydropower and solar in Nigeria. Future development will depend on resource assessment, project economics, grid connectivity, transmission availability, and appropriate technical and regulatory support. Greater diversification through wind energy could nevertheless reduce dependence on individual renewable resources and contribute to a more balanced generation portfolio where suitable wind resources are available.

4.4 Biomass Energy Development

The reported biomass capacity increased from approximately 0.1 GW in 2025 to approximately 0.15 GW in 2026. Biomass therefore represents a smaller component of Nigeria's renewable-energy portfolio, but its development offers an opportunity to utilize agricultural and organic waste for electricity production. Biomass-based generation can provide a complementary source of electricity because its output is less dependent on short-term solar and wind variability. However, sustainable biomass deployment requires reliable feedstock availability, collection and transportation systems, suitable conversion technologies, and appropriate environmental-management practices.

4.5 Renewable Energy Growth Trend

The increase in total reported renewable capacity from approximately 3.59 GW in 2025 to 4.51 GW in 2026 indicates a positive development trajectory. However, capacity growth should not be interpreted directly as an equivalent increase in electricity generation because installed capacity and actual generation depend on capacity factors, resource availability, plant availability, grid constraints, and operational conditions. The difference between installed capacity and actual electricity contribution is particularly important when assessing variable renewable resources such as solar and wind. Therefore, renewable-energy integration should be evaluated using both capacity indicators and actual electricity-generation data.

4.6 Major Renewable Energy Projects

The projects presented in Table 1 demonstrate the increasing diversity of renewable-energy initiatives in Nigeria. The identified projects include large-scale hydropower, solar PV, hybrid systems, wind-energy development, biomass projects, and planned mini-grid deployment. This diversity suggests that Nigeria is gradually moving from reliance on conventional centralized generation toward a more diversified electricity architecture. Hybrid and mini-grid projects are particularly significant because they can provide electricity to areas where national-grid extension is technically or economically difficult. At the same time, utility-scale renewable projects can contribute to centralized electricity generation when adequate

transmission infrastructure is available. The simultaneous development of centralized and decentralized renewable systems therefore provides Nigeria with multiple pathways for improving electricity access and system resilience.

4.7 Renewable Electricity Generation

Hydropower remains the dominant renewable source, contributing approximately 23% of grid electricity in 2024 [17]. Solar and wind deployment are largely off-grid, highlighting limited grid integration capacity. This distinction between renewable capacity and renewable electricity generation is important because a technology may have significant installed capacity without contributing proportionally to grid electricity generation. Fig. 6 shows the share of electricity production from renewables.

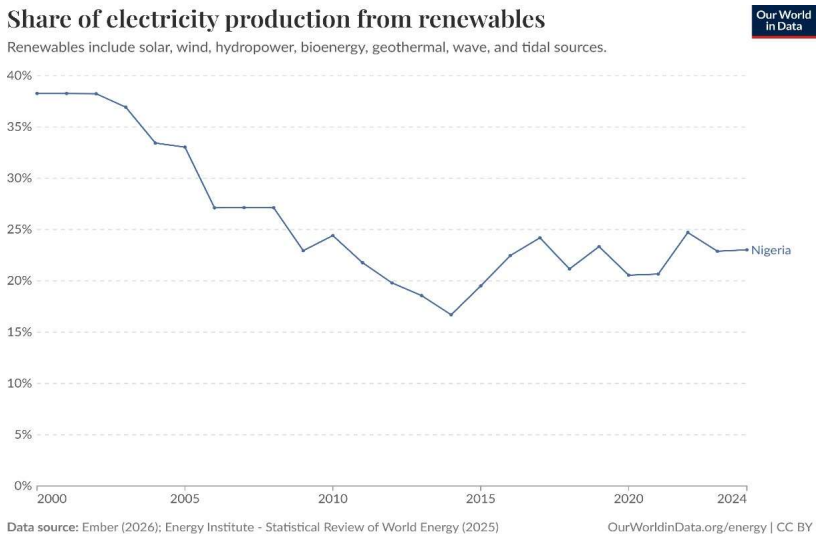

Fig. 6. *Electricity from renewable energy*

5. Results and Discussion

The findings of this study indicate that Nigeria possesses significant renewable-energy resources and has recorded gradual growth in renewable-energy capacity. However, the analysis also demonstrates that renewable-resource availability alone is insufficient to achieve effective integration into the national electricity system. The major constraints are interconnected and include grid instability, inadequate transmission and distribution infrastructure, technical skill shortages, intermittency, energy-storage limitations, financing constraints, and policy and institutional challenges. The interaction between these factors is particularly important. For example, increasing solar and wind capacity without strengthening transmission infrastructure and grid-control capabilities may increase operational difficulties. Similarly, investment in renewable generation without adequate technical expertise and appropriate regulatory mechanisms may limit the long-term performance of renewable-energy projects.

