



Renewable Energy and Sustainable Energy Production and Distribution in Nigeria

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Abstract

This review paper is based on an extensive survey of the existing literature and data obtained from reputable online research databases such as IEEE Xplore, ScienceDirect, Google Scholar, and Web of Science. Key reports and policy documents from Nigerian government agencies, the International Renewable Energy Agency (IRENA), the World Bank, and other international bodies were also utilised. The literature search focused on keywords including “renewable energy in Nigeria”, “energy policy Nigeria”, “solar energy Nigeria”, “wind energy Nigeria”, “biomass energy Nigeria”, and “hydropower Nigeria”. Included were papers that talked about Nigeria's energy sector, renewable energy technologies, policy frameworks, and socioeconomic effects. Relevant data were extracted from these sources and categorised as quantitative and qualitative. From the review, it is recommended that Nigeria should aggressively pursue the restructuring of its energy system, transitioning from a reliance on fossil fuels to the broad adoption of renewable energy through an effective policy and governance framework, promotion of infrastructure and technology, capacity building and public engagement, among others.

Keywords: Renewable Energy, Nigeria, Hydropower, Transmission, Qualitative.

Introduction

Electricity is the backbone of modern economies, fuelling various sectors that contribute to overall economic growth and development. The extent to which a country grows and industrialises is a function of her ability to produce an adequate quantity and quality of electric power and effectively distribute it to power homes and industries (Emovon et al., 2018). The significance of energy in whatever form is as vital as oxygen since it is a commodity that can be traded. The use of energy in various forms is indispensable, as it can be used in cooking, lighting, the use of appliances, piped water, primary healthcare needs (vaccine storage, emergency, and intensive care), educational support, communication, and transportation. Energy enhances productive activities such as commerce, manufacturing, industry, mining and agriculture. At the macro level, energy access improves living standards, eradicates poverty, provides security, and fosters economic expansion (Somoye, 2023). On the contrary, the absence of energy places significant limitations on economic output, the adoption of new technology, and the provision of essential social services like healthcare, education, and entertainment.

Nigeria as a country is potentially endowed with various types of energy sources, including conventional energies (fossil fuel, liquefied natural gas, and coal) and renewable energy resources (biomass, wind, solar, hydro, tidal, and geothermal, among others). Like most developing countries, Nigeria is far behind in integrating renewable energy (RE) into its energy mix, such that aside from large-scale hydro that contributes 22% to electricity generation in the country, RE contribution to the energy mix is negligible (Obada et al., 2024).

Also, Nigeria is a signatory to the Kyoto Protocol and, more recently, the Paris Climate Accord. However, the country is facing severe electricity shortages necessitating increased use of fossil fuels for power generation and transportation. Power generation in Nigeria is majorly achieved using natural gas in thermal power plants and from a few hydro stations. As of 2017, the total installed generating capacity was 7102 MW with actual power generation of 6882.8 MW (Obada, 2024). Thermal generation constitutes 81 per cent of the installed capacity, while renewable hydropower accounts for only 19 per cent of the mix. The energy sector, reliant on hydroelectric and thermal generation, faces challenges due to altered rainfall patterns and damage to infrastructure. In 2022, devastating flooding due to excessive rainfall affected millions of Nigerians and critical infrastructure, including roads and electricity installations (IEA, 2022). Presently, there is a huge deficit in Nigeria's electricity generation and supply, with only about 40 per cent of its population connected to the national grid, and in that, a meagre 10 per cent of rural families (Obada et al., 2024). Expansive industrialisation and massive migration to urban centres will lead to even greater energy



demand in the country in the next few years to come. It can be noticed from the foregoing that Nigeria is at great risk of climate-related hazards and will be a major beneficiary of climate change mitigating efforts.

Developing countries, such as Nigeria, with abundant natural gas reserves and existing gas pipelines can effectively address their energy needs and enhance the performance of their power grids by strategically adopting efficient gas-to-power processes (Adewuyi et al., 2023). This approach can also promote sustainability and a greener environment (Okoye et al., 2023). Nigeria has therefore reached a vital juncture at which it must decide whether to maintain its reliance on fossil fuels – accepting the inevitable environmental and economic risks that path entails – or capitalise on its ample indigenous renewable energy resources to drive economic development, decrease energy costs and significantly reduce its greenhouse gas emissions.

Sustainable energy is the driver of modern development. The availability of adequate, reliable, sustainable and cost-effective energy is important for the socio-economic development of any nation. Given Nigeria's progress in this regard, it is necessary to continue identifying options for scaling up sustainable energy supply to achieve Sustainable Development Goals (SDGs) in the country.

How can Nigeria meet its energy needs in the country? Renewable energy is a proven route for Nigeria to achieve both the objectives of mitigating climate change and energy security. The aim of this paper is to examine how integrating RE into the current energy mix will enhance sustainable electricity production and distribution in Nigeria.

