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Review Article

Renewable energy in Nigeria: Feasibility, policy gaps and pathways to adoption

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Abstract

Nigeria possesses an abundance of renewable energy resources, including solar, wind, biomass, and hydropower, yet these remain largely underutilized due to the nation's reliance on non-renewable energy sources. The development of renewable energy can help address this situation, as it utilizes renewable materials to generate useful energy products. This study examines Nigeria's renewable energy landscape, focusing on resource potential, policy frameworks, and challenges to clean energy adoption. A SWOT analysis identifies solar and wind energy as particularly promising, given the country's abundant sunlight and favorable wind conditions in rural areas. However, obstacles such as high initial costs, grid integration challenges, and skill shortages hinder progress. The review evaluates Nigeria's energy policies and reveals ambitious targets for renewable energy integration, but it also highlights significant barriers, including financial constraints, infrastructural deficiencies, and governance issues. To overcome these hurdles, the review study concludes and recommends that increased investment in research and development, specialized training programs, improved governance, and public awareness initiatives are critical for enabling a sustainable energy transition, reducing dependence on fossil fuels, and enhancing energy access across Nigeria.

1. Introduction

Despite Nigeria being rich in renewable energy sources, our over-dependence on fossil fuels has persisted without significant reduction [1-3]. The nation has not yet fully understood, harnessed, or optimized the potential of renewable energy sources. Currently, a large percentage of Nigeria's power generation is still reliant on fossil fuels [4], which poses economic and environmental challenges. As the population grows and industrialization advances, it is increasingly evident that relying solely on fossil fuels to meet Nigeria's energy needs is neither sustainable nor sufficient [5-7]. Access to reliable energy is critical for socioeconomic progress and poverty alleviation. However, across Africa, and particularly in Nigeria, securing clean, efficient energy services remains a major challenge [8]. Reports indicate that between 60 % and 70% of the Nigerian population still lacks access to electricity, exacerbating the nation's power crisis [9]. Without diversifying energy sources across domestic, commercial, and industrial sectors, these challenges will remain unresolved. Furthermore, adopting innovative technologies to minimize energy waste and reduce costs is essential to address the ongoing power shortages [10].

The potential benefits of renewable energy in Nigeria extend beyond environmental considerations; they offer strategic, financial, and technological advantages [11–13]. The recent rise in global oil prices, limited electricity access, and the significant costs associated with grid expansion have increased interest in sustainable energy development throughout the country [3, 14]. Studies emphasize that renewable energy options like biomass, solar, and wind are feasible in different regions, yet uptake remains limited due to a mix of economic, regulatory, and social factors [2, 9]. For example, Waziri et al. [15] highlight the potential of briquettes as an alternative cooking fuel in Borno State, a conflict-affected region. Their findings demonstrate the socioeconomic benefits of renewable alternatives while underscoring the need for policy support to drive adoption and sustain the briquette industry. In Delta State, Okoro [16] identifies that renewable energy technologies (RETs) such as solar and wind are regionally feasible. However, he cautions that biofuels may not be suitable due to potential adverse impacts on local cassava prices, suggesting that regional policies must consider local economic dynamics.

Adubaa and Shimadab [17] present another promising case for renewable energy adoption in Nigeria. Their study on rice husk-based waste-to-energy (WtE) projects within Nigeria's rice milling sector reveals a dual benefit of reducing CO_2 emissions while generating much-needed rural power. However, they highlight a lack of supportive policy frameworks and infrastructure as barriers to scaling up this approach nationally. Ugwua et al. [18] take a broader view, assessing the general landscape of renewable energy in Nigeria. They emphasize that while there is significant renewable potential, progress is limited by inadequate policy frameworks, insufficient investment, and limited technical capacity to support renewable energy expansion.

In rural areas where access to the national grid remains scarce, hybrid systems provide a potential solution. Mohammed et al. [19] studied the feasibility of a hybrid PV/Wind microgrid in Geidam, Yobe State. They found that combining solar and wind power could offer a viable and cost-effective alternative to diesel generators, with the added benefit of reducing dependence on imported fuels. However, this solution would require adequate investment, technical expertise, and supportive policy environments to become a reality. Given the range of regional, economic, and technological insights from these studies, it is clear that Nigeria's renewable energy strategy must be multifaceted. While the government has introduced various power reforms to encourage private investment and support sustainable energy growth, operational and financial barriers continue to pose significant challenges [20]. Comprehensive feasibility studies, effective policy implementation, and a thorough understanding of renewable energy system design and regional adaptability are essential to overcome these obstacles. This research thus aims to provide an evaluation of the feasibility of renewable energy adoption in Nigeria. By making use of literature on renewable energy potential, existing energy policies, specific renewable technologies, and key challenges, this study offers a holistic view of Nigeria's renewable energy landscape. A SWOT analysis of renewable energy technologies in Nigeria will guide this assessment, examining the feasibility and challenges of Nigerian energy policies for renewable transition and presenting an impact assessment alongside proposed solutions. Ultimately, this study seeks to contribute to the growing body of knowledge that will support policymakers, industry stakeholders, and researchers in designing robust and adaptable renewable energy strategies that align with Nigeria's unique energy needs.

