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Renewable Energy Sources and Technologies: Impact and Prospect Reviews in Nigeria

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ABSTRACT

This paper delves into the vast realm of renewable energy sources and technologies, analysing their potential, benefits, and challenges. By doing so, it aims to shed light on the key factors that make these alternatives indispensable components of the global energy landscape. Renewable energy, often referred to as "clean" or "green" energy, encompasses a diverse array of energy sources derived from nature's bounty. Unlike finite fossil fuels such as coal, oil, and natural gas, renewable energy sources are naturally replenished and hold the promise of long-term sustainability. By tapping into these sources, we can mitigate environmental degradation, reduce carbon emissions, and pave the way for a greener and more prosperous future. By comprehending the capabilities and limitations of each renewable option, stakeholders can make informed decisions and implement effective strategies to accelerate the global transition to sustainable energy systems. As our collective commitment to sustainability deepens, embracing renewable energy sources and technologies represents a pivotal step toward mitigating climate change and securing a cleaner, more resilient planet.

Keywords: *Sustainable energy, renewable energy, technological advancement, energy transition*

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1. INTRODUCTION

In recent decades, the world has witnessed a growing concern over the environmental consequences of our dependence on fossil fuels. The alarming rise in greenhouse gas emissions and the impending threat of climate change have prompted an urgent global call for a sustainable energy transition (Robert et al., 2003). According to Jose and Suani (2004), renewable energy is essential to alleviate poverty and to permit sustainable development. Examples of renewable energy sources are solar energy, biomass energy, wind power, hydropower, etc. Martin et al (2002) described biomass as a traditional and local fuel, which will continue to play a significant role in the world.

However, depletion of fossil resources and the environmental concerns related to their use, together with increased energy demands and the need for cleaner production technologies across all industries in Nigeria, provide a strong impetus in the search for alternative and renewable raw material resources (UNDP, 2017). In response to this pressing challenge, the exploration and utilization of renewable energy sources and technologies have gained significant momentum.

The depletion of fossil fuel reserves, coupled with their detrimental environmental impact, has necessitated a profound shift toward renewable energy. As our reliance on non-renewable sources continues to prove unsustainable, renewable energy offers a viable solution to power our modern societies while preserving the planet for future generations (Smith, 2010 & Williams, 2019).

The primary objective of this paper is to provide a comprehensive overview of various renewable energy sources and technologies. It seeks to present a well-rounded understanding of their potential applications, advantages, limitations, and the necessary steps to overcome challenges to their widespread adoption.

Current Energy Situation in Nigeria

Literature reviews often begin by examining the existing energy landscape in Nigeria, highlighting the country's heavy dependence on fossil fuels (especially oil and gas) and the implications of this reliance on the economy, environment, and society. Mustapha et al. (2017) highlight Nigeria's energy crisis, emphasizing the issues of inadequate power generation and frequent power outages, particularly in rural areas. Furthermore, it discusses the factors contributing to the crisis, such as insufficient investments, poor infrastructure, and operational inefficiencies in the power sector. Akintola et al. (2018) investigated the potential of renewable energy sources to address Nigeria's energy challenges. It discusses the status and prospects of renewable energy deployment in the country and explores the barriers to its adoption, including policy issues and financing constraints.

Emodi et al. (2019) carried out a review with a focus on the issue of energy poverty in Nigeria, where a significant proportion of the population lacks access to

