

Clean and Sustainable Energy Revolution in Nigeria: Synopsis of Opportunities and Barriers in Perspective

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Abstract

Ensuring greater and worldwide access to clean energy is a fundamental requirement for modern socio-economic development. This can be achieved through a robust expansion of research and development in energy sustainable energy technologies especially in developing countries. Moving towards upgrading clean and sustainable energy technologies can unlock the potential for increasing energy supply across the globe. Most developing countries like Nigeria are naturally endowed with many renewable energy resources that remain inadequately untapped. Renewable Energy (RE) also known as clean and alternative energy has been at the forefront of global energy discourse in the last few decades due to climate change. Despite the current global level of utilization of fossil fuels for power generation, Nigeria is still not among the countries with a balance in the level of energy supply and demand for the citizens. The country has so many isolated rural communities that are not connected to the national electric power system due to the challenge of economic constriction. However, the application of RE technologies for energy supply in rural communities could be a cost-effective alternative to the much-anticipated grid extension to rural communities by the energy stakeholders and planners in the country. Therefore, this study presents a synopsis of the opportunities and barriers to developing clean and sustainable technologies in Nigeria. Core problems affecting the smooth deployment of RE in the country were identified through a perceptive literature review in addition to relevant recommendations towards increasing investment in RE investment in the country.

Keywords: Clean Energy, Electricity, Microgrid, Power System, Nigeria.

Introduction

Nigeria like many other countries has dwelled in the energy crisis for a very long time but the country has been striving towards making a good way into the use of sustainable energy. Because the global attention of energy stakeholders has shifted from fossil fuel consumption to renewable energy, the country seeks to diversify its energy generation mix. It is however an undoubted fact that the required paradigm shift from fossil-based energy to renewable energy involves some critical challenges. Exploitation and promotion of clean and sustainable energy can play a vital role in economic progression and poverty

eradication in the country. Future economic growth in Nigeria critically hinges on the long-term availability of clean and sustainable energy supply in the context of global sustainability. Unfortunately, the present situation is that Nigeria is currently engulfed in energy poverty with consequential socio-economic deficiency affecting industrial and commercial settings in the country. Many indigenous research efforts towards the assessment of the viability and applicability of RE in Nigeria have been carried out (Oyedepo, 2012). The energy crisis scenario in Nigeria conditioned the country into the state with the lowest rates of energy consumption in Africa due to an insufficient supply of useable energy (Oyedepo, 2012). The country is blessed with RE resources but the current level of utilization of sustainable energy is quite small.

The speedy depletion of traditional fossil fuels for energy generation is gradually changing and making a landmark wave of global concern due to climate change apprehension. Clean energy conception is the development and utilization of Renewable Energy (RE) such as solar energy, wind energy, bioenergy, and hydroelectricity energy. RE application has tremendous solutions to the prevailing energy crisis scenarios in different parts of the world. On a global scale, the transition from conventional energy to clean and sustainable energy in developing countries is usually a difficult task involving multifaceted challenges. From the beginning, clean energy initiatives sometimes seem techno-economically challenging which usually compels energy engineers to rely more on fossil fuels. However, most developing countries are naturally blessed with abundant RE resources. The global RE adaptation has risen in the last decade as shown in Figure 1. In the western part of the world, substantial progress has been achieved to guarantee adequate access to modern energy (Stern, 2004). In 2019, the percentage of people globally with access to electricity pinpointed that more than 700 million people worldwide still lack access to power (Ajayi et al., 2022). It was reported that providing better energy services to the impoverished populations of developing nations is still a critical barrier to the successful implementation of sustainable development and rural transformation initiatives (Elliott et al., 2017; Bisaga et al., 2021; Guan et al., 2018).

The Objective of the Study

Nigeria has enormous renewable potential that has not yet been fully exploited for national development due to some unresolved challenges. Therefore, the fundamental objective of this study is to provide a review of the opportunities and challenges confronting the deployment of clean and sustainable in Nigeria.

Problem Statement

The global quest for carbon emission reduction with a target of net zero by 2020 is in line with the Paris Agreement which is an agenda of energy transition from a fossil-based economy to RE technologies. Increasing RE energy consumption has helped improve access

to energy and facilitates the integration of RE technologies into the national electric power grid. The population of Nigeria is highly expanding but the country's energy strategies do not comprehensively capture the expanding energy demand of the country. In addition, the lack of priority for rural-centered energy provision to the rural communities in the country has hampered the expected socioeconomic development. Policies on energy development are more favourable to urban and sub-rural areas. Based on this perspective, the inhabitants of rural areas usually depend on the exploitation of agricultural biomass from wood and charcoal for their energy needs. This has conditionally resulted in the degradation of the national forest resources with an attendant impact on the emission of Greenhouse Gases (GHGs). Global warming and environmental problems are highly connected to deforestation. Therefore, this paper presents the prospects and the challenges.