2. Materials and methods

This review study presents a comprehensive survey of evidence-based research on renewable energy and its challenges in Nigeria, a major oil-producing nation. The review covers various renewable energy sources in Nigeria, including solar, wind, hydropower, biomass, geothermal, nuclear, wave, and tidal energy. Additionally, the study provides an updated overview of the electricity situation, policy frameworks, and challenges in the renewable energy sector in Nigeria.

A feasibility study analysis was conducted using a SWOT analysis framework to assess the suitability

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and challenges of the identified renewable energy technologies. This analysis aimed to identify the strengths, weaknesses, opportunities, and threats of each technology in the context of Nigeria's energy needs, available resources, and socio-economic conditions. The technologies analyzed include solar, wind, hydropower, biomass, and other emerging renewable sources.

Moreover, an impact assessment was carried out to evaluate the challenges associated with the adoption of renewable energy in Nigeria. This assessment included analyzing the political, technical, financial, and social factors that influence the development and implementation of renewable energy solutions. Furthermore, a feasibility analysis of existing policies was undertaken to understand the extent to which current governmental frameworks support or hinder the adoption of renewable energy. The review examined the literature on energy policies, including government initiatives and investment incentives, to assess their effectiveness in facilitating renewable energy deployment.

The study utilized various search engines to identify all pertinent scientific publications related to renewable energy in Nigeria and sub-Saharan Africa, with a primary focus on solar, wind, and hydropower, as well as emerging challenges and government policies on power and the environment. Search terms such as 'Renewable energy in Nigeria', 'Renewable energy in Africa', 'Energy scenario in Nigeria', and 'Energy policy in Nigeria' were employed. Given the limited number of published scientific articles on renewable energy in Nigeria during the 2000 to 2024 timeframe, the researchers also incorporated relevant scientific reports and grey literature into the analysis.

3. Results and discussion

3.1. Nigeria electricity situation

In Nigeria, there are about 7 power plants and numerous independent Power Projects producing commercial electricity. Nigeria's current per-person electricity capacity of 28.57 Watts and the national electricity generating capacity of 3,920MW are inadequate for domestic consumption [1, 21]. To fulfill its energy requirements, the nation must have an energy capacity of no less than 1000 Watts per individual or a total power generating/operating capacity of 140,000 MW, which significantly surpasses the present 3,920 MW. Consequently, the country's electricity availability ranged from about 27% to 60% of installed capacity and approximately 28% of the country's electrical production was lost due to transmission and distribution losses [1, 2, 21]. Nigeria possesses the sixth-largest oil reserves globally and nearly 5,000 billion cubic meters of confirmed natural gas reserves. The country also holds an estimated 2.7 billion tons of coal and lignite, along with 31 billion barrels of oil equivalent in tar sand reserves [1, 2]. Identified hydroelectricity sites offer a capacity of around 14,250 megawatts, while biomass resources are available for both conventional and modern energy use, such as electricity production. The current installed capacity of grid electricity stands at around 6,000 megawatts, with roughly 67 percent being thermally-generated and the remainder hydro-based [1].

Nigeria's power sector is segmented into three divisions: generation, transmission, and distribution [22]. At present, there are 23 grid-connected energy plants (thermal and hydro) owned and operated by both public and private entities in these sectors. The sector is solely handled by the government and has a transmission firm with a wide-ranging nationwide network link. There are 11 (eleven) privately owned and operated businesses in the distribution industry that handle consumer distribution [22, 23].

As of December 2013, Nigeria was reported to have 23 electricity generating facilities with a total installed capacity of around 10,396 MW. Among these, approximately 8457.6 MW is derived from a thermal plant with a usable capacity of 4996 MW [24 – 26]. The hydropower plant has a capacity ranging from approximately 1938 MW to 1060 MW. The ownership and operation of the 23 power plants is divided between the government, represented by the National Integrated Power Projects, and private entities such as Independent Power Producers and privatized Generation Companies, with majority ownership and management resting with the government [26].

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The demand-supply mismatch is severe, and there are few generating plants available. Many industrial customers have invested heavily in their own power generators in response to the inadequate services provided by the Nigerian economy, resulting in a significant financial outlay on their part. The percentage of Nigerians without access to energy services would rise over time if things remain as they are [1–3, 27]. Since its inception in 1981, the Rural Electrification Program has only focused on grid expansion; expenses per connection are still high and annual connection rates are low. With low rates for rural areas and a persistent lack of accessible producing capacity, the power sector in Nigeria has little motivation to support an expansion program [27]. Overall, the capital equipment for rural electricity continues to deteriorate due to theft and vandalism, as well as neglect [27].