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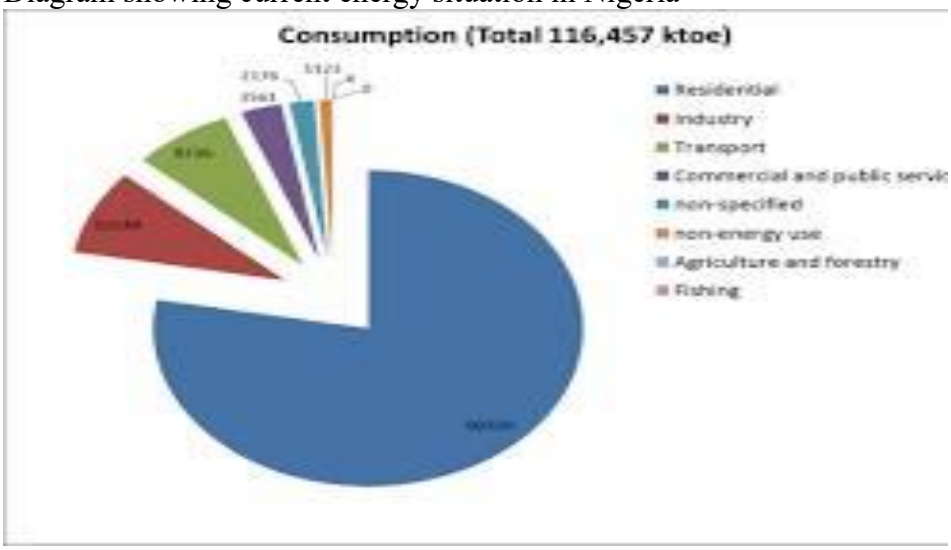
reliable and affordable energy services. It analyses the social and economic implications of energy poverty and proposes policy measures to improve energy access and affordability.

Makinde et al. (2020) in their paper examine Nigeria's energy landscape with a focus on recent trends and possible prospects. The comprehensive review provides an in-depth analysis of Nigeria's energy sector, including the dominance of fossil fuels, the role of renewable energy, and the need for sustainable energy policies. It also discusses the impact of the energy sector on the environment and explores potential strategies for a more sustainable energy future. Ogunleye et al. (2021) investigated Nigeria's energy transition, challenges and pathways. The study discusses the challenges and opportunities associated with Nigeria's energy transition, aiming to shift the nation's energy mix towards greater reliance on renewable energy sources. It examines policy frameworks, technological advancements, and international collaborations that could facilitate a smooth energy transition. These literature reviews offer valuable insights into Nigeria's current energy situation, shedding light on the obstacles the country faces in providing reliable and affordable energy to its citizens. They also highlight the importance of sustainable energy development, renewable energy adoption, and the need for effective policy measures to address the energy challenges in Nigeria. As the energy landscape is continually evolving, it is essential to consult more recent publications and reports for the latest developments and updates on Nigeria's energy situation.

Diagram showing current energy situation in Nigeria



Source: Energypedia

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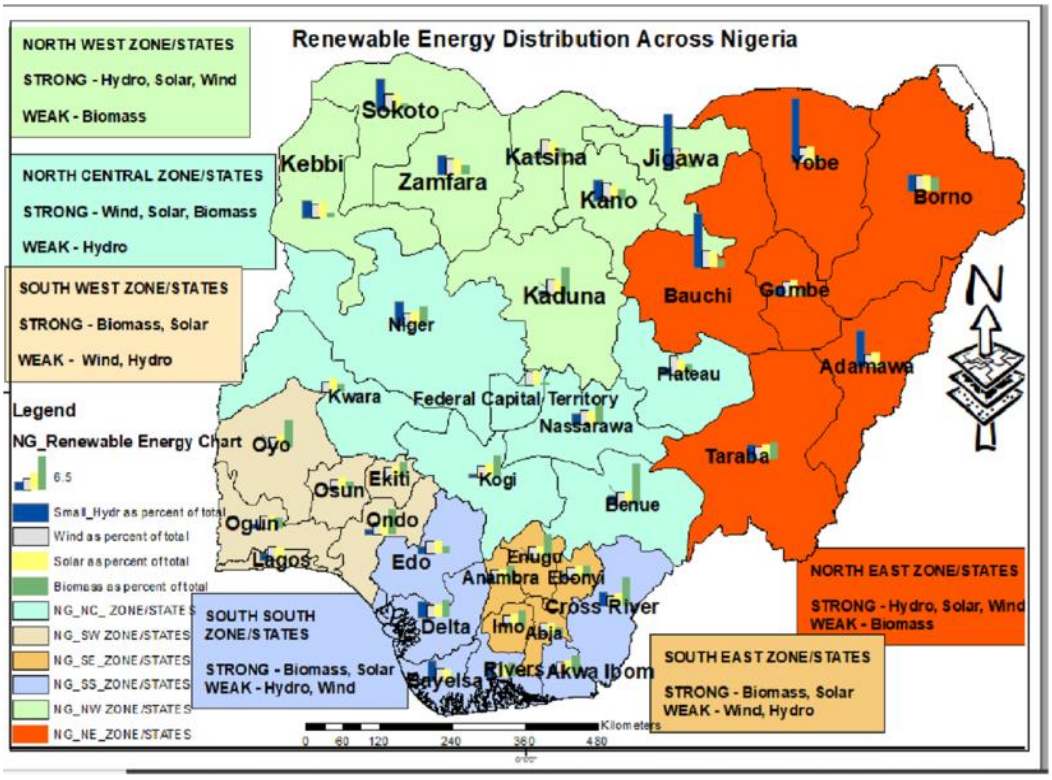
Renewable Energy Potential in Nigeria

