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Harnessing Abundant Rural Materials and Community Involvement for Nigeria's Energy Transition: A Pathway to Sustainable Development

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ABSTRACT

Energy transition is essential for sustainable development in Nigeria, given the country's heavy reliance on fossil fuels and the challenges of energy poverty in rural areas. While global discussions on energy transition emphasize technical and policy innovations, there is a critical need for the early involvement of rural communities in this process. In Nigeria, where rural populations are often marginalized from mainstream energy planning, including them in decision-making, implementation, and management of renewable energy projects can enhance community acceptance and sustainability. Additionally, the current focus of multinational corporations on large-scale projects without community involvement exacerbates energy disparities and environmental issues. This paper explores the importance of harnessing abundant rural materials such as agricultural wastes, afforestation initiatives, and rivers in Nigeria's energy transition strategy, highlighting the necessity

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of early community involvement. It also discusses the current dependence on the national grid and fossil fuels, the pivotal role of villages in the energy transition, and the need for a comprehensive national plan that prioritizes rural communities. Comparative cost tables and benefits are provided to illustrate the economic viability of decentralized renewable energy solutions. Case studies and recent publications are referenced to demonstrate successful models of community-led energy projects, emphasizing how early engagement can foster local ownership and long-term success.

Keywords: Energy transition; rural materials; rural communities; sustainable development.

1. INTRODUCTION

Energy Transition refers to the global shift from traditional energy sources, primarily fossil fuels such as coal, oil, and natural gas, to renewable energy sources like solar, wind, hydropower, and bioenergy. This transition aims to reduce greenhouse gas emissions, mitigate climate change, and create more sustainable, efficient, and equitable energy systems. The energy transition is essential for meeting international climate goals, such as those outlined in the Paris Agreement, which seeks to limit global temperature rise and achieve net-zero emissions by mid-century [1,2]. Energy Poverty on the other hand refers to the lack of access to modern energy services, particularly electricity and clean cooking technologies. It affects billions of people worldwide, especially in rural and marginalized communities. Energy poverty can lead to negative social, economic, and health outcomes, as it limits access to essential services like healthcare, education, and communication. Addressing energy poverty is a crucial aspect of the energy transition because, without equitable access to clean and affordable energy, the broader goals of sustainability and social equity cannot be achieved [2].

1.1 Relevance of Energy Transition and Energy Poverty

The energy transition has gained momentum globally, as countries increasingly invest in renewable energy sources and policies aimed at reducing dependence on fossil fuels. However, energy poverty remains a persistent issue, particularly in developing regions, where large segments of the population still rely on traditional biomass for cooking and have little or no access to electricity [3]. Bridging this gap is vital for ensuring that the benefits of the energy transition, such as clean energy and improved livelihoods, reach all communities.

The interconnectedness of energy transition and energy poverty means that efforts to decarbonize energy systems must simultaneously focus on extending access to clean energy solutions. According to IEA [4], addressing energy poverty through renewable energy solutions, such as decentralized solar power or small-scale bioenergy systems, can improve energy access while supporting broader climate goals.

In Nigeria, a country heavily reliant on oil and gas, the shift towards sustainable energy presents both significant challenges and opportunities [5]. The nation's rural areas, which comprise a substantial portion of the population, are particularly affected by energy poverty and lack access to reliable electricity. Despite Nigeria's vast renewable energy potential, including solar, wind, biomass, and hydropower, these resources remain largely untapped in rural communities [6].

Early involvement of villagers in energy transition efforts is essential to ensure sustainable outcomes, equitable access to clean energy, and improved livelihoods. This paper emphasizes the necessity of including rural communities in the planning and execution stages of energy transition, explores the potential of rural materials for renewable energy production, and addresses the challenges and strategies for effective community participation. Additionally, it critiques the current focus of multinational corporations on large-scale projects that often exclude local communities [7], exacerbating energy disparities and environmental degradation.

