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# INTEGRATING RENEWABLE ENERGY INTO NIGERIA'S NATIONAL GRID: CHALLENGES AND PROSPECTS

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## Abstract
Nigeria's energy sector is undergoing a critical transformation amid growing electricity demand, persistent power shortages, and rising climate commitments. With a population exceeding 220 million and an electrification rate around 55%, the country faces an urgent imperative to expand energy access while transitioning to a cleaner and more resilient power system. Despite abundant renewable energy resources including solar, hydro, wind, and biomass renewables account for less than 10% of total electricity generation due to entrenched structural challenges. These include technical limitations, outdated grid infrastructure, frequent system collapses regulatory inconsistencies, financial barriers, and a shortage of skilled human capital. This paper critically examines the multifaceted constraints hindering renewable energy integration into Nigeria's national grid and evaluates policy and technological interventions aimed at overcoming them. Key policy reforms, such as the Electricity Act 2023 and the Energy Transition Plan (ETP), signal a shift toward decentralized, low-carbon energy development. Additionally, technological advancements in smart grids, energy storage, and falling renewable costs create favorable conditions for accelerated deployment. The study highlights the importance of coordinated investments in grid modernization, regulatory clarity, capacity building, and innovative financing mechanisms to unlock Nigeria's renewable energy potential. A strategic, multi-stakeholder approach will not only improve energy access and grid reliability but also catalyze economic growth, environmental sustainability, and energy resilience.

**Keywords:** Renewable Energy Integration, Grid Modernization, Decentralized Energy System, Energy Transition Policy and Infrastructure Challenges

## 1.0 Introduction
Nigeria's power sector is at a critical inflection point. With a population exceeding 220 million and an electrification rate hovering around 55%, the country faces an urgent need to expand energy access and improve supply reliability (World Bank, 2022). Simultaneously, the global shift toward cleaner energy sources and Nigeria's own commitments to climate action under the Paris Agreement have intensified the push to integrate renewable energy into the national grid. However, while Nigeria possesses abundant renewable energy resources especially solar, hydro, wind, and biomass grid integration remains a significant challenge due to infrastructural, regulatory, and operational barriers. The national grid, operated by the Transmission Company of Nigeria, is plagued by frequent collapses, outdated infrastructure, and limited flexibility to accommodate the variability of renewables (TCN, 2023). Despite these limitations, the government has articulated ambitious plans through the Renewable Energy Master Plan and the Electricity Act 2023, which both emphasize the expansion of renewable generation capacity and decentralized energy models (NERC, 2023). Nevertheless, without grid modernization and coherent planning frameworks, the full potential of renewable energy will remain untapped. Moreover, successful


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integration of renewable energy into the grid is not merely a technical challenge it has significant economic and developmental implications. By displacing expensive fossil fuel-based generation, improving grid stability, and catalyzing investment, renewables can support Nigeria's broader objectives of sustainable economic growth, energy security, and climate resilience (IRENA, 2023). The transition to a cleaner grid also offers prospects for localized employment, improved air quality, and greater energy sovereignty.

This paper explores the multidimensional challenges of integrating renewables into Nigeria's grid ranging from technical limitations and regulatory fragmentation to financial and institutional constraints. It also outlines the key prospects and pathways through which Nigeria can leverage its renewable energy potential to transform its power sector, foster inclusive development, and meet its national and international energy goals.

## 2.0 Overview of Nigeria's Power Sector and Renewable Energy Potential

Nigeria's power sector is characterized by a complex and underperforming structure that has consistently failed to meet the country's growing electricity demand. With a population exceeding 220 million and an estimated peak electricity demand of over 28,000 MW, the country's available generation capacity remains significantly constrained delivering on average only 4,000–5,000 MW to end-users (NERC, 2023). The national grid is centrally operated by the Transmission Company of Nigeria (TCN), and the power sector is segmented into generation, transmission, and distribution sub-sectors. Despite the unbundling of the Power Holding Company of Nigeria (PHCN) in 2013 and the partial privatization of the generation and distribution arms, systemic inefficiencies persist across the value chain.

The generation mix in Nigeria is heavily skewed towards fossil fuels, with thermal power (mainly natural gas) accounting for approximately 80% of installed capacity, while large hydropower contributes around 17% (IEA, 2022). This reliance on gas-fired generation exposes the power sector to vulnerabilities such as gas supply disruptions, pipeline vandalism, and foreign exchange risks related to gas pricing.