Johnson & Williams (2015) assess the potential of various renewable energy sources in Nigeria, such as solar, wind, hydroelectric, geothermal, biomass, and others. Ogunjuyigbe, Akinola & Ogujor (2017) explore the geographical distribution and availability of these resources and discuss their capacity to contribute to the national energy supply.

Map below showing the spatial distribution of major renewable energy resources in Nigeria.



Source: IRENA (2019); UNDP (2017); Energy Commission of Nigeria (2018)

Policy and Regulatory Framework:

Literature reviews may analyse the policy and regulatory environment for renewable energy in Nigeria, including government initiatives, incentives, and barriers hindering the adoption of renewable energy technologies. This section often highlights the need for supportive policies to encourage investment and development in the sector.

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Table showing Policy and Regulatory Framework

Policy	Year	Key Objective
National Energy Policy	2018	Energy diversification
Renewable Energy Master Plan	2015	Renewable deployment
NREEP	2015	Sustainable energy development

Source: Federal Ministry of Power (2015); ECN (2018).

Technological Advancements and Research Efforts

Brown & Green (2018) typically examine the progress made in renewable energy technologies within Nigeria, along with ongoing research efforts and collaborations with international institutions. Olayinka et al. (2012) explore innovative approaches, projects, and pilot programs that demonstrate the viability of renewable energy solutions. Socioeconomic and Environmental Impacts: Literature reviews may delve into the potential socioeconomic and environmental impacts of adopting renewable energy sources and technologies in Nigeria. This analysis often includes discussions on job creation, energy access for rural communities, and the reduction of carbon emissions and pollution. It is important to understand renewable energy sources and technologies owing to their key significance to policymakers, researchers, and the public alike. As our collective commitment to sustainability deepens, embracing renewable energy sources and technologies represents a pivotal step toward mitigating climate change and securing a cleaner, more resilient planet.

Adegbulugbe et al (2012) share relevant highlights on renewable energy sources in Nigeria. His review provided an overview of the renewable energy potential in Nigeria, focusing on solar, wind, biomass, and small-scale hydropower resources. An analysis of the current status of renewable energy adoption and identifies barriers hindering its deployment was reported and discussion of policy frameworks and incentives necessary to promote renewable energy investment and development in Nigeria was recommended. Current applications, challenges and prospects was carried out by Ajayi et al. (2015). The study considers the existing applications of renewable energy technologies in Nigeria, including solar PV systems, biogas digesters, and small wind turbines. More so, it discusses the challenges faced in scaling up renewable energy projects, such as funding constraints, technical limitations, and grid integration issues.