3.2. Renewable energy development in Nigeria

Access to energy plays a vital role in ensuring stability, prosperity, and the elimination of poverty in a nation [1-4]. It is essential for all countries to prioritize the reliable supply of energy. The sustainable availability of accessible, affordable, and environmentally friendly energy sources is pivotal for long-term economic development [2, 7]. As seen in Fig. 1, renewable energy sources accounted for 29.1% of electricity generation globally in 2022, total of 8 440 TWh.

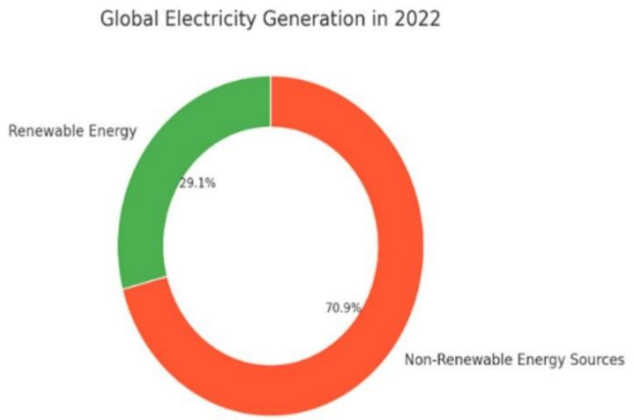

Figure 1. In 2022, electricity generation from renewable sources made up 29.1% of the global total, while, the majority, 70.9%, was produced from non-renewable sources, including fossil fuels, nuclear power, and pumped storage. Adapted from [28].

The other 70.9% (20 591 TWh) corresponded to fossil fuels, nuclear energy, pumped storage and other non-renewables [28]. Solar modules serve as the origin of solar systems, capturing sunlight to generate direct current electricity. The electricity output is proportional to the amount of sunshine received, making these modules essential cores of solar energy systems [1-3, 20]. Worldwide, in 2023, solar energy dominated the global renewable energy landscape, contributing 1,418 GW and representing 36.7% of total capacity. Hydropower ranked second with 1,265 GW (32.7%), followed by wind energy at 1,017 GW (26.3%) [20, 28]. Bioenergy accounted for 149 GW (3.9%), while geothermal and marine energy made only minor contributions as indicated in Fig. 2 [28].

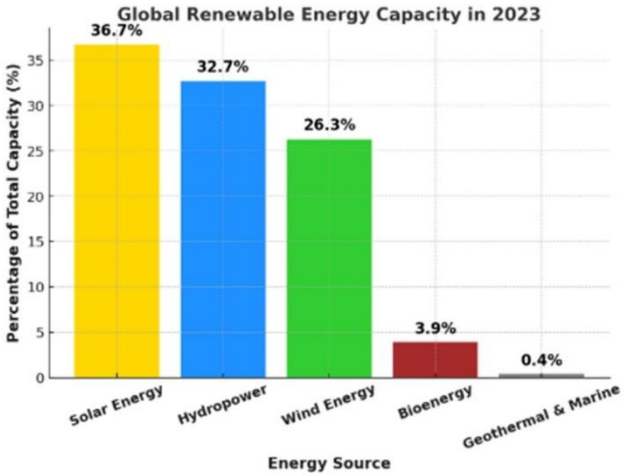

Figure 2. Global Renewable energy landscape. Adapted from [28].

In Nigeria, solar and wind power are the primary sources of renewable energy. Despite being relatively new in the public's perception, clean energy has been a significant source of grid power generation since the 1960s, mostly from hydropower [1, 3]. Until recently, Kanji and Jebba Dams provided about half of Nigeria's reliable electricity supply before gas power plants took over [23]. However, their importance is constrained by the inadequate national grid infrastructure and inconsistent gas supply [23, 29].

Solar power is widely embraced in Nigeria as one of the most favored forms of renewable energy. With its limitless potential, solar energy stands out as a highly promising source of renewable energy [3, 30,

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31]. Nigeria is estimated to receive 5.08 x kWh of solar energy daily, highlighting the significant potential of solar power. Notably, this sunlight is available for about 26% of the day [32].

Nigeria has a plentiful supply of both renewable and nonrenewable energy sources. Nigeria slipped from the first spot in 2015 to 104th spot in 2016 in the Energy Trilemma Index ranking from the World Energy Council [33]. The nation is currently in eighth place globally for energy security; however, its lack of diversity and sustainability in energy sources has caused it to drop to ninth position overall [34]. Gas-powered electricity generation accounts for 80% of the nation's power supply, while hydropower contributes only 14% [30-34]. Nigeria, a major global oil producer, receives considerable solar radiation, but despite these abundant resources, just 48% of the population has access to electricity [30]. Nigeria possesses considerable potential for hydropower energy, currently meeting around 29% of the country's overall electricity requirements. The primary and most substantial hydroelectric facility in Nigeria is located at Kanji, Niger State, on the Niger River. It currently has a capacity of 836 MW, with future expansion opportunities to reach 1,156 MW [30, 35].