### Renewable Energy Potential in Nigeria

Nigeria is endowed with vast and largely untapped renewable energy (RE) resources, including solar radiation, wind, biomass, and small hydropower, which offer significant potential to diversify the energy mix and enhance energy security.

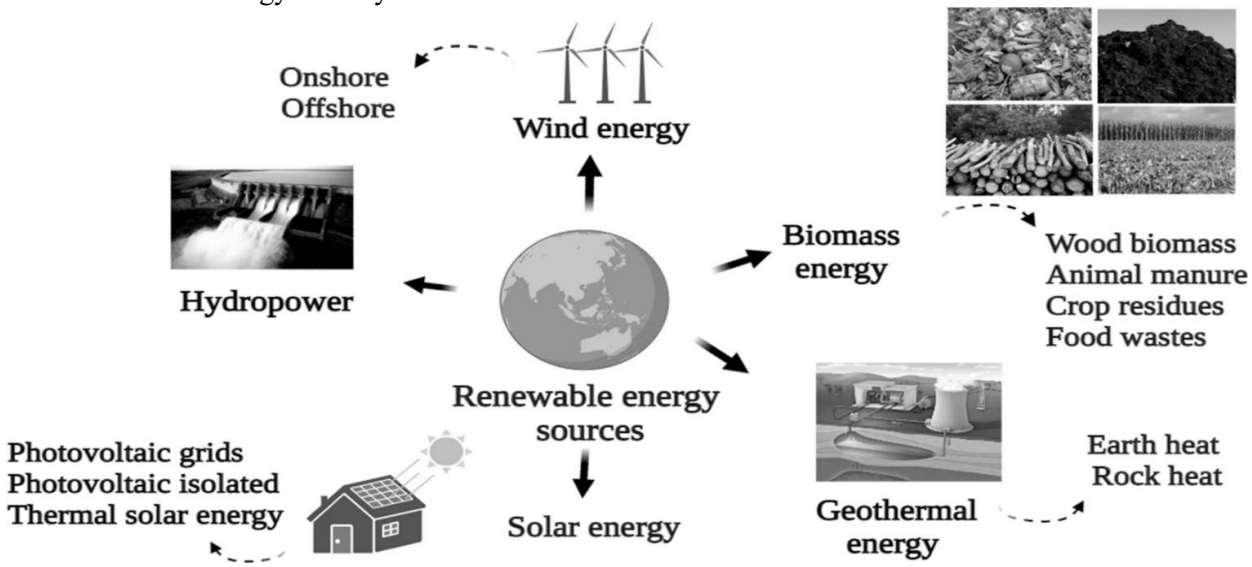


Fig 1: Renewable Energy Sources (https://link.springer.com/article/)



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**2.1 Solar Energy Potential:** Nigeria possesses vast solar energy potential, making it the country's most abundant renewable resource. With average solar irradiation levels ranging between 4.0 and 6.5 kWh/m²/day and about 300 sunny days per year, the estimated solar photovoltaic (PV) capacity exceeds 427,000 MW (IRENA, 2023; Shaaban & Petinrin, 2014). This significant potential is particularly well-suited for both grid-connected and off-grid energy solutions, especially in remote rural areas where transmission infrastructure is sparse. As a result, solar mini-grids and standalone PV systems are being increasingly implemented through initiatives such as the Nigeria Electrification Project (NEP) led by the Rural Electrification Agency (REA).

**2.2 Hydro Power:** Nigeria has an estimated **hydropower potential of 14,750 MW**, of which about 3,500 MW is classified as small-scale or mini-hydro (NERC, 2023). While large hydropower plants such as Kainji, Shiroro, and Jebba are already operational, many small and medium hydro sites remain underdeveloped. These offer considerable opportunities for rural electrification and decentralized energy generation.

**2.3 Wind Energy:** Nigeria's wind energy potential, though moderate, is considered viable—particularly in northern states like Katsina, Sokoto, and Kano, where average wind speeds range from 3.5 to 7 m/s at a height of 10 meters (Ayodele et al., 2012). The Katsina Wind Farm remains Nigeria's only grid-connected wind project to date, although operational challenges related to maintenance and grid integration have affected its overall performance (NESP, 2022). In contrast, wind speeds in southern Nigeria are generally lower, except in coastal and offshore areas like Lagos and Bonny, where conditions are more favorable.