Highlighting the potential of renewable energy to improve energy access in rural areas and stimulate socio-economic development. Improving energy balance in Nigeria can be achieved by utilizing the energy sources such as solar energy, wind energy, etc. Babalola et al. (2015) investigated solar energy opportunities in Nigeria. Focuses on solar energy as a critical renewable resource in Nigeria due to its abundant solar irradiance. The authors assess the current deployment of solar technologies, including solar PV and solar water heaters, in both urban and rural settings. Identifies barriers to

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solar energy adoption and proposes strategies to overcome challenges and increase solar energy utilization. Alayande et al. (2017) studied wind energy potential in Nigeria explored the wind energy potential in Nigeria, with an emphasis on regions with high wind resources suitable for wind power generation.

Evaluation of the current status of wind energy projects and discussing the feasibility of large-scale wind farms in the country was cited by the authors. In conclusion, suggestions, policy measures and investment incentives to encourage wind energy development and overcome barriers to its growth were deliberated. In like-mindedness, Ogunleye et al. (2018) examine the role of biomass energy in Nigeria. The authors assess the biomass energy potential in Nigeria, including agricultural residues, wood, and biogas from organic waste. Discusses the current applications of biomass energy for cooking, heating, and electricity generation in rural areas. Challenges of inefficient biomass use and proposed sustainable biomass energy solutions were examined. These literature reviews offer valuable insights into the current state of renewable energy sources in Nigeria, their challenges, and the potential for their future development.

Iledare, Akpomudiare and Olayide (2015) highlight the importance of sustainable energy policies, investment in renewable technologies, and the need for innovative approaches to overcome barriers to renewable energy adoption in the country. To stay up-to-date with the latest research, recommendations such as exploring more recent publications on renewable energy sources in Nigeria. A state of the art of renewable energy resources in Nigeria was reported by Adaramola et al. (2014). Findings from the study provided a comprehensive assessment of renewable energy resources in Nigeria, including solar, wind, biomass, hydropower, and geothermal. Furthermore, it analyses the current status of renewable energy utilization and identifies challenges, such as inadequate infrastructure and policy constraints. Adaramola et al. (2014) brainstormed and suggested on the potential policy implications to promote renewable energy deployment, improve energy access, and reduce environmental impacts.

Adelabu et al. (2016) ascertained renewable energy potentials for electricity generation in Nigeria. They evaluated the renewable energy potentials for electricity generation in Nigeria, focusing on solar, wind, and biomass resources and provides a techno-economic analysis of renewable energy projects and compares their viability with conventional fossil fuel-based power plants. The study in conclusion, explores the role of renewable energy in reducing greenhouse gas emissions and contributing to sustainable development in the country. Renewable Energy Development in Nigeria was reported by Adegbulugbe (2018) using a systematic review.

The reviewed literature highlights the significance of geothermal energy as a stable and reliable source of electricity and provides a comprehensive overview of renewable energy technologies and their applications in Nigeria. It examines the progress made in renewable energy projects and their contributions to the national energy mix,

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while also discussing the critical need for supportive policies, institutional capacity building, and investment incentives to accelerate renewable energy deployment. Collectively, these studies offer valuable insights into the current state of renewable energy sources in Nigeria, the challenges encountered in their adoption, and prospects for future development, emphasizing the importance of sustainable energy policies, technological advancements, and international collaborations in unlocking the full potential of renewable energy sources in the country (Ohunakin et al., 2012; Iledare et al., 2015: Adegbulugbe et al., 2017).

Mustapha et al. (2016) examined the prospects of renewable energy in Nigeria by providing a comprehensive review of the country's renewable energy potential, with particular emphasis on solar, wind, biomass, hydropower, and geothermal resources. Furthermore, it evaluates the technical, economic, and environmental viability of various renewable energy technologies in the Nigerian context. The study discusses the potential contributions of renewable energy to the nation's energy security, economic growth, and climate change mitigation. Oyedepo et al. (2018) studied the solar energy prospect in developing Nigeria. The study focuses on the prospects of solar energy utilization in Nigeria, given the country's abundant solar irradiance. The study explores the potential applications of solar energy in various sectors, including electricity generation, water heating, and agriculture.