Specifically, the research seeks to address the following questions: What strategies can be employed to facilitate a just energy transition that ensures energy security, environmental protection, and socioeconomic equity? How effective are the current energy policies in promoting sustainable energy development? What are the key barriers to the effective adoption and integration of renewable energy sources in Nigeria?

Literature Review

Renewable Energy and Energy Security

Renewable energies are energy sources whose supply is replenished naturally almost as quickly as they are utilised (Ellabban, Abu-rub, & Blaabjerg, 2014). They are derived from the sun either directly, as thermal, photochemical, and photoelectric energy, or indirectly, through wind, hydropower, and the photosynthetic energy stored in biomass.

These sources of energy are inexhaustible, but the supplies can be exhausted if used faster than they can be replenished (Oyedepo, 2012). Renewable energies,

however, do not include energy derived from fossil fuels or waste derived from inorganic sources. Renewable energy technologies are employed to convert renewable energy into usable forms, including heat, electricity, and fuels (Ellabban, Abu-rub, & Blaabjerg, 2014). With global energy demand on the increase, constant improvement in modern energy technologies and increased awareness of the need to mitigate climate change, various countries are looking to increase energy supply and reduce interruption in supply through diversification of their energy mix to include alternative clean renewable energy sources.

Between 2012 and 2015, “over 100 Gigawatts (GW) of new renewable capacity have been added each year, accounting for more than half of net capacity additions in the global power sector” (IRENA, 2023). Over 144 countries have established ambitious renewable energy targets, reflecting a growing commitment to a sustainable energy future. China aims to have renewable energy contribute 20% of its primary energy supply by 2030. Denmark has a more aggressive projection of having renewable energy account for all of its energy. Renewable energy is of high significance to energy security because as renewable sources increase in the general energy mix, so does their importance to energy security (IRENA, 2023).

Fossil fuels contribute about 85% of the global energy production, and they have contributed to industrial growth, but they are finite and costly; hence, they are inevitably unsustainable (Mathews, 2014). The price of fossil fuels has become increasingly unstable, disproportionately impacting poorer communities, who bear the greatest burden due to their heavy reliance on liquefied petroleum gas and kerosene. Furthermore, fossil fuel has a ripple effect on the government's inadequacies to fund healthcare, provide clean water and education, and other basic essentials for development. The unpredictable pricing of fossil fuels is primarily attributable to a rise in government subsidies for fossil fuels (Flavin and Aeck, 2010). Renewable energy matched with continuous technology improvements and a decrease in cost has provided several renewable energy alternatives that are tailored to allow poor people to have access to modern energy utilities (ibid). Renewable energy, by increasing primary energy supply, can help reduce reliance on fossil fuels, particularly oil (Althusmann & Ruppel, 2016).

Renewable energy will enhance sustainable energy supply, thereby “reducing global poverty” (Althusmann & Ruppel, 2016, p. 13). About 2 billion people in the world lack access to a modern energy supply. This suggests that they lack the favourable conditions to eliminate poverty on their own (ibid.). Furthermore, renewable energy can enhance people's lives by creating work opportunities. In Europe, renewable energy



provided around 550,000 jobs with a turnover of approximately 33.4 billion euros in 2009 (Hinrichs-Rahlwes, 2013).

Furthermore, Lucas et al. (2016) presents five advantages of renewable energy. Firstly, unlike conventional energy facilities, renewable energy has the advantage of having fewer risks of insecurity in terms of "physical failure and sabotage (primary energy risk)" (p. 2). Second, renewables (excluding hydropower) are relatively less dangerous than traditional energies in the event of an accident. Thirdly, renewables are 'zero marginal cost' technologies that do not need 'fuels' to generate power; hence, they are not influenced by fossil fuel price fluctuations in the international energy markets. Fourthly, renewables can serve as a stabiliser of the fossil fuel price fluctuations, as they are uncorrelated. Finally, "renewables could reduce energy vulnerability through the diversification of the energy mix regarding both technologies and energy sources" (p. 2). Therefore, in terms of sustainability, risks identified with renewables are minimal compared to conventional energy sources (ibid.).

Despite all the advantages stated above, renewables have their shortcomings as well. Ölz & Kirchner (2007) affirm by analysing how the output variability of the respective renewables can hinder stable and reliable supply. Hydropower can experience seasonal variability in seasons that are dry or have little rainfall, especially in areas that lack adequate reservoir capacity, thereby making it difficult to have a "predictable power supply". Solar photovoltaics can also have low output variability due to seasonal variation, regular variation from daylight to nightfall and temporary variation from fluctuating cloud cover. In terms of wind energy, there can be low output variability if there is inadequate wind speed or too much wind (turbines are stopped to reduce the chances of getting damaged), and it can also be seasonal.

Lehr (2009) also concurs by pointing out the affordability issues of renewable energy. GEF in Flavin & Aeck (2010) analyses the affordability of renewables as well, stating that "upfront cost of equipment and installation and maintenance cost are not affordable to many rural residents without long-term financing options" (p. 17). In light of the foregoing, it is pertinent to note that renewable energy will not eradicate all issues that hamper energy security; it can improve it, but new issues will definitely come up as long as there is a continuous advancement in the energy sector. Therefore, there is a need for continuous review so as to come up with strategies to tackle these new issues (Johansson, 2013).