2. THE CONTEXT OF NIGERIA'S ENERGY TRANSITION

Nigeria's energy sector is predominantly reliant on oil and natural gas, which provide over 80% of government revenue and more than 90% of export earnings [8]. This heavy dependence on fossil fuels poses significant economic and environmental risks, including vulnerability to global oil price fluctuations and substantial greenhouse gas emissions. Concurrently,

Nigeria's renewable energy potential, particularly solar, wind, and biomass, is vast yet underutilized. The Federal Government's Renewable Energy Master Plan (REMP) outlines ambitious goals for integrating renewable energy sources into the national grid and providing off-grid solutions for rural communities. However, despite these policies, millions of rural Nigerians still lack access to electricity, highlighting the persistent energy poverty in these regions [9].

2.1 Current Focus on Multinational Corporations and Its Limitations

The current energy transition efforts in Nigeria are significantly influenced by multinational corporations (MNCs) focusing on large-scale renewable energy projects. While these initiatives contribute to national energy goals, they often overlook the involvement of local communities. This top-down approach can lead to resistance, lack of community support, and inefficient project implementation, as local needs and socio-cultural contexts are not adequately considered [10]. The exclusion of rural communities from the planning and decision-making processes undermines the sustainability and acceptance of renewable energy projects, perpetuating energy disparities and environmental challenges.

2.2 Harnessing Abundant Rural Materials for Energy Transition

2.2.1 Agricultural wastes (Biomass and Biogas Energy from Agricultural Residue)

Nigeria's rural areas, especially those in the agricultural belt, produce substantial agricultural waste, including crop residues, livestock manure, and agro-processing by-products. These wastes can be converted into bioenergy using anaerobic digestion and gasification technologies. Biomass energy is a versatile renewable source suitable for electricity generation, heating, and biofuel production [11]. Though versatile it is one of the most underutilized resources in Nigeria's rural communities. Crop residues like rice husks, corn stalks, and cassava peels can be converted into bioenergy through anaerobic digestion, producing biogas for cooking and electricity [12]. In Northern Nigeria, small-scale biogas digesters have been adopted by communities, reducing reliance on firewood and mitigating deforestation and indoor air pollution [13].

2.2.2 Benefits of bioenergy in energy transition

- **Reduction of Energy Poverty:** Bioenergy provides affordable and reliable electricity to rural areas not connected to the national grid, alleviating energy poverty [14].
- **Environmental Protection:** Utilizing agricultural waste for energy reduces greenhouse gas emissions, as these wastes would otherwise release methane when decomposed.
- **Job Creation:** Bioenergy projects, including the operation of biogas plants, generate employment, contributing to local economic development.

2.3 Afforestation (Wood-based Energy)

Afforestation—the process of planting trees in deforested or non-forested areas—plays a crucial role in environmental conservation, carbon sequestration, and energy production. In the context of energy transition, afforestation is a sustainable strategy for creating renewable energy sources, particularly wood biomass [15]. Wood-based energy, derived from afforestation programs, can be utilized for electricity generation, heating, and cooking, offering a renewable alternative to fossil fuels and reducing reliance on unsustainable logging practices in rural areas [16].

2.3.1 Sustainable wood biomass

Sustainable wood biomass production through afforestation involves the cultivation of fast-growing trees, such as eucalyptus, bamboo, and acacia, specifically for energy purposes. These trees, planted in managed forests or degraded lands, offer a renewable source of fuelwood without the need for continuous deforestation. The concept of energy forests—plantations grown explicitly for fuel production—has gained traction as an effective way to mitigate the environmental impact of traditional logging while addressing energy poverty in rural areas [17]. Planting fast-growing trees like eucalyptus and bamboo can ensure a steady supply of biomass for energy production while serving as a carbon sink, mitigating climate change [15]. Research has shown that wood biomass derived from afforestation programs can be used for small-scale electricity generation in rural areas, either through direct combustion for heat or in combined heat and power (CHP) systems. These systems convert wood biomass into both

electricity and thermal energy, improving energy efficiency and reducing waste. Additionally, wood chips and pellets, which are produced from tree residues, can be utilized in biomass power plants to generate clean electricity, offering a viable energy source for off-grid communities [12].