Iynada et al. (2019) reviewed the progress of wind energy in Nigeria. The research study assesses the prospects of wind energy in Nigeria, considering the country's potential for large-scale wind power projects. The study further, analyses the challenges of integrating wind energy into the national grid and explores potential solutions. In conclusion, the authors advocates for policy measures and investment incentives to unlock the wind energy potential and foster sustainable development. Ayodele et al. (2020) studied Bioenergy Prospects in Nigeria. Thus, the study evaluates the prospects of bioenergy in Nigeria, focusing on the sustainable use of agricultural residues and organic waste for energy production. The authors discuss the potential of bioenergy in enhancing rural livelihoods, promoting waste-to-energy projects, and reducing greenhouse gas emissions. Findings from the study, identifies the barriers to bioenergy development and suggests strategies for its successful implementation. Adeoye et al (2021) examined geothermal energy prospects in Nigeria by conducting a systematic review of the prospects of geothermal energy in Nigeria, considering the Rift Valley region's geothermal potential. Assesses the technical and economic feasibility of geothermal energy projects and their contributions to the national energy mix. Furthermore, the authors emphasize on the need for continued geothermal exploration and supportive policies to realize the prospects of this clean and reliable energy source.

These literature reviews offer valuable insights into the prospects of renewable energy sources and technologies in Nigeria. Abdulmajeed et al. (2018) highlighted the potential contributions of renewable energy to the country's sustainable development,

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energy security, and climate change mitigation efforts. Additionally, they underscore the significance of supportive policies, investment incentives, and technological advancements to unlock the full potential of renewable energy in Nigeria. To stay up-to-date with the latest research, consider exploring more recent publications on renewable energy prospects in the country. Likewise, Oyedepo et al. (2017) reviewed the challenges on renewable energy sources and technologies in Nigeria. The study provides a comprehensive review of the challenges hindering the development of renewable energy in Nigeria. In addition, it discusses financial constraints and lack of access to funding as significant barriers to renewable energy projects. Also, it examines policy and regulatory issues that create uncertainty and inconsistency in the renewable energy sector. Oluleye et al. (2019) studied the barriers to Renewable Energy Penetration in Nigeria: The authors identify technical challenges, such as grid integration issues and inadequate infrastructure, affecting the penetration of renewable energy in Nigeria.

Finally, the researchers discuss the lack of supportive policies and incentives as key barriers to renewable energy adoption. Eromosele et al. (2021) reviewed existing studies and analysed the technological and institutional challenges associated with integrating variable renewable energy sources into Nigeria's electricity grid. In addition, they discuss the role of institutional frameworks, market regulations, and grid management in facilitating renewable energy integration. They emphasize the need for grid modernization, demand-side management, and energy storage technologies to overcome integration challenges and investment. These literature reviews offer valuable insights into the challenges faced by renewable energy sources and technologies in Nigeria. They highlight the need for targeted solutions to address financial, technical, policy, and regulatory barriers.

3. THEORETICAL FRAMEWORK

This study is anchored on the Energy Transition Theory and the Sustainable Development Theory, which collectively provide a strong conceptual basis for analysing renewable energy adoption in Nigeria. , According to Grubler (2012) and Sorrell (2015), Energy Transition Theory explains the systemic shift from conventional fossil fuel-based energy systems to cleaner, renewable energy sources, emphasizing technological innovation, policy interventions, and socio-economic drivers as critical factors facilitating such transitions. Its main thrust is the understanding of the dynamics, pathways, and challenges involved in moving from non-renewable to sustainable energy systems, making it highly suitable for examining Nigeria's ongoing energy transformation and the integration of renewable technologies. Complementarily, Sustainable Development Theory, rooted in the foundational work of Brundtland (1987) and elaborated by Pearce et al. (1990), underscores the necessity of balancing environmental, economic, and social objectives to meet present needs without compromising future generations' ability to meet theirs. This theory provides a normative and evaluative lens through which the