Also, Nigeria has abundant traditional and alternative energy sources, including biomass, hydroelectric, solar and wind power. These resources have the potential to meet the country's energy needs and even allow for exporting excess energy to neighboring countries as a profitable commodity for generating revenue [30, 35]. Due to the continuous increase in the country's population, there is currently a shortage of domestic supply, which cannot meet the demand. This requires prompt action to prevent further escalation. The insufficiency in supply leads to various repercussions [22]. Despite substantial investments by the Nigerian government over the past twenty years aiming to enhance energy provision through traditional resources, severe energy deficits still persist within the country [36]. Due to the widespread unavailability of the national utility grid, most people resort to producing their own energy through burning wood or other non-renewable sources. This has adverse effects on both the environment and local inhabitants. Using sustainable energy sources could potentially alleviate these issues in areas with rapid population growth, especially in rural areas [3, 37]. To swiftly expand the availability of electricity in the country, Nigeria's Federal Government has incorporated non-traditional renewable energy as a key element in its comprehensive strategy [37, 38]. In addition to large-scale hydropower, Nigeria's power sector benefits from alternative sources such as small hydro stations, wind, and solar photovoltaic technology [38, 39].

3.3. Renewable energy sources

Over the years, experts and various industries have diversified and switched their attention to exploring renewable sources of clean fuel. Nigeria has a vast wealth of renewable energy at her fingertips. Below are some of these renewable sources found in Nigeria with respect to power generation.

3.4. Solar energy

The Nigerian Meteorological Agency (NIMET) highlights that Nigeria receives an average of 6.25 hours of sunlight per day throughout the year. Positioned within tropical latitudes (4° to 13° N) and spanning around 924,000 square kilometers, the country experiences a broad range in sunlight exposure coastal areas average around 3.15 hours daily, while northern regions see up to 9 hours. This extensive sunlight provides Nigeria with an impressive 4.851 trillion kWh of solar energy every day [40, 41]. Nuclear fusion occurring at the sun's core produces solar energy, which can be harnessed through solar power systems. Solar energy can be converted into usable forms using either solar thermal or photovoltaic technology (Fig. 3) [1, 30, 35]. Solar thermal energy systems are a method of transforming solar radiation into thermal energy. This can be utilized for various purposes, such as heating, cooling, electricity generation, and mechanical energy production. Common applications include drying, distillation, cooking, refrigeration, and power generation in plants [3, 20, 22, 30, 42]. An example of this is Concentrated Solar Power, where mirrors are utilized to reflect sunlight

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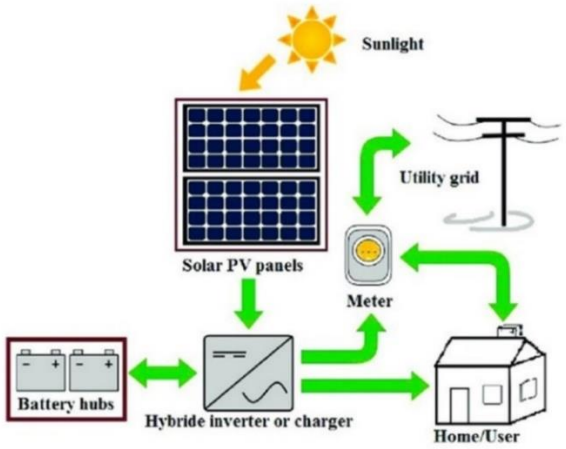

Figure 3. Schematic diagram of a typical solar PV system [1].

onto receivers, which then gather the solar energy and convert it into heat. By employing a steam turbine/heat engine that drives a generator, the converted heat energy is harnessed to produce electricity [42].

On the other hand, the solar photovoltaic (PV) is a system of converting solar radiation into direct current electricity via semiconductors. This is achieved through the photovoltaic effect [1, 30]. In this process, electrons are first in the ground state, but they absorb the energy from the light, which causes them to reach an excited state and release energy that can be utilized. When the energy is used, the electrons return to the ground state, allowing the process to restart.

Nigeria's geographical position presents a significant opportunity for the advancement of solar power, particularly due to its location in the equatorial region. Solar energy is evenly spread across Nigeria, as illustrated in Figs. 4 and 5, with a greater share reaching the northern region [30, 43].

As a result, the country experiences plentiful sunshine, with studies indicating that Nigeria receives almost 290 days of sunlight annually [30, 40]. With approximately 6 hours of daily sunlight, harnessing solar panels to encompass only 1% of Nigeria's total land area has the potential to generate more than one hundred times the current amount of electricity consumed by the grid in the country [3, 43].

3.5. Wind energy

The utilization of wind to produce electricity for

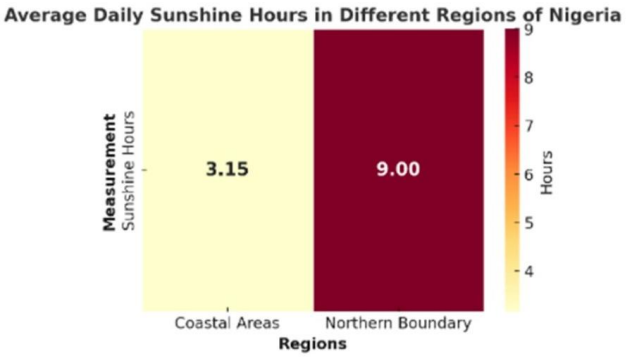

Figure 4. Solar energy potential across two regions of Nigeria showing the highest solar energy potential based on hours of sunshine. Adapted from [40].