Renewable energy gains more momentum due to the awareness to reduce environmental pollution partly caused by major reliance on fossil fuel as a major source of energy, the increase in demand for world energy due to increase in population growth and the decrease in the cost of renewable energy technologies (Francés et al., 2013).

Renewable energy has become an important energy policy to achieve energy security in many nations of the world. Hence, this paper will assess if renewable energy will help to improve energy security in Nigeria.

Energy security assessment network

Fig. 1 shows the assessment of energy security by Cherp & Jewell (2013); this diagrammatic framework was developed to include indicators coined from Jegen's (2009) and Shrestha & Kumar's (2008) definition of energy security as stated earlier. This was tailored to the peculiarities of the Nigerian energy system.

For the purpose of this paper, the concept of energy security will focus on the security of energy supply through diversification of the sources of supply by integrating other sources of renewable energy rather than the current over-reliance on biomass as an alternative source of energy. Energy security will be assessed using indicators specific to the Nigerian energy system. Since these indicators carry different meanings, it is essential to clarify how each will be applied in this study.

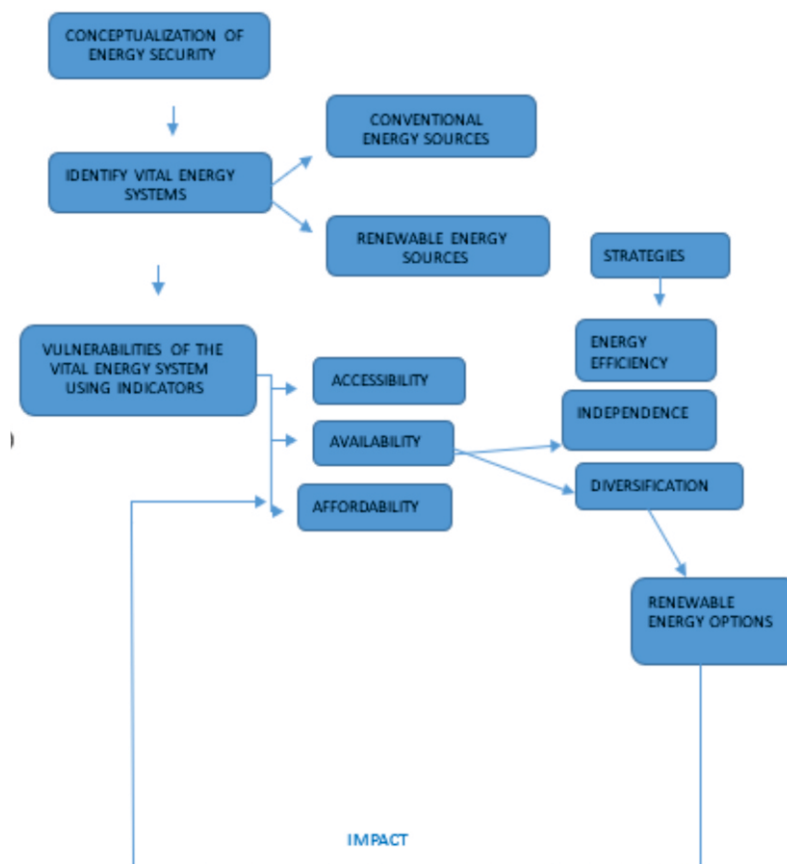


Fig. 1: Energy Security Assessment (Obideyi, 2017)

To ensure consistent availability, there has to be relative independence and diversification of energy fuels and services (Sovacool, 2011). This implies running an energy system that aims to reduce reliance on imported fuels and provide an adequate and uninterrupted supply of energy. Additionally, diversification refers to both source and spatial diversification.

Source diversity entails incorporating multiple sources of energy into the energy mix, whereas spatial diversification ensures the dispersion of sites for energy infrastructure. Accessibility refers to the ease with which individuals or communities can obtain reliable electricity and modern energy services. A high level of accessibility is associated with greater energy consumption and reduced energy poverty, while limited access and fewer energy options result in low energy use, heavy dependence on traditional biomass, and inadequate access to efficient energy technologies (Sovacool, 2011).

Affordability is having equitable prices that are not only relative to income but also stable and, most importantly, not volatile. Hence, affordability is what is affordable, stable and equitable (Sovacool, 2011).

The Nigerian Energy Resource Mix

The Nigerian energy sector can be compared to a newborn that has refused to grow over time, and slow growth stifles industrialisation, innovation, and development. Over the years, the sector has struggled with undeveloped energy resources, limited infrastructure development, and energy demand fuelled by imports, resulting in an unavoidable energy supply crisis.