**2.4 Biomass and Waste-to-Energy:** Nigeria generates over 144 million tons of biomass annually from agricultural residues, animal waste, and forest products (African Development Bank, 2023). Biomass-based power generation, particularly from rice husk, animal dung, and sawmill waste, has gained traction in states like Ebonyi and Niger. However, commercialization is still limited by technology gaps and collection logistics.

**2.5 Geothermal and Emerging Technologies:** Though geothermal resources in Nigeria are less documented, early surveys suggest potential in areas such as the Benue Trough and the Lower Niger Valley. Emerging technologies like green hydrogen and tidal energy are still largely unexplored but represent future opportunities in Nigeria's clean energy mix (IEA, 2023).

Despite these substantial resources, renewable energy contributes less than **10%** to Nigeria's electricity generation capacity, mostly from large hydropower. The underutilization of RE resources is due to multiple barriers including lack of infrastructure, policy uncertainty, limited financing, and weak investment in technology and innovation. However, the declining cost of renewables particularly solar photovoltaics combined with increasing energy demand and environmental concerns, presents a compelling case for scaling up renewable deployment.

In the context of Nigeria's Energy Transition Plan (ETP) and the Electricity Act 2023, unlocking the country's renewable potential is not just a climate imperative but a pathway to sustainable development, job creation, and long-term energy security.


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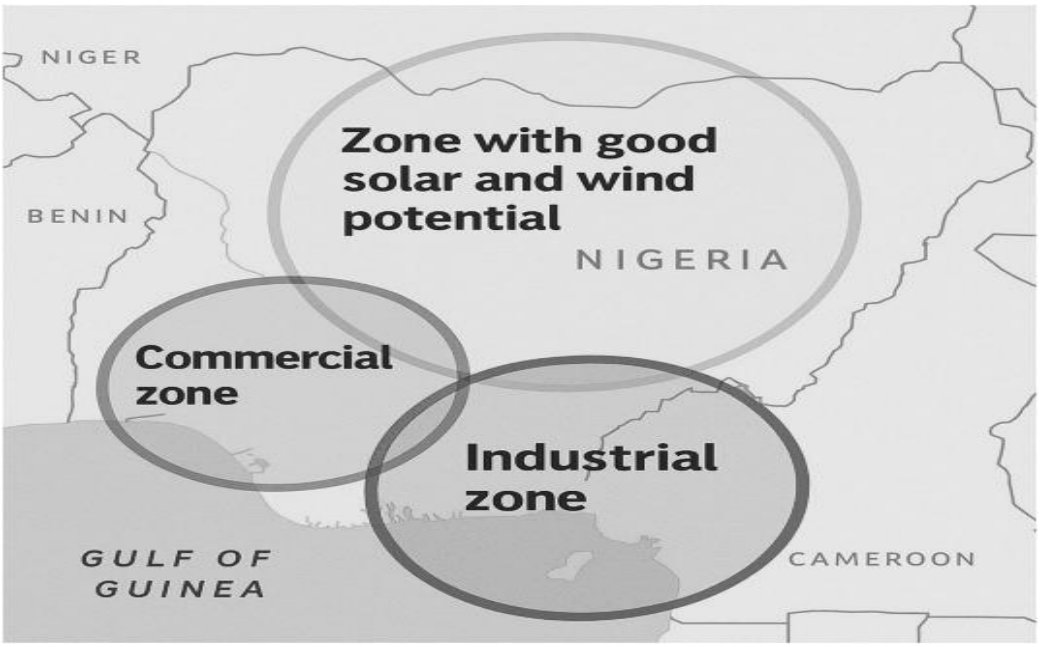


Fig. 2. Map of Nigeria showing energy resources distribution and socio-economic zones (Yan et.al., 2025)

Figure 2 illustrates the geographical distribution of Nigeria's renewable energy resources alongside key socio-economic zones. The map highlights a large northern region labeled as a "Zone with good solar and wind potential," indicating the country's high renewable energy resource availability in that area. In the south, two key economic regions are marked: the "Commercial zone" in the southwest, which includes cities like Lagos, and the "Industrial zone" in the southeast, which covers parts of the Niger Delta. This spatial distinction underscores the potential synergy between renewable energy development in the north and energy demand in the southern economic hubs.

## 3.0 Challenges to Integration of Renewable Energy into Nigeria's National Grid

The integration of renewable energy into Nigeria's national grid is widely recognized as essential for ensuring long-term energy security, environmental sustainability, and inclusive development. However, this transition is hindered by a complex set of technical, regulatory, financial, institutional, and infrastructural challenges. These barriers must be addressed holistically to facilitate a successful energy transition.