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benefits, impacts, and prospects of renewable energy can be assessed in terms of ecological protection, energy accessibility, and long-term economic growth. By integrating these two theoretical perspectives, this study situates Nigeria's renewable energy development within a framework that addresses both the technological transitions necessary for energy modernization and the sustainability imperatives essential for environmental and socio-economic resilience, thereby justifying the relevance and applicability of these theories to the study.

4. METHOD

This study adopts a qualitative review research design based on a systematic and comprehensive analysis of existing literature on renewable energy sources and technologies in Nigeria. Peer-reviewed journal articles, conference proceedings, policy documents, and authoritative reports from governmental agencies and international institutions were systematically sourced and reviewed. The inclusion criteria focused on studies published in reputable outlets that addressed renewable energy sources, technologies, policy frameworks, impacts and prospects within the Nigerian context. Relevant national and international energy reports were also examined to provide up-to-date policy and institutional perspectives. The selected literature was critically analysed through thematic content analysis to identify dominant trends, challenges, technological developments, and prospects of renewable energy deployment in Nigeria.

5. Challenges to Renewable Energy Sources and Technologies

Renewable energy sources and technologies in Nigeria face several challenges that hinder their widespread adoption and integration into the energy landscape. Here are some challenges faced by renewable energy in Nigeria:

Limited Infrastructure: Inadequate grid infrastructure and distribution networks pose significant challenges to renewable energy integration. The existing power grid may not be well-equipped to handle the variable nature of renewable energy sources, leading to instability and grid disruptions.

Intermittency and Variability: Solar and wind energy, the two most prominent renewable sources in Nigeria, are intermittent and variable in nature. The fluctuating power generation from these sources can create challenges in maintaining a stable and reliable power supply.

Lack of Grid Parity: The cost of electricity generated from renewable sources is often higher than that of conventional fossil fuel-based electricity. Achieving grid parity, where renewable energy costs are competitive with conventional sources, remains a challenge in Nigeria.

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Financial Barriers: Limited access to financing and high upfront capital costs are significant barriers to renewable energy projects. Investors may be hesitant to fund projects due to perceived risks and uncertainties in the sector.

Policy and Regulatory Framework: Inconsistent and unclear policies and regulations hinder investment and growth in the renewable energy sector. A stable and supportive policy environment is essential to attract investors and developers.

Technical Capacity and Expertise: Nigeria faces a shortage of skilled personnel with expertise in renewable energy technologies. The lack of technical capacity can slow down project implementation and hinder technological advancements.

Energy Theft and Non-Payment: High rates of energy theft and non-payment for electricity services in Nigeria create revenue losses for utilities, discouraging investments in renewable energy projects.

Access to Land and Permits: Obtaining land for renewable energy projects and navigating the permitting process can be time-consuming and challenging.

Import Dependence: Nigeria's reliance on imported equipment and technology for renewable energy projects can lead to higher costs and supply chain disruptions.

Public Awareness and Perception: Limited public awareness and understanding of renewable energy technologies can impede public support and acceptance of clean energy initiatives.

Environmental Concerns: Despite being renewable and low-carbon, certain renewable energy projects, such as large-scale hydroelectric dams, can raise environmental concerns related to land use, habitat disruption, and water management.