Moreover, afforestation projects have the potential to create job opportunities, particularly for rural residents, in areas such as tree planting, forest management, and biomass processing. This can contribute to rural development and poverty reduction by providing new income streams and improving local livelihoods [18]. Additionally, integrating afforestation into rural development programs promotes community ownership of energy resources, empowering local people to manage their own energy systems and participate in the energy transition [10].

2.4 Carbon Sequestration and Climate Change Mitigation

One of the key environmental advantages of afforestation is its role in carbon sequestration. Trees absorb carbon dioxide (CO2) from the atmosphere during photosynthesis, storing it in their biomass and soil. By expanding forest cover through afforestation programs, CO2 is removed from the atmosphere, helping to mitigate the effects of climate change [19]. This dual function—carbon sequestration and renewable energy production—makes afforestation an attractive strategy for countries like Nigeria, which are working towards their carbon reduction commitments under international climate agreements such as the Paris Agreement [17].

In addition to carbon sequestration, afforestation projects also contribute to biodiversity conservation. Managed forests can serve as habitats for various plant and animal species, supporting ecosystem services such as water filtration, pollination, and soil fertility [14]. These environmental co-benefits further enhance the sustainability and long-term viability of afforestation programs as part of the broader energy transition strategy.

2.5 Benefits of Afforestation in Energy Transition

- **Carbon Sequestration:** Afforestation helps sequester carbon, mitigating climate change while providing renewable energy.
- **Rural Job Creation:** Afforestation programs generate jobs in tree planting, biomass harvesting, and management of biomass energy systems.
- **Sustainable Fuel:** Using sustainable wood biomass reduces dependence on unsustainable fuel sources like firewood, preventing deforestation.

2.6 Challenges and Policy Recommendations

Despite its potential, afforestation for wood-based energy faces several challenges. These include land availability, the risk of monoculture plantations, and inadequate policy frameworks to ensure the sustainability of afforestation programs. The establishment of energy forests may compete with agricultural land, especially in densely populated regions. Additionally, monoculture plantations, where only one type of tree species is grown, can negatively impact soil health and biodiversity if not properly managed [16].

To address these challenges, experts recommend that afforestation programs be integrated into broader land-use planning strategies, ensuring that they do not displace agricultural activities or harm local ecosystems. Furthermore, promoting mixed-species plantations and agroforestry systems—where trees are grown alongside crops—can enhance biodiversity, improve soil fertility, and provide additional income sources for farmers [17]. Policymakers should also establish clear guidelines for the management and monitoring of afforestation projects to prevent unsustainable practices and ensure long-term success.

Government support and incentives are essential to scale up afforestation efforts for renewable energy. Financial mechanisms such as subsidies for tree planting, tax breaks for biomass energy producers, and grants for rural communities to participate in afforestation programs can encourage investment in sustainable wood biomass production [20]. Additionally, collaboration with international organizations and private sector actors can help provide the technical expertise and resources needed to implement large-scale afforestation projects in Nigeria [12].

3. RIVERS AND SMALL-SCALE HYDROPOWER

Nigeria’s rural villages are often located near rivers and streams, offering significant potential

for small-scale hydropower. Unlike large hydropower projects, small-scale systems are less invasive and can provide sustainable energy to rural areas [21].

3.1 Mini and Micro-Hydropower Systems

Mini and micro-hydropower systems, generating less than 10 megawatts of electricity, can be installed on small rivers to supply local communities. These systems are ideal for off-grid areas, providing reliable electricity without the need for extensive infrastructure [11]. In Plateau State, a successful small-scale hydropower project improved electricity access for a rural village, enhancing quality of life and supporting local economic activities like irrigation and agro-processing [22].