**3.1 Technical Infrastructure Limitations:** The Nigerian grid is characterized by aging infrastructure, inadequate transmission capacity, and frequent collapses. Designed primarily for centralized thermal and hydropower generation, the grid lacks the flexibility and automation needed to accommodate variable renewable energy sources such as solar and wind. In 2023 alone, Nigeria experienced over a dozen grid collapses, highlighting its fragility (TCN, 2023). Without substantial upgrades to transmission and distribution networks, further renewable energy integration risks exacerbating existing system instabilities.

**3.2 Regulatory and Policy Inconsistencies:** Although the **Electricity Act of 2023** marks a turning point by decentralizing the electricity market and empowering states to develop their own energy frameworks, regulatory implementation remains inconsistent. Multiple layers of bureaucratic oversight, unclear interconnection standards, and delays in policy enforcement create uncertainty for investors and


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project developers (NERC, 2023). Furthermore, many renewable energy policies lack alignment between federal and state governments, undermining cohesive planning and market development.

**3.3 Financial and Investment Barriers:** Renewable energy projects in Nigeria are capital-intensive and often face difficulty securing financing due to perceived risks and weak financial guarantees. Power Purchase Agreements are frequently delayed or non-bankable due to liquidity challenges within the power sector, especially among Distribution Companies (DisCos) (World Bank, 2022). The absence of robust credit enhancement mechanisms and the underdevelopment of green finance instruments further deter private sector participation.

**3.4 Poor Utility Performance and Revenue Collection:** The financial instability of Nigeria's power utilities, particularly DisCos, affects their ability to invest in grid infrastructure or adopt modern RE technologies. High Aggregate Technical, Commercial, and Collection (ATC&C) losses ranging between 30% and 45% undermine the financial sustainability of the electricity market (NERC, 2023). This reduces their capacity to engage in grid modernization or support decentralized renewable connections.

**3.5 Inadequate Data, Planning, and Coordination:** Reliable data is crucial for grid planning, resource mapping, and forecasting renewable energy output. However, Nigeria suffers from fragmented and outdated data systems, making it difficult to plan for variable energy sources or conduct long-term integrated resource planning (IRENA, 2023). Inadequate coordination between planning agencies, utilities, and regulators leads to misalignment in capacity expansion, infrastructure development, and investment prioritization.

**3.6 Human Capital and Technical Skills Gap:** There is a substantial shortage of trained professionals in the fields of solar PV engineering, grid automation, energy storage systems, and smart metering. This technical capacity gap affects the quality of project implementation and limits the scalability of renewable energy solutions across urban and rural areas (Power for All, 2023).

The integration of renewable energy into Nigeria's grid is not only a technological endeavor but a systemic reform challenge. Each obstacle from outdated grid infrastructure to fragmented regulation and financing gaps reflects deeper structural issues in the country's power sector. Addressing these challenges will require a multi-stakeholder approach involving significant public investment, policy reform, private sector engagement, and institutional capacity building.
Nigeria's success in renewable integration will ultimately depend on how effectively it can modernize its grid, de-risk its energy market, and coordinate efforts across all levels of government and industry.

## 4.0 Prospects and Opportunities for Renewable Energy Integration in Nigeria

Nigeria's renewable energy sector holds substantial promise, driven by abundant natural resources, evolving policy frameworks, and growing demand for clean and reliable electricity. Despite significant challenges, the country is positioned to capitalize on various opportunities to expand renewable energy integration, which can stimulate economic growth, improve energy access, and reduce environmental impacts.

**4.1 Abundant Renewable Resource Endowment:** Nigeria's geographical location offers significant potential across multiple renewable sources. Solar radiation levels averaging 4.0 to 6.5 kWh/m²/day and the presence of untapped hydro, wind, and biomass resources provide a diversified energy portfolio (IRENA, 2023). This resource variety allows Nigeria to develop a balanced and resilient renewable energy mix tailored to regional potentials and energy needs.


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**4.2 Policy and Regulatory Advances:** Recent reforms, particularly the **Electricity Act 2023**, decentralize electricity regulation and encourage private sector participation, creating a more conducive environment for renewable energy investments (NERC, 2023). The Nigeria Energy Transition Plan (ETP) aims for 30% renewable electricity generation by 2030 and sets a pathway toward net-zero emissions by 2060 (Federal Government of Nigeria, 2022). These policies signal strong government commitment and offer a clear roadmap for renewable deployment.