Nigeria's energy mix, depicted in Figure 1, is heavily reliant on fossil fuels, with oil (33%), coal (27%), and gas (25%) dominating, and is on the point of a transformative shift towards a more sustainable and renewable future. Endowed with a wealth of renewable resources such as solar, wind, hydropower, and biomass resources, the country should be resolute to tackle its energy crisis head-on (Ezealigo et al., 2021). The prospect of deploying solar photovoltaic (PV) panels over just 0.01% of Nigeria's land area to yield outputs matching millions of tonnes of oil equivalent showcases the vast potential of solar energy (Solar Report Nigeria, 2021). Wind energy, too, has promising prospects, particularly in the coastal and northern regions known for their favourable wind speeds (Brimmo et al., 2017). The hydropower sector, already a contributor to the national grid, harbours considerable untapped potential along Nigeria's rivers and waterways. Small- to medium-scale hydroelectric projects could dramatically increase the energy supply, especially in areas not served by the grid (Fasipe et al., 2021).

Biomass energy, derived from agricultural residues, not only contributes to energy generation but also promotes more sustainable farming practices. The country's geographical diversity supports the varied potential for solar and wind renewables in the arid north and hydro and biomass renewables in the more verdant south and central regions (Edeh & Okpo, 2023). The integration of these renewable energies into Nigeria's grid promises to meet the essential needs of its population, catalyse job creation, and boost local industries (Golobish et al., 2023).

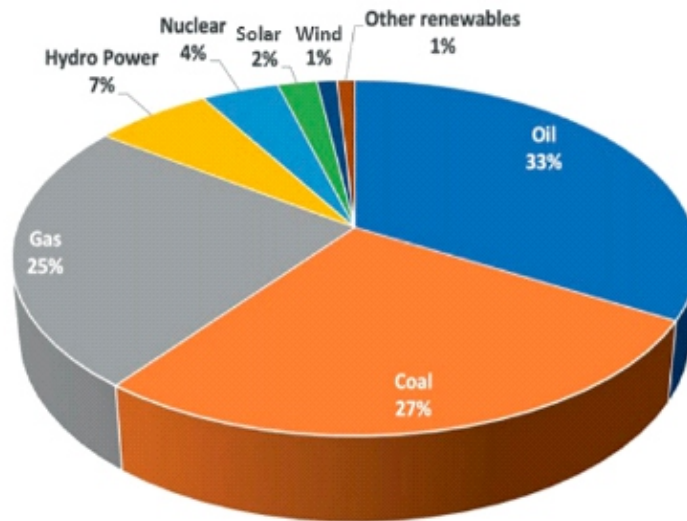


Figure 2: Energy Mix in Nigeria

Renewable Energy Potentials in Nigeria

Renewable energy sources have contributed to Nigeria's energy mix in the last few centuries, albeit in a largely primitive way. Nigeria as a country is potentially endowed with various types of energy sources, including conventional energies (fossil fuel, liquefied natural gas, and coal) and renewable energy resources (biomass, wind, solar, hydro, tidal, and geothermal, among others). Nweze (2015) opined that only solar and biomass energy, if fully harnessed, can generate all the energy needs of the country, thereby totally reducing the challenges of CO₂ emission in the atmosphere. Sad to say, the potential of RE in Nigeria arguably has not been fully discovered by policymakers. In particular, renewable energy (RE) offers significant potential benefits such as meeting rural energy demands, providing reliable household heating and electricity, and

supporting the operation and heating needs of industrial plants, among other applications (Ani, 2017).

Biomass Energy Potential in Nigeria

The presence of various biomass resources (including agricultural crops, residues, forestry materials, municipal solid waste, and animal waste) offers substantial opportunities for biofuel production and energy generation (Edeh & Okpo, 2023).

Biomass is primarily derived from four key sources: agricultural waste, municipal solid waste, animal residue, and forest residue (Laska & Ikeh, 2023). These sources collectively contribute to a significant portion of the nearly 220 billion tonnes of biomass produced globally each year, offering a renewable energy alternative capable of generating considerable energy with relatively low greenhouse gas emissions compared to fossil fuels.

Nigeria generates approximately “227,000 tonnes of fresh animal waste daily, and 1 kilogram (kg) of the fresh animal waste produces 0.03 m³ of gases, and as such, Nigeria can produce about 6.8 million m³ of biogas daily.” Nigeria generates 145,000 tonnes of municipal waste daily, mostly in the urban water areas. The increasing urbanisation and industrialisation places Nigeria with the ability to generate over 20,000 MW of electricity daily from biogas, eliminating power outages and environmental degradation through the process of recycling the waste generated on a daily basis in the country (Sasongko et al., 2023).

Table 1 shows the estimated energy potential from various Biomass Source in Nigeria.