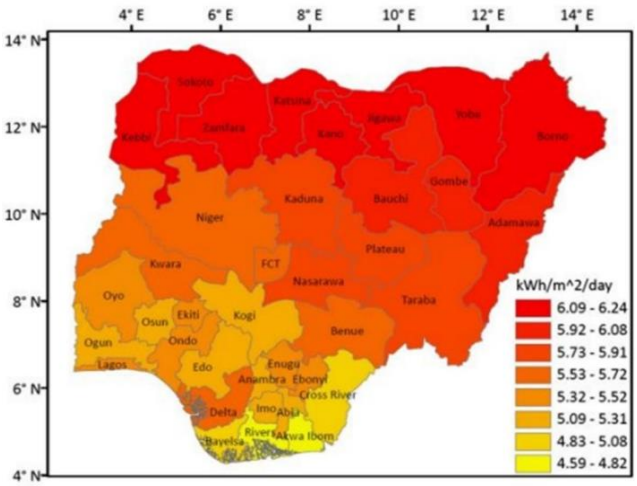

Figure 5. Nigeria's average sun hours' map [43].

practical applications is known as wind energy. The quantity of electricity produced by a wind turbine depends on the variation in temperature at the Earth's surface, which occurs as a result of changes in the Earth's features due to fluctuations in temperatures caused by the Sun's radiation [30]. Wind power devices such as wind turbines for electricity generation, windmills, and water pumps vary in their effectiveness due to the fluctuating intensity of wind across different geographical locations [30]. Therefore, the average power output of a single wind turbine at one spot does not always ensure its overall energy efficiency [44]. Wind power is inherently clean, plentiful, cost-effective, limitless, and eco-friendly [30]. These benefits have contributed to its rapid expansion within the global renewable energy sector.

Wind power is a viable alternative for generating

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electricity in a developing country like Nigeria. It is easily deployed and distributed, even in rural or hilly places [45]. A new study has been dedicated to assessing the wind speed patterns and energy generation prospects in various regions of Nigeria. The Sokoto Energy Research Centre and Abubakar Tafawa Balewa University are working together to enhance technology for generating wind power [30]. Given that wind-generated power is limitless, these investigations should be pursued immediately. Furthermore, using wind energy systems for electricity production might lead to huge reductions in oil usage while dramatically lowering carbon emissions [30].

3.6. Hydro energy

In Nigeria, hydropower has great potential, as it is presently responsible for nearly 29% of the country's total energy production. Hydro energy, which is the utilization of the gravitational force of falling or flowing water to create electricity, is the most common type of renewable energy and is available almost everywhere in the world [2, 23]. Hydropower plants are typically located inside huge dams that have high gravitational pulls. This energy is subsequently transformed into electricity, which may be utilized to run machinery, industries, houses, and street lights [23]. There are a variety of techniques for releasing energy from water. One frequent way is to employ a turbine driven by the velocity of the water. With technological developments, this has become one of the most frequent methods for producing hydroelectric electricity. The turbine turns a generator, which generates energy [30]. Another option is a pump storage hydro plant, in which water is pushed back to the top of a waterfall or stream and let to flow down again to generate electricity as needed [23]. Nigeria is facing a depletion of its natural (water) resources, leading to inadequate power supply and energy. In numerous areas, rivers and streams offer a reliable source of electricity when compared to other forms of renewable energy. Small-scale hydro facilities can be constructed in these locations using just a river and dam [23, 30]. This could provide electricity to rural areas located far from urban centers and power infrastructure while minimizing the impact on the environment caused by fossil fuel energy exploitation.

3.7. Biomass

Fossil fuels, which are composed of biological elements, have a very high energy density due to the release of energy during the oxidation of carbon into carbon dioxide and hydrogen into water following combustion. The term "biomass" refers to material that has recently or directly come from live organisms. They can also be referred to as biologically derived organic non-fossil material [20, 30]. They are made of organic molecules with carbon serving as the base, followed by hydrogen, and often minor amounts of oxygen, nitrogen, and other elements. The term "biomass energy" describes energy derived from biological systems, such as wastes and wood. Byproducts can also be used to create biomass [46].

Nigeria has historically lacked a comprehensive waste management system. Households have resorted to their methods for disposing of refuse. Most garbage is either tossed into the ocean or deposited haphazardly on landfill grounds and allowed to degrade [47]. Currently, in Nigeria, waste at landfills not only produces filth and stink, but it also contributes to climate change by decomposing and emitting greenhouse gases [47].