3.2 Benefits of Small-Scale Hydropower in Energy Transition

- **Renewable and Reliable:** Hydropower is a constant and reliable energy source, especially in areas with perennial rivers.
- **Off-grid Solutions:** Small-scale hydropower systems are ideal for rural communities not connected to the national grid, providing affordable and sustainable energy.
- **Low Environmental Impact:** Compared to large dams, small hydropower systems have a minimal environmental footprint and require fewer alterations to river ecosystems.

4. INVOLVEMENT OF RURAL COMMUNITIES IN ENERGY TRANSITION

4.1 Community Ownership and Acceptance

Engaging rural communities from the outset fosters ownership and enhances project acceptance. When villagers participate in decision-making about energy projects, they are more likely to support and maintain these initiatives, ensuring their long-term success [10].

4.2 Improved Economic Outcomes

Renewable energy projects in rural areas can generate employment and income, improve agricultural productivity through bio-fertilizers from biogas, and reduce operational costs through energy efficiency. Economic benefits incentivize villagers to prioritize renewable energy infrastructure [23].

5. ADDRESSING ENERGY POVERTY

Addressing energy poverty is a critical challenge, particularly in Nigeria, where over 85 million people lack access to electricity, with the majority residing in rural areas [24]. Renewable energy projects, such as solar mini-grids, wind turbines, and clean cooking technologies, offer promising solutions to bridge this energy gap. Early community involvement is essential to designing and implementing solutions that meet the specific needs of these underserved areas. Tailored renewable energy systems can improve access to reliable electricity, which not only enhances living standards but also boosts economic productivity, education, and healthcare access.

Additionally, clean energy technologies can reduce the reliance on polluting fuels like kerosene and firewood, which are common in rural households and pose serious health risks due to indoor air pollution. This shift to clean energy can significantly improve public health outcomes by reducing respiratory illnesses and other pollution-related diseases" [25-27]. Furthermore, renewable energy solutions promote environmental sustainability by minimizing deforestation and carbon emissions, contributing to broader climate goals. Empowering communities with clean, affordable, and reliable energy through sustainable projects is key to tackling energy poverty and advancing social and economic development across Nigeria.

5.1 Cultural and Social Integration

Cultural and social integration is crucial for the success and sustainability of energy projects, particularly in diverse or rural communities. By understanding and incorporating local traditions, beliefs, and social structures, projects can align more effectively with the needs and values of the population they serve. This approach not only fosters trust and collaboration but also ensures that the project is perceived as beneficial and respectful of local ways of life. When community members feel their voices are heard and their customs are acknowledged, they are more likely to participate actively, support the project long-term, and take ownership of its outcomes. This can be especially important in community-led renewable energy initiatives, where local

knowledge and participation drive both implementation and maintenance. Moreover, such integration can help avoid potential conflicts and ensure that the project is adaptable to the unique socio-cultural dynamics of the region, ultimately contributing to its broader success [20].

6. CURRENT DEPENDENCE ON NATIONAL GRID AND FOSSIL FUELS

Nigeria's energy infrastructure is heavily dependent on the national grid and fossil fuels, which are centralized and often unreliable, especially in rural areas. This dependence not only perpetuates energy poverty but also makes the country vulnerable to disruptions in oil supply and price fluctuations. Decentralized renewable energy solutions, harnessing rural materials, offer a pathway to reduce this dependence by providing reliable and sustainable energy directly to local communities [28].

7. STRATEGIES FOR EARLY INVOLVEMENT OF VILLAGERS

7.1 Inclusive Energy Planning

Incorporating rural representatives in energy planning processes at both local and national levels ensures that the unique needs and concerns of rural communities are addressed. This inclusivity helps tailor renewable energy policies and projects to fit the specific socio-economic and cultural contexts of these communities, enhancing the relevance and effectiveness of energy solutions [19,29,30].

7.2 Capacity Building and Education

Education campaigns and training programs are vital to raising awareness about the benefits of renewable energy and equipping villagers with the necessary skills to operate and maintain energy systems. Capacity building should focus on technical training, financial literacy, and sustainable practices, enabling communities to manage renewable energy projects independently and ensure their long-term sustainability [18].