Organic Waste (Biomass)	Estimated biogas potential (billion m³/yr)	Bio-methane potential (BMP) of biogas (billion m³ /year)	Energy Potential of biogas (TJ) per annum
Cattle manure	6.52	3.65	142,350
Sheep and goat manure	2.3	1.61	62,790
Pig manure	0.92	0.55	21,450
Poultry manure	2.5	1.65	103,350
Abattoir manure	4.42	2.65	103,350
Human Manure	2.6	1.69	65,910
Crop residue	4.98	3.0	117,000

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Municipal solid waste (MSW)	3.29	2.85	83,150
Total	27.53	15.65	660,350

Source: Ngumah et al (2013)

From Table 1, the estimated biogas is around 660,000, which is equivalent to 170,541.66 MWh. Comparing the result to the works of Ngumah et al. (2013) revealed that the biogas generated from the 170,541.66 MWh is equivalent to 1.01 trillion m³. This implies that about “17% (4.34 billion m³) of the 25.53 m³ total estimated biogas potential is required to totally displace kerosene and coal as domestic fuel, while 80% (20.42 billion m³) of this total estimated biogas potential will reduce wood fuel consumption by about 66%.”

Technologically, biomass can be converted into various forms of energy and products using either thermochemical or biochemical methods. Each method has unique advantages and limitations, influenced by the characteristics of the biomass feedstock and the desired end product (Ong et al., 2019). The potential for the commercial exploitation of biomass for electricity generation in Nigeria is significant, particularly given the high value of fuel products derived from these processes.

Solar Energy Potential in Nigeria

Solar energy, derived from the sun's radiant light and heat, is increasingly being recognised as a vital component of the global energy landscape (Chanchangi et al., 2023). The location of Nigeria close to the equator places the country at an advantage to generate enough solar energy that can drive the economy through various solar energy technologies.

Nigeria has immense solar energy potential due to its favourable geographical location near the equator, which provides abundant sunshine throughout the year (infoguidenigeria.com, 2024). The country's solar energy potential is estimated at around 6500 terawatt hours (TWh) per year, which is currently higher than the country's current electricity output at an average of 3570 TWh. This potential is further supported by Nigeria's wind potential, approximately at 76 gigawatts, indicating that there is an abundant resource available for renewable energy generation in the country (infoguidenigeria.com, 2024). Research indicates that solar energy has the significant potential to contribute to Nigeria's energy mix, providing clean, reliable, and stable power to its population (Chanchangi et al., 2023). The country's solar radiation varies from 3.5 to 7.0 kWh/m² per day, with an average solar radiation level of about 5.5 kWh/m² per day (Bamisile et al., 2017). The estimated potential of solar energy in

Nigeria, considering a 5% device conversion efficiency, is 5.0×10^{14} KJ of useful energy annually, equivalent to about 258.62 million barrels of oil produced annually and about 4.2×10^5 GWh of electricity production in the country.

Extensive research has been conducted to assess the solar energy landscape, focusing on critical factors such as irradiation and radiation intensity. Banisile et al. (2017) conducted a comprehensive analysis that revealed the greater solar irradiation in the northern regions compared to the south, reinforcing the suitability of these areas for solar power generation. A separate study conducted by Bawonda et al. (2023) estimated the solar energy potential of Nigeria through analytical and simulation techniques, considering the techno-economic and environmental aspects of renewable energy projects. Their findings emphasised Sokoto as an ideal location for solar energy investment, boasting abundant solar energy output and an attractive internal rate of return. These findings supported earlier findings by Osinowo et al. (2015) and Ohunakin et al. (2015), who highlighted the prevalence of elevated solar radiation in the northern parts of Nigeria, reaffirming the region's suitability for solar power projects. In line with this, the northern regions of Nigeria, particularly the northeast and cities like Kano, Sokoto, and Niger State, have the highest solar energy potentials due to their higher levels of solar radiation compared to the other regions of the country (Ogunjo et al., 2021).

Wind Energy Potential in Nigeria

Wind energy has the potential to complement all other conventional and renewable energy sources in Nigeria, ensuring a stable supply of electricity. Its applications extend to irrigation and meeting domestic needs in rural regions. Electricity from wind energy is generated by harnessing the kinetic energy of moving air. Wind turbines, or wind energy conversion systems, play a pivotal role in this process by converting this kinetic energy into electrical power. The amount of energy produced is contingent on several factors, including the wind speed, turbine size, and blade length (Adeshina et al., 2024).

Nigeria has yet to tap into the full potential of wind energy (Mukasa et al., 2024). Notably, North African countries like Morocco, Egypt, and Tunisia have taken the lead in wind energy utilisation. To unlock the complete spectrum of wind energy benefits, both onshore and offshore wind resources need to be explored. The distinction between onshore and offshore wind hinges on the wind's direction: onshore wind travels from the sea to the land, while offshore wind flows from the land to the sea. In the southern regions of Nigeria, wind speeds tend to be generally low, with some exceptions in coastal areas (Ajayi, 2010). Conversely, northern Nigeria boasts stronger winds, particularly in hilly terrains, as revealed in Al-Hinai et al. (2021). Africa has seen the

completion of several wind energy projects, with others currently underway. However, the development of wind power on the continent has primarily centred on onshore projects, owing to a limited understanding of the potential for offshore wind energy (Adeshina et al., 2024).