**4.3 Declining Costs of Renewable Technologies:** Global trends in renewable energy technologies, especially solar photovoltaic (PV) and battery storage, have seen dramatic cost reductions solar photovoltaic module prices have fallen by over 80% since 2010 (IRENA, 2023). These declining costs enhance the economic viability of renewable projects in Nigeria, making them competitive with conventional fossil fuel generation and attractive to both domestic and foreign investors.

**4.4 International Financial and Technical Support:** Nigeria benefits from increased engagement by international development partners, multilateral banks, and climate funds that provide concessional finance, technical assistance, and risk mitigation tools for renewable projects. Initiatives such as the World Bank's Nigeria Electrification Project and the African Development Bank's green financing programs are catalyzing investment and capacity building in the sector (African Development Bank, 2023; World Bank, 2022).

**4.5 Technological Innovation and Grid Modernization:** Advances in smart grid technologies, digital metering, and energy storage solutions offer opportunities to overcome existing grid integration barriers. Nigeria's Transmission Rehabilitation and Expansion Programme (TREP) and pilot projects deploying battery energy storage systems (BESS) demonstrate early steps toward enhancing grid flexibility and resilience (TCN, 2023). Increased adoption of these technologies can facilitate higher renewable penetration while maintaining system reliability.

**4.6 Growth of Decentralized Renewable Energy Systems:** Beyond grid-connected projects, decentralized renewable energy solutions such as mini-grids and off-grid solar home systems are rapidly expanding in Nigeria. These systems enhance energy access in rural and underserved areas and can operate independently or in hybrid configurations with the national grid (Power for All, 2023). Their scalability and cost-effectiveness make them vital components of Nigeria's overall energy strategy.

**4.7 Regional Power Market Integration:** Nigeria's active participation in the West African Power Pool (WAPP) presents an opportunity to trade renewable energy regionally, balance supply and demand across borders, and optimize resource utilization. Regional integration enhances grid stability and opens larger markets for renewable energy producers (ECOWAS, 2023).

Nigeria's prospects for renewable energy integration are underpinned by a convergence of natural resource abundance, enabling policies, technology advancements, and international collaboration. However, realizing this potential requires coordinated efforts to scale investments, modernize grid infrastructure, and build institutional capacity. The alignment of these factors will position Nigeria not only as a leader in Africa's energy transition but also as a catalyst for sustainable economic growth.

## 5.0 Recommendations

Effective integration of renewable energy into Nigeria's national grid requires a multifaceted strategy that addresses technical, regulatory, financial, and institutional barriers while building on emerging prospects.


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Based on the analysis of existing challenges and opportunities, the following key recommendations are proposed:

i. Modernize transmission and distribution networks to reduce congestion and technical losses.
ii. Adopt smart grid technologies such as automated controls, digital substations, advanced metering infrastructure and expand battery energy storage system for improved grid flexibility and reliability.
iii. Fast-tracking implementation of the Electricity Act 2023 through clear interconnection codes, grid access rules, and cost-reflective tariffs.
iv. Establishing enforceable Renewable Portfolio Standards (RPS) requiring Distribution
    a. Companies (DisCos) to procure renewable energy.
v. Encourage innovative financial models like public-private partnerships (PPPs) and pay-as-you-go (PAYG) systems for decentralized renewable energy solution.
vi. Provide specialized training in solar photovoltaic, wind energy, smart grid operation and energy storage technologies.
vii. Strengthen local research and development institutions to support indigenous innovation
    a. in renewable technologies.
viii. Establish Integrated Resource Planning (IRP) at both federal and state levels to synchronize renewable energy targets with generation, transmission, and distribution planning.

## 6.0 Conclusion

Nigeria is at a critical point in its energy journey, facing the twin challenge of expanding electricity access and meeting sustainability goals. Although the country has abundant renewable energy resources including solar, wind, hydro, and biomass their integration into the national grid is limited by technical, regulatory, financial, and human capacity barriers. Nonetheless, opportunities for progress are growing, supported by policy reforms like the Electricity Act 2023 and the Energy Transition Plan, alongside advancements in technology and increased international support. To realize its renewable energy potential, Nigeria must adopt a coordinated approach involving infrastructure upgrades, consistent policy enforcement, investment mobilization, and capacity building. Doing so will enhance energy access, stabilize the grid, and support a sustainable, inclusive, and low-carbon energy future.

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