7.3 Collaborative Partnerships

Effective energy transition in rural Nigeria requires collaboration between the government, private sector, and international organizations. These partnerships can provide the necessary financial, technical, and logistical support to implement renewable energy projects. Additionally, involving local cooperatives and village associations can facilitate the organization and representation of community interests, ensuring that projects are community-driven and locally managed [19].

7.4 Financial Models and Incentives

Developing innovative financial models, such as community investment funds, microfinancing, and public-private partnerships, can help overcome financial constraints faced by rural communities. Providing incentives for renewable energy adoption, such as subsidies, tax breaks, and grants, can encourage communities to invest in sustainable energy solutions [14].

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7.6 Comparative Cost Tables and Benefits

The cost-benefit analysis is shown in Table 1.

Benefits:

1. **Economic Empowerment:** Renewable energy projects generate local employment, reduce energy costs, and create income opportunities, fostering economic growth in rural areas [23].
2. **Energy Security:** Decentralized energy systems reduce dependence on the national grid and fossil fuels, enhancing energy security and resilience against disruptions [28].
3. **Environmental Sustainability:** Utilizing agricultural waste, afforestation biomass, and rivers for renewable energy reduces greenhouse gas emissions, combats deforestation, and mitigates climate change impacts [31].
4. **Social Inclusion:** Community ownership and management of renewable energy projects promote social inclusion and empower rural populations, ensuring equitable access to energy resources [10].

Table 1. Comparative cost and benefits of rural energy sources

Energy Source	Cost of Installation (USD)	Annual Operating Costs (USD)	Lifespan	Benefits	Challenges
Biogas (from Waste)	$1,500–$5,000 per system	$200–$500 per system	15–20 years	Reduces greenhouse gases, produces bio-fertilizers	High initial cost, requires consistent feedstock
Fuelwood (Afforestation)	$300–$800 per hectare	$50–$100 per hectare	20–25 years	Carbon sequestration, job creation	Risk of deforestation without sustainable management
Small-Scale Hydropower	$1,000–$3,000 per kW	$100–$300 per kW	40–50 years	Reliable electricity, minimal emissions	Geographic limitations, seasonal variability
Solar Energy	$2,000–$5,000 per kW	$50–$100 per kW	25–30 years	Clean, inexhaustible energy	High upfront cost, requires storage for consistent supply

8. POLICY AND INSTITUTIONAL SUPPORT FOR RURAL ENERGY TRANSITION

8.1 National Energy Policy Integration

Integrating rural energy development into national energy policies ensures that energy transition strategies are inclusive and comprehensive. Policies should prioritize rural electrification through decentralized renewable energy solutions and mandate community involvement in energy projects.

8.2 Government Support and Financing

Government support is crucial for promoting renewable energy in rural areas. Providing financial incentives, such as subsidies, low-interest loans, and grants, can significantly lower the barriers to adopting clean energy technologies. These incentives help reduce the upfront costs for local communities and private investors, making projects like solar mini-grids, biomass energy generation, and clean cooking solutions more accessible. Moreover, the establishment of dedicated rural energy transition funds can streamline the financing process and ensure targeted support for regions most in need. By doing so, the government can foster long-term energy sustainability, reduce poverty, and contribute to improved public health and economic opportunities. Successful rural electrification models, as seen in countries like Kenya and India, have shown that government-backed incentives paired with private sector participation can accelerate the adoption of renewable technologies [32,25].