Olayinka (2011) investigated the wind energy potentials of six high-altitude regions in Nigeria using Weibull distribution models and 36 years of wind speed data. The mean wind speed in Katsina was 9839 m per second, while the mean wind speed in Kaduna was 3397 m per second. In contrast to Gusau, which might be used for wind energy with taller turbine towers, Katsina and Kano are suitable locations for the construction of wind turbines. Kaduna, Bauchi, and Potiskum, however, have just a little amount of wind energy potential. Kano and Potiskum had the highest and lowest wind power density and energy, at 368.92 W/m² and 3224.45 kWh/m²/year, respectively. Similarly, Adaramola and Oyewola (2011) analysed the distribution of the wind speed and the potential for wind energy at three locations in Nigeria's Oyo state using wind speed data that was gathered over a 12–20-year period. The average monthly wind speed in Oyo is 3.15 m/s, with power densities ranging from 27.08 to 164.48 w/m². For its 250-kilowatt maximum output and a minimum wind speed of 2.7 m per second, the WES30 wind turbine is universally recommended. In all except the windiest environments, low-rated wind turbines (those with cut-in wind speeds of roughly 2.5 m/s) will produce the most energy. The G-3120 type with a rated wind speed of 8 m/s is recommended since it has a high-capacity factor. By modifying the specified wind turbine types to run at lower wind speeds than their rated wind speeds, the annual energy production and capacity factor may be greatly increased.

Hydroelectricity Energy Potential in Nigeria

Hydropower stands as a cornerstone of the global renewable energy portfolio, boasting an impressive total installed capacity of approximately 1360 GW (IHA, 2022). Nigeria is among the African countries richly endowed with abundant water resources, providing substantial potential for hydropower generation. Harnessing this potential could significantly alleviate the nation's persistent electricity challenges; however, only a small portion of this resource has been developed and utilised (Ugwu et al., 2022).

Although there are no globally acknowledged criteria for classifying hydropower, Nigeria's hydropower systems are classified according to the size and capacity of their power-producing facilities, reflecting the country's abundance of varied water sources, such as major streams and rivers.

Table 2: Classification of Hydropower

Different Types of Hydropower	Capacity
Pico hydropower	≤5 kW
Micro hydropower	≥5 kW and ≤100 kW
Mini hydropower	≥100 kW and ≤1 MW
Small hydropower	≥1 MW and ≤10 MW
Medium hydropower	≥10 MW and ≤100 MW
Large hydropower	>100 MW

Source: ECN (2023)

The table above presents the classes of Nigeria's hydropower ranges, from pico to large hydropower. Nigeria has the capacity to generate around 86,400 GWh of electricity annually from its large-scale hydropower, with an exploitable capacity of 24 GW. However, about 14,750 MW of the total has been identified, while the total installed capacity stands below 2400 MW as of 2022, representing about 16% of its identified potential, highlighting the vast untapped potential in the country (Muhammadu & Usman, 2022; ECN, 2023). Notable among the large hydropower plants in Nigeria are the Kainji, Jebba, and Shiroro hydropower stations, with installed capacities of 760 MW, 570 MW, and 600 MW, respectively, and representing 30% of the national electricity (Ogunbiyi et al., 2021). These three stations are strategically located on the Niger and Kaduna rivers. Nigeria's dedication to harnessing its hydropower potential to meet its growing energy demands, reduce reliance on fossil fuels, and enhance energy security while contributing to the global transition toward renewable energy sources has brought about the Zungeru Hydroelectric Power Plant, which is currently under construction and is projected to add 700 MW to the national grid. As part of its commitment to sustainable energy development, Nigeria is embarking on ambitious future expansion plans, including the Mambilla Hydroelectric Power Project, with the potential to contribute up to 3050 MW.

Table 3: Small Hydropower Station in Nigeria

Rivers	Location (State)	Installed Capacity (MW)
Annoke Ugbokpo	Benue	1.2
Bagel I	Plateau	1
Bagel II	Plateau	2
Bakalori	Sokoto	3
Challawa Gorge	Kano	7
Ikere	Oyo	6
Kurra	Plateau	8
Kwali Falls	Plateau	6
Lere	Plateau	8
Ouree	Plateau	2
Oyan	Ogun	9
Tiga	Kano	6
Total		59.2

Source: ECN, 2023; IRENA, 2023

From Table 3, boasting diverse capacities, only a 59.2 MW capacity is installed. But these capacities collectively contribute to Nigeria's considerable untapped hydropower potential. Harnessing this energy to its fullest would be instrumental in narrowing the energy divide, particularly in remote communities of the country.

Renewable Energy Policies in Nigeria

The Renewable Energy Master Plan (REMP) seeks to increase the supply of renewable electricity from 13% of total electricity generation in 2015 to 23% in 2025 and 36% by 2030. Renewable electricity would then account for 10% of Nigerian total energy consumption by 2025.