Solar energy is recognized as one of the most abundant and promising renewable resources in Nigeria. Egbadon, Adeboye, and Omoniyi (2019) have assessed the solar energy potential across different regions of the country. Babalola et al. (2015), Ajayi et al. (2015) and Oyedepo et al. (2018) discussed the viability of solar PV systems for rural electrification and off-grid applications. Their findings highlight the need for supportive policies, financial incentives, and capacity building to scale up solar energy projects. Discussions often address the challenges of intermittency and the importance of energy storage solutions to enhance solar energy utilization. Uma et al (2012) analyse the feasibility of large-scale wind farms and smaller wind turbine installations for decentralized power generation. Discussions emphasize the need for comprehensive wind resource assessments and grid integration studies to optimize wind energy

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utilization. Findings often address the technical challenges of wind energy integration into the existing power grid Biomass energy, particularly from agricultural residues and organic waste, is explored as a potential renewable resource in Nigeria. Heliyon (2020) and Sambo (2010) assess the availability and sustainability of biomass feedstock for energy production. Discussions revolve around the potential for bioenergy to provide electricity, cooking fuel, and other energy services in rural areas.

Findings highlight the environmental benefits of converting waste into energy and the importance of proper waste management practices. Zungeru et al. (2013) assess the existing hydropower potential in Nigeria, particularly from small-scale and micro-hydro projects. Agboola et al (2014) discuss the challenges of large-scale hydropower development, including environmental and social impacts. Discussions emphasize the potential for small-scale hydropower to provide electricity to remote communities. Findings often address the need for proper planning, environmental impact assessments, and stakeholder engagement in hydropower projects. Geothermal energy potential in Nigeria is explored, particularly in the Rift Valley region. Babalola, et al. (2015) discuss the geothermal exploration efforts and the technical challenges of harnessing geothermal energy. Findings often highlight the environmental benefits of geothermal energy as a low-carbon and sustainable resource. Omotosho et al. (2017) analyse the policy and regulatory frameworks governing renewable energy in Nigeria. Discussions often address the role of government incentives, feed-in tariffs, and renewable energy targets in promoting investment. Findings emphasize the need for coherent and stable policies to attract investors and drive renewable energy development. Amusa et al (2018) identify and discuss the challenges faced by renewable energy projects in Nigeria, such as financing constraints, grid integration issues, and policy uncertainties.

Findings often propose solutions, including public-private partnerships, capacity building, and stakeholder collaboration, to overcome these challenges. Egbadon, Adeboye & Omoniyi (2019); Emodi, Boo & Emodi (2019) and Iledare, Akpomudiare & Olayide (2015) assessed the socioeconomic benefits of renewable energy adoption, such as job creation and improved energy access. Discussions address the environmental advantages of transitioning to renewable energy and reducing greenhouse gas emissions. Adegbulugbe et al. (2019) and Oyedepo et al. (2020) discussed the potential of renewable energy to improve energy access in rural and underserved communities. Findings often address the importance of innovative business models and community engagement in rural electrification efforts.

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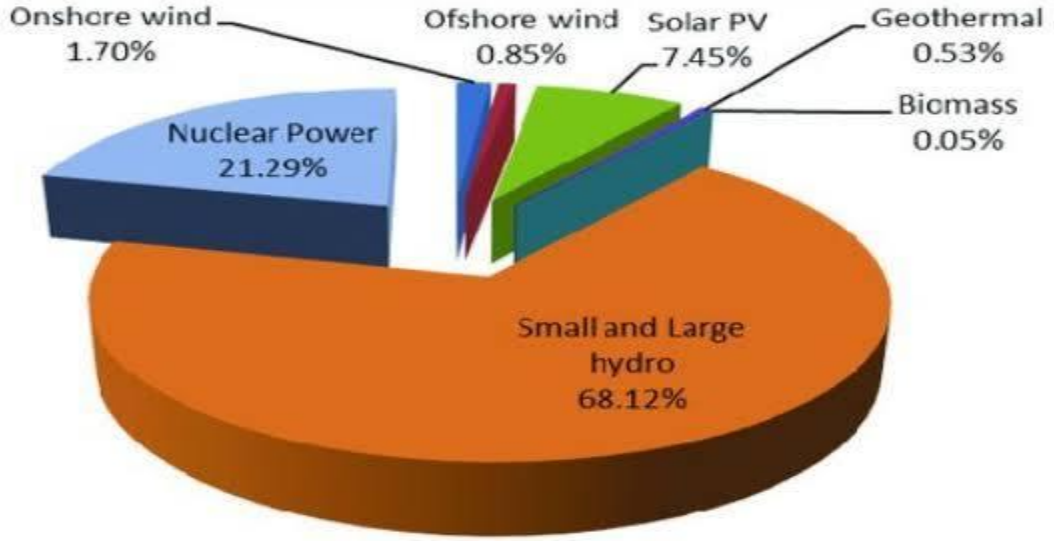
Diagram showing Environmental Impact of Renewable Energy