8.3 Technical Support and Infrastructure Development

Technical Support and Infrastructure Development play a critical role in ensuring the success of renewable energy projects, especially in rural areas. Providing technical assistance ensures that communities have the knowledge and skills to manage and maintain renewable energy systems effectively. This support can include training on the operation of technologies such as solar mini-grids, biomass energy systems, and wind turbines, enabling communities to take ownership of these systems and reduce dependence on external technicians [24,33]. Additionally, developing necessary infrastructure like roads, communication networks, and storage facilities is essential for enhancing the accessibility and efficiency of these projects. Improved infrastructure facilitates the transportation of renewable energy equipment to remote areas, reduces operational costs, and improves the reliability of energy distribution. Furthermore, enhanced communication networks can aid in monitoring systems remotely, ensuring quick responses to maintenance issues [34,25].

8.4 Monitoring and Evaluation

Monitoring and Evaluation frameworks are essential for assessing the effectiveness and sustainability of renewable energy projects, especially in rural areas. By establishing clear performance indicators, these frameworks help track progress toward project goals, identify areas for improvement, and ensure the long-term viability of renewable energy solutions. Regular assessments can also reveal the social, environmental, and economic impacts of these initiatives, providing data-driven insights that inform future projects and policy decisions [24]. A key element of successful monitoring and evaluation is the collection of baseline data, which serves as a reference for comparing the outcomes of energy interventions. This enables the tracking of changes in energy access, health improvements, economic development, and reductions in environmental degradation. For example, evaluating the impact of solar mini-grids in rural communities could measure improvements in access to electricity, household savings, or reductions in the use of polluting fuels like kerosene [34].

Additionally, these frameworks are crucial for understanding the sustainability of projects over time. They allow stakeholders to assess whether energy systems are being maintained correctly, identify any technical issues, and ensure that the community remains actively engaged. When integrated with feedback mechanisms, the insights gained from monitoring can guide the adaptation of strategies, ensuring that projects continue to meet evolving needs [25].

8.4.1 Case studies in Nigeria

1. **Solar Mini-Grids in Nigeria's Rural Communities:** In Jigawa State, a solar mini-grid project was successfully implemented with active community participation. Village leaders and members were involved in the planning, construction,

and management of the mini-grid, resulting in high community acceptance and sustained usage [10]. The project provided reliable electricity to over 500 households, improved educational facilities by powering schools, and enhanced healthcare services by energizing health centers.

2. **Biogas for Rural Agriculture in Northern Nigeria:** A study by Audu et al. [35] examined the implementation of biogas projects in agricultural communities in Northern Nigeria, demonstrating the substantial benefits of early involvement of local farmers. By integrating these stakeholders in the design and operation of biogas digesters, the project saw notable improvements in agricultural productivity. The use of biogas technology helped to recycle agricultural waste, turning it into valuable energy resources, thereby reducing energy costs for the communities and simultaneously mitigating greenhouse gas emissions. The biogas systems not only improved environmental outcomes by reducing the reliance on traditional fuels but also contributed to better waste management. Farmers reported an increase in crop yields due to the availability of organic fertilizers produced as a byproduct of the biogas process. Additionally, the initiative created local employment opportunities, with some farmers generating additional income by selling surplus biogas to nearby households. This economic empowerment fostered a sense of ownership and long-term sustainability of the projects, reinforcing the importance of community involvement in renewable energy solutions [35].

   These outcomes are consistent with findings from other studies on renewable energy in rural areas, such as Olanipekun and Gbadamosi [25], which emphasize the need for local engagement in energy projects to ensure their success and sustainability.

3. **Small-Scale Hydropower in Plateau State:** In Plateau State, a small-scale hydropower project was successfully initiated to supply electricity to a rural village [22]. The community played a key role in both the design and management of the project, ensuring that it met local energy needs and garnered widespread support. This grassroots involvement was crucial for the project's success, as it promoted a sense of ownership and ensured that the system was adapted to the specific requirements of the community. The reliable electricity generated by the hydropower plant had a transformative impact on the village. It facilitated the growth of small businesses, such as grain milling and welding shops, which were previously unfeasible due to the lack of electricity. Additionally, the project supported agricultural development by powering improved irrigation systems, enabling more consistent and efficient crop production. This contributed to increased food security and income for the residents. Furthermore, the availability of electricity improved the overall quality of life, with better access to lighting, refrigeration, and communication services [35].