The Plan also encompasses capacity targets installed for a set of suitable renewable energies, declining as follows:

- Small-hydro: 600 MW in 2015 and 2,000 MW by 2025;
- Solar PV: 500 MW by 2025;
- Biomass-based power plants: 50 MW in 2015 and 400 MW by 2025;
- Wind: 40 MW for wind energy by 2025;

Simultaneously to this increase in power supply, the REMP targets higher electrification rates, from 42% in 2005 to 60% in 2015 and 75% by 2025.

The REMP also implements a set of fiscal and market incentives to support RE deployment. In the short term, the plan includes a moratorium on import duties for

renewable energy technologies. In the longer run, the plan advises the design of further tax credits, capital incentives and preferential loan opportunities for renewable energy projects.

According to Ajayi and Ajayi (2013), Nigerian energy policy was initially written in 2003, revisited in 2013, and used as the foundation for the creation of many energy policy documents. Some policies include:

- National Energy Policy (2003, 2006, 2013)
- National Economic Empowerment and Development Strategy – NEEDS (2004)
- Renewable Electricity Policy Guidelines – REPG (2006)
- Renewable Electricity Action Program – REAP (2006)
- Nigerian Biofuels Policy and Incentives – NBPI (2007)
- Renewable Energy Master Plan – REMP (2012)
- Sustainable Energy for All – SE4ALL (2012)
- National Renewable Energy Action Plan – NREAP (2016)
- National Renewable Energy and Energy Efficiency Policy – NREEEP (2015)

Challenges of Renewable Energy Integration for Nigeria's Energy Security

The development of renewable energy (RE) technologies in Nigeria has been slow, despite acknowledging their potential as a sustainable alternative to fossil fuels. Challenges bedevilling the realisation of RE in Nigeria arise from ineffective policies, insufficient training, high costs, and a dearth of skilled personnel. A summary of these challenges would suffice;

Solar Energy

The overall technical potential for solar PV is vast, with projections ranging up to 427 GW of the installed capacity. Currently, adoption of solar energy remains low despite significant potential. Solar home systems and mini-grids are growing, but large-scale solar plants are still in their infancy. Challenges facing solar energy realization are; High upfront costs for solar PV; Lack of financing models for rural and urban adoption; Policy inconsistency and lack of incentives. According to IRENA (2023), the following could drive realization of solar energy Declining cost of solar PV technologies; Favorable geographic conditions; Growing off-grid electrification demand.

Wind Energy

Estimated wind energy potential of 2–4 m/s at a 10 m height. Suitable areas for wind energy are largely in the northern regions. Total technical potential for onshore wind

power is about 27 GW. At present, wind energy adoption is minimal, with only a few pilot projects in states like Katsina. Large-scale wind farms have not been established. Challenges to the realisation of RE sources are low wind speeds in most regions, lack of technical expertise, and inadequate investment in wind technology. However, as posited by **56** www.environewsnigeria.com (2024), this resource can be driven by wind potential in Northern Nigeria (e.g., Sokoto, Kano, and Borno) and rising demand for decentralised energy solutions.

Hydropower

Estimated potential of 14,120 MW (small, medium, and large hydropower). Small hydropower potential alone is about 3500 MW. Currently, hydropower is the most developed RE source, contributing about 30% of Nigeria's energy mix, mainly from large dams such as Kainji, Shiroro, and Jebba. Small hydropower remains underdeveloped. Challenges are high initial capital costs for dam construction, environmental and social impacts, including displacement, and poor infrastructure for rural communities. The drivers for this resource as identified by IRENA (2023) include strong government focus on hydropower, development of small hydropower to boost rural electrification, and renewable energy policies (e.g., the Renewable Energy Master Plan).

Biomass Energy

The biomass potential in Nigeria is vast, with estimates ranging from 144 million tonnes/year from wood to over 14.6 million tonnes/year from crop residue. The biomass-to-electricity potential is about 5 GW. Currently, biomass is used for traditional cooking (wood, charcoal), and modern cooking (biogas) is widespread. However, modern biomass for electricity remains limited due to the lack of technology and industrial interest. The identified challenges are lack of infrastructure for modern biomass technologies, deforestation and unsustainable harvesting practices, and lack of awareness and policy focus. In view of the notable challenges, the drive for biomass could be enhanced through an abundance of agricultural waste and wood biomass and high demand for rural electrification solutions (Acen et al., 2024).

Conclusion and Recommendations

Renewable energy (RE) has been identified as the most potent source of energy in terms of sustainability, availability and environmental friendliness. This is because of its ability to transmit, convert and save other sources of energy as well as its potential to

generate sufficient energy in an environmental manner. RE guarantees sustainable development of the economy, especially the UN Sustainable Development Goals (SDGs), ensures survival of mankind and ultimately ensures the preservation of the environment. Renewable energy (RE) has considerable potential in Nigeria and could bridge the major energy gaps created by fossil fuels in Nigeria, such as the improvement of Nigerian economic growth through RE policies and measures and the abundance of natural resources in Nigeria from which RE can be drawn. The quest to fully appreciate the benefits of these potentials through energy security is on the increase globally.