5.1 Grid Instability and Power Quality Constraints

The intermittent nature of renewable energy sources introduces variability that can destabilize weak grid systems. In Nigeria, inadequate grid management infrastructure, including limited real-time monitoring and forecasting capabilities, exacerbates voltage and frequency fluctuations [18]. Without proper control mechanisms, increased renewable penetration may intensify grid disturbances. The problem is particularly relevant to solar and wind generation because their power output varies according to solar irradiation and wind conditions. Rapid changes in renewable generation can create imbalances between electricity supply and demand, requiring flexible generation, energy storage, demand-side management, or other balancing mechanisms. Kroposki et al. [18] demonstrated that power systems operating with high levels of variable renewable energy require improved system flexibility, forecasting, advanced operational practices, and appropriate balancing resources. These requirements are relevant to Nigeria because the existing grid must progressively develop the capability to accommodate larger quantities of variable renewable electricity without compromising frequency and voltage stability.

5.2 Inadequate Transmission and Distribution Infrastructure

Aging transmission networks, limited capacity, and high technical losses restrict the grid's ability to accommodate additional renewable inputs. Grid congestion and energy curtailment remain prevalent, particularly in regions with weak infrastructure [19]. Expanding and modernizing the transmission network is therefore critical for effective integration. The geographical distribution of renewable resources further increases the importance of transmission infrastructure. Renewable resources may be located far from major electricity-demand centers, requiring adequate transmission capacity to transport generated electricity to consumers. Weak distribution networks can also limit the integration of distributed solar PV and mini-grid systems. High technical losses reduce the effective utilization of generated electricity and can undermine the economic benefits expected from renewable-energy investments.

5.3 Technical Capacity and Skill Gaps

The integration of renewable energy systems requires advanced expertise in power electronics, system control, and grid management. Nigeria faces a shortage of skilled professionals in these areas, resulting in suboptimal system design and operation [20]. Strengthening technical education and local capacity development is essential for sustainable deployment. Renewable-energy integration involves multidisciplinary expertise covering electrical engineering, power electronics, control systems, energy storage, forecasting, cybersecurity, system protection, and energy-market operation. The shortage of personnel with these combined competencies can affect project design, commissioning, maintenance, and long-term operation.

5.4 Discussion of Findings

The findings demonstrate that Nigeria's renewable-energy transition involves a combination of technical, infrastructural, economic, institutional, and human-capacity factors. The growth in reported renewable capacity between 2025 and 2026 indicates positive progress, but the relatively limited contribution of solar and wind to grid electricity demonstrates that capacity expansion has not yet translated into broad renewable penetration across the national electricity system. The dominance of hydropower provides an important foundation for renewable electricity generation, but greater diversification is necessary to reduce dependence on a limited number of renewable resources. Solar PV provides significant expansion potential because of its modularity and resource availability, while wind and biomass can provide additional diversification where technically and economically feasible. The analysis also indicates that the most appropriate strategy is unlikely to involve a single integration pathway. Instead, Nigeria will require a combination of utility-scale grid-connected renewable generation, hybrid power systems, decentralized mini-grids, and energy-storage technologies. This integrated approach can provide complementary benefits. Utility-scale renewable generation can increase total electricity supply, hybrid systems can improve reliability in weak-grid and off-grid locations, and energy storage can provide flexibility and support the integration of variable renewable resources. However, these technologies must be accompanied by transmission and distribution modernization, advanced control systems, technical capacity development, appropriate tariff mechanisms, and stable investment policies. Without these supporting measures, additional renewable generation capacity may not produce a proportional improvement in electricity reliability.

5. Conclusion and Recommendations

The integration of renewable energy into Nigeria's power stations represents a viable and necessary pathway for addressing the country's persistent electricity challenges. The assessment presented in this study demonstrates that Nigeria possesses considerable renewable-energy resources, particularly hydropower, solar, wind, and biomass, which can contribute to diversifying the national electricity-generation mix. While progress has been recorded, particularly between 2025 and 2026, the scale of integration remains insufficient relative to projected demand growth. The reported increase in renewable-energy capacity indicates positive progress; however, the contribution of renewable sources to the national electricity system remains constrained by limited grid integration, inadequate transmission and distribution infrastructure, and the variable nature of renewable generation. This study highlights that effective integration requires not only technological deployment but also systemic improvements in grid infrastructure, policy frameworks, and human capacity. The findings further indicate that grid-connected renewable systems, hybrid power systems, and energy-storage-integrated systems can provide complementary pathways for increasing renewable-energy penetration. Strategically, renewable energy integration should be positioned as both an engineering solution and a national development priority. Enhanced awareness, investment in grid modernization, and coordinated stakeholder engagement will be

essential in driving Nigeria's transition toward a resilient, sustainable, and inclusive energy future.

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Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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