8.4.2 Case studies from other countries

Harnessing abundant rural materials and community involvement for energy transitions has been successfully implemented in several countries, providing valuable lessons for Nigeria's pathway to sustainable development. Karekezi and Kithyoma [36] have highlighted that small-scale renewable energy projects in rural Africa have demonstrated the benefits of community involvement noting that that locally managed renewable energy projects can ensure greater sustainability and alignment with local needs, particularly in rural settings. Some examples around the world include:

1) **India: Biomass and Solar Power in Rural Areas:** India has made significant strides in harnessing rural materials, particularly biomass, and engaging local communities in its energy transition. The National Biomass Cookstove Initiative (NBCI) promotes the use of efficient cookstoves, reducing the reliance on traditional biomass and improving health outcomes. In addition, India's solar energy programs, such as the **Kusum Scheme**, enable farmers to install solar pumps, reducing diesel consumption and integrating solar energy into agricultural practices [37,38].
2) **Brazil: Biofuels and Local Empowerment:** Brazil has been a pioneer in the production of biofuels, particularly ethanol from sugarcane. The Proálcool Program successfully involved rural communities and farmers in the production

process. Smallholder farmers participate in growing feedstock, contributing to energy security while creating jobs in rural areas [39,40]. This model of using biofuels has helped Brazil reduce its carbon footprint and foster local economic development.

3) **Kenya: Community-Based Solar and Micro-Grids:** Kenya is one of Africa's leading examples of using community involvement for rural electrification. The installation of solar micro-grids in rural areas by organizations like M-KOPA Solar and Power Hive has provided access to electricity for thousands of households. These projects leverage local materials and labor, and they involve communities in managing and maintaining the micro-grids, fostering sustainability and local ownership [41,42].
4) **Nepal: Micro-Hydro Power for Rural Development:** Nepal has successfully harnessed its abundant water resources through community-based micro-hydro projects. The Nepal Micro-Hydro Programme, supported by the government and NGOs, has empowered rural communities to develop, manage, and operate small hydroelectric projects [43,44]. This initiative has improved access to electricity in remote areas and has stimulated local economic development by enabling small industries and businesses.
5) **Germany: Community-Driven Renewable Energy Cooperatives:** Germany's Energiewende (Energy Transition) heavily involves community participation through energy cooperatives. Citizens and local communities have invested in renewable energy projects, such as wind and solar farms. By 2020, more than 40% of Germany's renewable energy capacity was owned by citizens and cooperatives, showcasing how community involvement can lead to substantial energy transitions [45,46].
6) **Denmark: Wind Energy and Local Ownership:** Denmark's wind energy revolution is often cited as a global model for community involvement in energy transitions. Local communities and cooperatives own a significant portion of the country's wind turbines. This decentralized approach has created local jobs, generated wealth for rural areas, and fostered strong community support for renewable energy projects [47,48].

9. KEY TAKEAWAYS FOR NIGERIA

Nigeria has vast untapped resources such as biomass, solar energy, and hydro resources, which can be harnessed to achieve sustainable energy development, especially in rural regions. Drawing from international examples, particularly in countries like Kenya, India, and Brazil, Nigeria can adopt models that emphasize community engagement and local ownership of renewable energy projects, ensuring sustainability and socio-economic benefits for rural populations.