Nigeria is a nation with energy resources that are not fully tapped; it faces the problem of inadequate infrastructure, vandalism and oil theft. According to an International Energy Agency (IEA) report of 2015, Nigeria is one of the countries with the least energy access; it has an utterly weak electricity sector, which was ranked 187 of 189 countries by the World Bank in terms of access. With all the challenges listed above, the nation continually faces the challenge of energy security. Nevertheless, with the growing population, increase in energy demand and high fluctuations in global oil price, energy security will continue to decline, and the nation will continue to remain a developing nation if more reliable energy sources are not incorporated into its current energy mix. This has led the government and other international organisations to introduce certain renewable energy projects, such as solar electrification, biofuel production and wind power projects in the country.

Since 2005, Nigerian power reforms have focused on privatising the generator and distribution assets and encouraging private investment in the power sector. The government continues to control transmission assets whilst making "modest progress" in creating a regulatory environment attractive to foreign investors. Until the power sector reforms of 2005, power supply and transmission were the sole responsibility of the Nigerian federal government. As of 2012, Nigeria generated approximately 4,000 - 5,000 megawatts of power for a population of 150 million people as compared with Africa's second-largest economy, South Africa, which generated 40,000 megawatts of power for a population of 62 million. An estimated 14 - 20 gigawatts of power is provided by private generators to make up for the shortfall. Nigeria has a theoretical capacity of more than 10,000-megawatt generation capacity using existing infrastructure but has never reached close to that potential.

The nation has the potential to resolve the electric power crisis because she is endowed with vast varieties of both renewable and non-renewable energy resources. In Nigeria, however, the electricity supply crisis has been a persistent issue, hindering the country's ability to achieve its full economic potential. The electricity sector in Nigeria is characterised by a significant gap between supply and demand, ageing infrastructure,

inefficiencies in distribution, and high transmission losses. As of 2021, Nigeria, with a population exceeding 200 million, had an installed generation capacity of approximately 13,000 megawatts (MW), but only about 4,000 MW was being distributed, a figure grossly inadequate for the country's needs (World Bank, 2021).

It is recommended that Nigeria aggressively pursue the restructuring of its energy system, transitioning from a reliance on fossil fuels to the broad adoption of renewable energy. This shift aligns with the nation's objectives of enhancing energy security and stimulating economic growth. Nigeria has ambitiously targeted the installation of 10 GW of renewable energy by 2030 and aims to increase this capacity to 30 GW by 2050.

Alongside these goals, Nigeria is committed to reducing carbon emissions by 50% from 2010 levels by 2030 and achieving net-zero emissions by 2060. To address energy poverty and drive socioeconomic growth, the country should strive for universal electricity access by 2030, with a focus on utilising renewable sources for 90% of new connections.

To ensure the successful implementation of Nigeria's energy transition strategy, a structured and strategic plan is crucial. The model should be as follows:

Policy and Governance: For a successful transition, strengthening the regulatory framework to support renewable energy adoption and energy efficiency is crucial. It is advised to mobilise USD 5 billion in renewable energy investments through financial incentives such as tax reliefs, feed-in tariffs, and direct subsidies, attracting both the domestic and international investments necessary to realise these ambitious energy targets.

Infrastructure and Technology: To accommodate a diversified energy mix and integrate renewable energy effectively into the national grid, substantial infrastructure upgrades and expansions are essential. An investment target of USD 2 billion for grid modernisation by 2030 will support an additional 20 GW of renewable capacity (Obad et al., 2024). The goal is for renewables to make up 40% of Nigeria's energy mix by 2030, with a focus on scalable developments in solar, wind, biomass, and geothermal energy.

Capacity Building and Public Engagement: Enhancing capacity-building initiatives and engaging the public is essential to support Nigeria's energy transition. The strategy should include training at least 500 experts from each state in Nigeria in the renewable energy sector by 2030 and conducting widespread public awareness campaigns to inform 60% of the population. These steps are vital to developing a skilled workforce and an informed public that actively support and participate in the energy transition.

Financing and Investment: Securing adequate financing is pivotal to the success of Nigeria's energy transition. It is recommended to attract USD 10 billion in private investment and to leverage USD 3 billion in international climate finance by 2030. These funds are crucial for launching large-scale energy projects that meet Nigeria's renewable energy targets.

Research and Development: To ensure the sustainability of the energy transition, Nigeria is committed to promoting research and development in renewable energy technologies. The government plans to allocate USD 500 million to R&D by 2030, aiming to foster innovation and adapt technologies suitable for Nigeria's unique environmental and socioeconomic conditions.

Environmental and Social Justice: The transition strategy also emphasises environmental and social justice, aiming to ensure that the shift to renewable energy sources contributes positively to societal welfare and reduces environmental degradation.

An inter-ministerial committee to align with both national priorities and international climate commitments should guide the strategies.

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