3.8. SWOT analysis of renewable energy technologies in Nigeria

The SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted to evaluate the potential and challenges of renewable energy technologies in Nigeria. This assessment was based on a review of existing literature, government policies, industry reports, and expert opinions. The strengths and weaknesses were identified by examining the internal factors influencing the development of renewable energy, such as resource availability, technological capacity, and policy support. Conversely, the opportunities and threats were derived from external factors, including market trends, regulatory frameworks, and socio-economic influences. This structured approach provided a comprehensive evaluation of the viability of renewable energy adoption in Nigeria. Table 1

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Table 1. Result of SWOT analysis chart (Grid Layout) for renewable energy technologies in Nigeria [1 – 3, 8 – 10, 19, 20, 30].

Strengths	Weaknesses
Abundant Renewable Resources – Nigeria has significant solar, wind, biomass, and hydro energy potential.	Intermittency Issues – Solar and wind energy depend on weather conditions, affecting reliability.
Growing Energy Demand – Increasing population and industrialization drive the need for alternative energy sources.	High Initial Costs – Renewable energy infrastructure requires significant upfront investment.
Government Policies and Incentives – Supportive policies like tax incentives and renewable energy targets encourage growth.	Limited Technical Expertise – A shortage of skilled professionals to develop, install, and maintain renewable energy systems.
Environmental Benefits – Reduces carbon footprint and mitigates climate change effects.	Energy Storage Challenges – Battery storage is expensive and limits efficiency.
International Partnerships – Foreign investments and collaborations support renewable energy projects.	Weak Grid Infrastructure – The national grid is inefficient and struggles with integrating renewables.
Opportunities	**Threats**
Growing Private Sector Interest – Businesses are investing in off-grid solar and mini-grid solutions.	Fossil Fuel Dominance – Nigeria's economy relies on oil and gas, slowing the transition to renewables.
Rural Electrification Potential – Renewable energy can expand electricity access to off-grid rural communities.	Regulatory and Policy Instability – Inconsistent policies can hinder long-term investment in renewables.
Technological Advancements – Innovations in solar panels, wind turbines, and battery storage improve efficiency and cost-effectiveness.	Funding Constraints – Limited access to financial support and investor confidence delays projects.
Global Climate Commitments – Nigeria's participation in international climate agreements creates pressure to adopt clean energy.	Energy Theft and Vandalism – Theft of infrastructure and sabotage affect the viability of renewable projects.
Carbon Credit and Green Bonds – Financial instruments can attract investment into clean energy projects.	Foreign Exchange Risks – Dependence on imported renewable energy technology makes costs volatile.

provides the result of the SWOT analysis for the renewable energy options considered.

The analysis revealed that Nigeria possesses significant renewable energy potential, particularly in solar, wind, hydro, and biomass resources. Government incentives and international collaborations further enhance the prospects for renewable energy expansion. However, challenges such as high initial costs, weak grid infrastructure, and limited technical expertise remain key obstacles to large-scale deployment. Opportunities exist in rural electrification, private sector investment, and technological advancements that can improve efficiency and affordability. Additionally, Nigeria's commitment to global climate agreements presents an avenue for green financing through carbon credits and renewable energy bonds. However, threats such as policy instability, heavy reliance on fossil fuels, and financial constraints continue to hinder progress. Energy theft and vandalism also pose risks to infrastructure sustainability [1-3, 10, 19, 20, 30].

3.9. Some Nigeria energy policies

This section provides an overview of Nigerian energy policies and strategies, tracing their development from the earliest to the most recent initiatives aimed at promoting renewable energy.

3.9.1. National electric power policy (NEPP) of 2001

Following the Nigerian power sector reform, the National Electric Power Policy was introduced as a pioneering initiative. This development stemmed from the suggestions put forth by the Electrical Power Implementation Committee, which had been tasked with revamping and modernizing the power sector in 1999 [38, 48]. The NEPP, established in March 2001, articulated ambitious objectives for restructuring the power sector through three key measures [48]. The initial move was to introduce integrated power producers (IPPs) and privatize the National Electric Power Authority or NEPA, which was formerly held by the government. The following

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stage was boosting market competitiveness, progressively eliminating subsidies, and selling surplus power to distribution companies or DISCOs. The last stage proposed that the market and competition would have become fiercer, leading to an opportunity for implementing full cost pricing of supply. Additionally, the liberalization of the electricity market would have been fully achieved [48].

3.9.2. National energy policy (NEP) of 2003, 2006 and 2013

The National Energy Policy (NEP) lays out the government's objectives for energy supply, production, and usage. Its key goal is to guarantee energy security by diversifying energy sources and forms, while promoting an energy market where modern renewable energy plays a larger role in overall consumption and offers consistent access to power throughout Nigeria, thereby promoting sustainable development [38, 49].

3.9.3 Renewable electricity policy guidelines (REPG) of 2006

The Renewable Power Policy Guidelines (REPG) were established by the Federal Ministry of Power and Steel in December 2006. These guidelines aimed to empower the Nigerian government to raise the share of power generated from renewable sources to a minimum of 5% of total electricity production, equivalent to at least 5 TWh. This policy declaration outlines the aspirations, strategies, regulations, and targets set by the Nigerian government for advancing renewable energy sources within the electricity sector [38].