- Community Ownership and Management: In many successful international renewable energy projects, community involvement in decision-making, management, and operations has been key. For example, community-based microgrids in rural India and solar cooperatives in Germany have helped ensure that local populations benefit directly from energy generation. In Nigeria, a similar approach could be applied by empowering local communities to take ownership of projects, such as biofuel production or solar mini-grids. This would ensure that projects are aligned with the specific needs of the community, enhancing both local support and project sustainability.
- Utilizing Rural Resources: Nigeria's vast agricultural and forestry sectors generate significant biomass and agricultural waste that can be repurposed for energy. For instance, biofuel projects can utilize by-products such as palm kernel shells, cassava waste, and rice husks, turning them into renewable energy sources. This can contribute to reducing reliance on fossil fuels while creating jobs and income-generating opportunities in rural areas. According to Olanipekun & Gbadamosi [25], leveraging biomass and other renewable resources offers an affordable and accessible solution to Nigeria's energy poverty, particularly in rural areas.
- Renewable Energy Cooperatives: Cooperatives can offer a viable model for deploying renewable energy technologies in rural Nigeria, as seen in several countries. By pooling resources and enabling local ownership, cooperatives can increase access to affordable energy, reduce operational costs, and build local expertise in managing renewable energy systems. This model also promotes job creation and local economic development,

ensuring that the benefits of energy transition reach those who need them the most.

- Focus on Micro-Grids and Solar: Rural areas in Nigeria are well-suited for decentralized energy solutions such as solar-powered microgrids. Internationally, microgrids have proven successful in providing reliable, off-grid power in remote regions. By prioritizing solar microgrids and other small-scale renewable energy systems, Nigeria can extend electricity access to the over 85 million Nigerians currently without it, particularly in areas where extending the national grid is not economically viable.

By embracing these strategies, Nigeria can ensure an inclusive and resilient energy transition that aligns with global sustainability goals while addressing its unique energy needs.

10. CONCLUSION

Nigeria's vast untapped rural materials—such as agricultural wastes, afforestation biomass, and rivers—hold immense potential for supporting the country's energy transition goals. These renewable resources offer sustainable and cost-effective alternatives to traditional fossil fuels, helping to alleviate energy poverty, especially in underserved rural communities. Utilizing agricultural waste, for instance, through bioenergy initiatives like biogas or biomass-to-energy projects, can not only provide clean energy but also help reduce environmental waste and improve agricultural productivity.

Promoting Environmental Sustainability and Economic Growth: The adoption of renewable energy sources will contribute to environmental sustainability by reducing greenhouse gas emissions and lessening the pressure on natural resources. Rural areas, rich in natural resources, can become centers for clean energy production, spurring local economies. For example, afforestation biomass can support small-scale bioenergy projects, providing employment opportunities in managing and maintaining these energy systems. Additionally, utilizing hydropower potential from rivers and small dams can create a reliable source of electricity for rural areas, boosting both agriculture and small-scale businesses.

Importance of Early Community Involvement: Ensuring the early involvement of local communities in energy projects is key to their long-term success and sustainability. Projects designed with the input and ownership of villagers are more likely to align with local needs and gain widespread support. This inclusive approach fosters a sense of ownership, which is essential for maintaining renewable energy systems. Community-based initiatives also help ensure equitable access to energy resources, ensuring that the benefits of the energy transition reach all segments of the population [49].

Overcoming Challenges Through Strategic Planning: There are challenges to this transition. These include a lack of awareness, cultural barriers, and financial constraints that limit the uptake of renewable energy solutions in rural areas. Addressing these barriers requires comprehensive planning that includes raising awareness about the benefits of clean energy, providing financial incentives, and offering technical support. By prioritizing inclusive planning, capacity building, and establishing collaborative partnerships between government, private sector, and local communities, Nigeria can facilitate a smooth and equitable energy transition.

A Comprehensive National Plan for Rural Energy: A national plan that prioritizes rural communities and provides them with the tools, knowledge, and infrastructure to manage renewable energy systems will not only enhance energy access but also promote economic empowerment. By focusing on locally available resources, Nigeria can create jobs, improve health outcomes through reduced air pollution, and stimulate sustainable development. If these measures are effectively implemented, Nigeria has the potential to become a leader in renewable energy adoption in Africa, setting an example for other countries in their own energy transition efforts.

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Details of the AI usage are given below:

1.ChatGPT4o used to produce Table 1: Comparative cost and benefits of Rural Energy

Sources. Prompted to summarize by arranging the energy sources, cost, and benefits.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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