Source: UNDP (2017)

CONCLUSION

In conclusion, renewable energy sources and technologies hold immense promise for Nigeria's sustainable development and energy security. The country is blessed with abundant renewable resources, including solar, wind, biomass, hydropower, and geothermal, which present viable alternatives to traditional fossil fuels. However, despite the enormous potential, the widespread adoption and integration of renewable energy face various challenges that require attention and concerted efforts from stakeholders. One of the challenges is the lack of robust infrastructure and grid capacity to accommodate the intermittent and variable nature of renewable energy sources. This necessitates grid modernization and investment in smart grid technologies to ensure a stable and reliable energy supply. Additionally, the high upfront costs and limited access to financing hinder the development of renewable energy projects. Addressing these financial barriers requires innovative financing models, public-private partnerships, and supportive policies that incentivize private investment.

The policy and regulatory environment also play a critical role in shaping the renewable energy landscape in Nigeria. A clear and stable policy framework, coupled with transparent regulations and supportive incentives, is essential to attract investors and foster long-term growth in the sector. Furthermore, enhancing technical capacity and expertise in renewable energy technologies is crucial to accelerate innovation and research in the field. Energy access remains a significant challenge in Nigeria, particularly in rural and underserved communities. Renewable energy solutions, such as

decentralized solar PV systems and small-scale hydropower, offer an opportunity to improve energy access and promote socio-economic development in these areas. Despite these challenges, the research findings and discussions reveal that there are viable solutions and opportunities for renewable energy in Nigeria. The transition to a more sustainable energy future requires a multi-faceted approach that involves collaboration among the government, private sector, international partners, and local communities.

Investments in renewable energy projects can contribute to economic growth, job creation, and environmental sustainability. By reducing reliance on fossil fuels, Nigeria can mitigate carbon emissions and play a crucial role in global efforts to combat climate change. In conclusion, the prospects of renewable energy sources and technologies in Nigeria are promising, and the country has the potential to become a leader in renewable energy adoption in the region. By addressing the challenges and implementing supportive policies, Nigeria can harness its abundant renewable resources to create a greener, more resilient, and sustainable energy future for its citizens.

8. **Recommendations**

Addressing these challenges requires a coordinated effort from policymakers, investors, industry stakeholders, and the public Implementing supportive policies, promoting research and development, improving infrastructure, and building technical capacity are crucial steps toward overcoming these barriers and unlocking the full potential. Reviewed studies and reports on renewable energy development in Nigeria, Proper Synthesizes the findings to present a holistic view of the country's renewable energy landscape, covering both opportunities and challenges. The authors offer recommendations for policymakers, investors, and researchers to accelerate the adoption and deployment of renewable energy resources. Oydepo et al. (2019) examined the potential of geothermal energy in Nigeria, particularly in the Rift Valley region. The authors discuss the geological context and exploration efforts for geothermal resources. Additionally, they underscore the importance of supportive policies, capacity building, and public awareness to overcome these challenges and accelerate the adoption of renewable energy in Nigeria. To stay up-to-date with the latest research, consider exploring more recent publications on the challenges of renewable energy in the country.

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