3.9.4 Renewable energy master plan (REMP) of 2005 and 2012

The Energy Commission of Nigeria (ECN) and the United Nations Development Programme (UNDP) worked together to develop the Renewable Energy Master Plan (REMP), which underwent a review in 2012. The REMP outlines Nigeria's goals and a strategy for enhancing the role of renewable energy in promoting sustainability. It is influenced by various national policies such as the National Economic Empowerment and Development Strategy, National Energy Policy, National Policy on Integrated Rural Development and Millennium Development Goals, as well as international agreements aimed at poverty reduction and combating climate change [38, 49].

3.9.5. National renewable energy and energy efficiency policy (NREEEP) of 2014

In 2014, the National Renewable Energy and Energy Efficiency Policy was formulated by the Federal Ministry of Power to delineate plans for advancing renewable energy and energy efficiency. Presently, this policy is pending endorsement from the Federal Executive Council [49].

3.9.6. Critical analysis of these Nigerian energy policies, focused on their key target, achievements, feasibility, and challenges

This section critically analyzed Nigeria's key energy policies by reviewing government reports, legal frameworks, and scholarly literature. A comparative matrix table was developed to assess each policy based on its key targets, achievements, feasibility, and challenges. The feasibility evaluation considered implementation success, regulatory support, financial backing, and infrastructure development, while challenges such as regulatory weaknesses, funding gaps, and policy inconsistencies were identified. The findings were structured into a comparative table for clarity, indicating feasibility levels and allowing for a clear side-by-side evaluation of policy effectiveness (Table 2).

The analysis of Nigerian energy policies reveals progressive but inconsistent efforts toward renewable energy adoption. While policies such as the NEPP (2001) and REPG (2006) introduced reforms to increase private sector participation and renewable energy targets, their implementation has faced significant challenges, including regulatory inconsistencies, financial constraints, and infrastructural limitations. The feasibility assessment indicates that while some policies, like the REMP (2005, 2012), align with national and international sustainability goals, their impact has been limited due to slow implementation and inadequate funding. The NREEEP (2014), designed to drive energy efficiency and renewable integration, remains pending government approval, delaying its effectiveness.

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Table 2. Result of feasibility analysis of Nigerian renewable energy policies [38, 48, 49]

Policy	Key target	Achievements	Feasibility score	Challenges
National Electric Power Policy (NEPP) 2001	Restructure power sector through privatization and IPPs	Privatization of NEPA, partial introduction of IPPs	Moderate	Political interference, high poverty rate, fossil fuel dependence
National Energy Policy (NEP) 2003, 2006, 2013	Ensure energy security and increase renewable energy adoption	Some renewable energy growth, but oil and gas still dominate	Moderate	Weak enforcement, lack of private sector incentives
Renewable Electricity Policy Guidelines (REPG) 2006	Increase renewables to 5% of electricity production	Progress made, but target not fully met	Moderate	Regulatory weaknesses, insufficient funding
Renewable Energy Master Plan (REMP) 2005, 2012	Expand renewable energy for sustainability and rural electrification	Policy aligns with national goals, but implementation lags	Moderate	Funding shortages, slow deployment
National Renewable Energy and Energy Efficiency Policy (NREEEP) 2014	Boost renewable energy and efficiency across sectors	Modern approach, but pending Federal Executive Council approval	Low	Lack of policy consistency, slow government action

The findings highlight that while Nigeria has ambitious energy policies, its success depends on stronger enforcement mechanisms, increased financial support, and better coordination between stakeholders. Addressing these challenges is crucial for achieving a sustainable energy transition.

3.10. Challenges and solutions for renewable energy in Nigeria

While renewable energy in Nigeria faces several challenges, it is important to critically assess their impacts on the nation's economy, environment, and society. Below is an impact assessment of each key challenge along with proposed solutions to address them and promote the growth of renewable energy in the country.

3.10.1. Impact assessment and proposed solutions for renewable energy challenges in Nigeria

A systematic assessment was conducted to evaluate the challenges hindering renewable energy adoption in Nigeria, focusing on their economic, environmental, and social impacts. This approach involved: Reviewing literature such as reports, academic studies, and industry publications, which were analyzed to identify key challenges, including financial barriers, technical skill gaps, policy enforcement issues, and low public awareness. Each challenge was assessed in terms of its effects on Nigeria's economy (investment and affordability), environment (sustainability and emissions), and society (job creation and public adoption). Proposed solutions were derived from our expert recommendations, and policy best practices, ensuring they are feasible, scalable, and tailored to Nigeria's energy landscape. The findings are summarized in a concise impact-solution matrix (Table 3).

The impact assessment above highlights key challenges affecting the growth of renewable energy in Nigeria, emphasizing their economic, environmental, and social consequences**.** Limited research and innovation hinder local technological advancement, increasing dependence on imported solutions. Technical skill gaps contribute to poor system installation and inefficiencies, while financial barriers restrict access to clean energy, particularly for low-income households. Policy and governance issues**,** including weak enforcement and regulatory inconsistencies, reduce investor confidence and slow sectoral growth. Additionally, low public awareness limits adoption, preventing widespread acceptance of renewable energy solutions. Addressing these challenges require targeted interventions such as

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Table 3. Impact assessment and solutions for renewable energy challenges in Nigeria [1, 20, 50– 54]

Challenge	Description	Impact	Proposed Solution
Limited Research and Innovation	Nigeria's renewable energy sector lacks significant research investments, particularly in solar and wind technologies. Financial constraints and weak institutional support limit local technological advancement.	• Slow technology adoption • High dependence on imported solutions • Missed local innovation opportunities	• Increase R&D funding • Partner with global research institutions • Provide grants for renewable tech development
Technical Skill Gaps	A shortage of trained professionals in solar installation, grid integration, and maintenance results in inefficiencies. Many installations are carried out by unqualified personnel, reducing system reliability.	• Poor installation quality • Increased system inefficiencies • Limited job creation in the sector	• Establish specialized training programs • Partner with private sector for hands-on training • Incentivize technical education in renewables
Financial Barriers	High upfront costs of solar panels and wind turbines make renewable energy inaccessible to low-income households. Limited financing options and high interest rates further restrict adoption.	• High upfront costs hinder adoption • Energy poverty in rural areas • Continued reliance on fossil fuels	• Introduce microfinance for solar access • Provide subsidies & incentives • Attract foreign investment
Policy and Governance Issues	Despite existing renewable energy policies, poor enforcement, mismanagement, and political instability hinder progress.	• Weak enforcement of renewable policies • Misallocation of energy funds • Reduced investor confidence	• Strengthen policy enforcement • Improve transparency in fund allocation • Establish a national renewable energy fund
Low Public Awareness	Many Nigerians are unaware of the benefits of renewable energy, leading to slow adoption rates. Skepticism from businesses and policymaker's further limits market growth.	• Slow consumer adoption • Limited market growth • Resistance to renewable energy policies	• Launch awareness campaigns • Integrate renewable education in schools • Engage community leaders in advocacy

increased R&D funding, vocational training, microfinance options, stricter policy enforcement, and public awareness campaigns. Implementing these solutions will enhance Nigeria's transition to a more sustainable and inclusive energy future, reducing fossil fuel dependency and promoting economic resilience.

4. Conclusion, future insights and recommendations

The review reveals significant untapped potential for renewable energy in Nigeria, with solar and wind energy emerging as the most feasible and scalable solutions for addressing Nigeria's energy needs. Solar energy stands out due to the country's favorable sunlight conditions, while wind energy shows promise in rural areas with suitable wind speeds. Biomass offers a dual benefit of waste management and energy generation but requires further infrastructure to be effectively implemented. The SWOT analysis proves that the primary barriers to renewable energy adoption, including high initial costs, technical skill gaps, and challenges related to integrating renewable sources with the national grid. Additionally, the review of Nigerian energy policies reveals ambitious targets but highlights critical issues in funding, infrastructure, and policy enforcement that have hindered progress. These findings suggest that Nigeria's renewable energy sector has substantial growth potential if financial, technical, and

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governance obstacles are adequately addressed.

Addressing this gap requires prioritizing research on policy awareness and adoption mechanisms, as existing policies alone are insufficient without effective implementation and public engagement. Advancing solar and wind energy technologies emerges as a strategic focus, given their feasibility within Nigeria's diverse regions. Furthermore, fostering public understanding of renewable energy benefits, as well as the associated policy and regulatory frameworks, is critical for achieving widespread acceptance and adoption. While Nigeria's National Energy Policy seeks to promote renewable energy utilization, it faces substantial hurdles in translating these ambitions into sustainable development outcomes. Overcoming these barriers will be crucial for enhancing the nation's energy capacity, alleviating energy poverty, and contributing to global climate change mitigation efforts. A concerted focus on capacity-building, public-private investment, and strengthening policy enforcement will not only drive progress in renewable energy but also pave the way for a resilient, economically sustainable, and environmentally responsible energy sector in Nigeria.

Future research should focus on conducting region-specific feasibility studies to determine the most suitable renewable technologies, particularly solar and wind, based on local environmental and economic conditions. This approach would enable tailored energy solutions, especially in rural areas where decentralized power systems may be more practical. Increasing investment in research and development (R&D) is essential for fostering local innovation in renewable energy technologies, which could reduce reliance on imported systems and create cost-effective, climate-appropriate solutions. In addition, examining the effectiveness of existing energy policies and regulatory frameworks could help identify areas for improvement in policy enforcement, as well as strategies to overcome governance challenges. To support policy adoption, research into the socioeconomic impacts of renewable energy, such as job creation, improved energy security, and poverty reduction can highlight the broader benefits of renewable integration, providing compelling evidence for policymakers and investors.

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Conceptualization, methodology, supervision, writing-review and editing, J.O.E.; Conceptualization, methodology, supervision, writing-review and editing, T.I.O.; Writing-original draft and supervision, A.N.

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