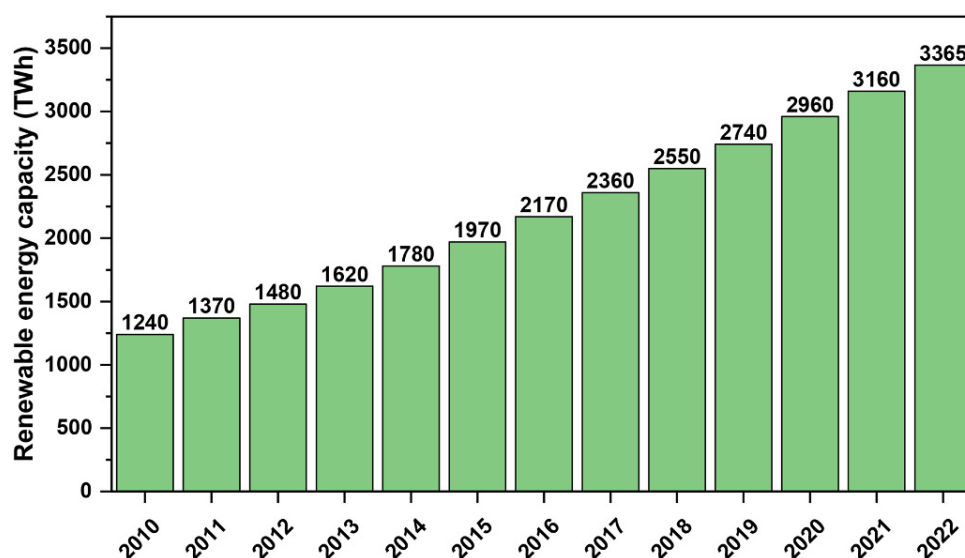


Figure 1: Global renewable energy adaptation for the years 2010-2022 (Garratt, et al., 2023)

Methodology

This study reviews the opportunities and challenges affecting Nigeria's planning, implementation and investment in clean and sustainable energy. In Figure 2, the chart of the research method is presented. The opportunities that exist for the generation and utilization of clean energy in Nigeria are presented. Barriers affecting the exploitation of the resources and the technological development are also highlighted in the framework of this study.

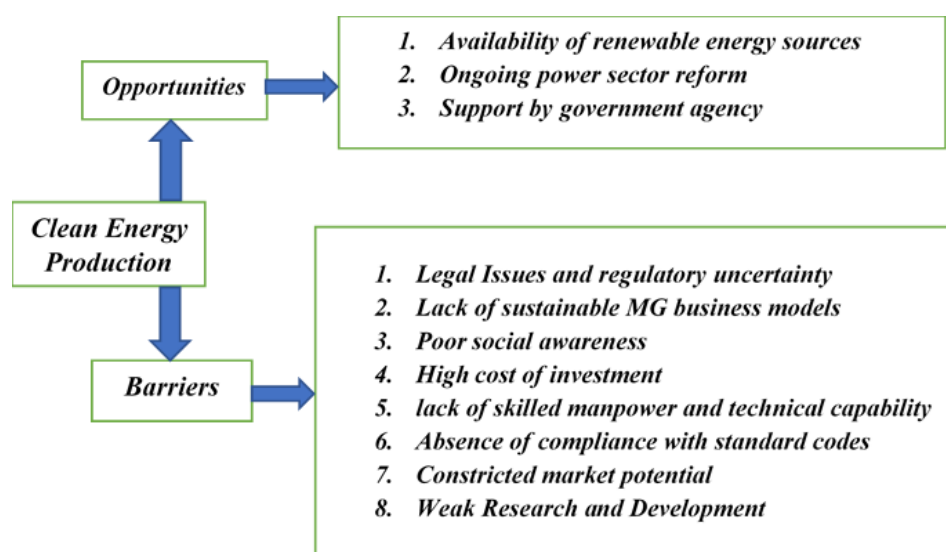


Figure 2: Flowchart of the research method

Opportunities for Clean Energy Development in Nigeria

Nigeria is among the countries that have prioritized RE development in the last few decades. The existing opportunities have not been captured to achieve a good step forward in renewable power generation in the country. Presently, the total number of installed capacity generation of RE in the country cannot be ascertained, unlike the situation in some developed countries such as China, India, America and Europe (Amir & Khan, 2022). Like many other African countries in sub-Saharan Africa (SSA), Nigeria is lagging in the adoption of RE power generation. It was reported by the United Nations Environment Programme (UNEP) that countries in the West African region are sufficiently rich in clean and sustainable energy sources to provide energy for the rest of the SSA region (Ajayi, 2010). In Nigeria like many other countries in SSA, the settlement pattern is a largely scattered rural system with few numbers of houses from tens to hundreds. In such isolated off-grid areas, smaller versions of electric power grids (MGs) are useful power structures in electrifying rural communities (Eid et al., 2014; Jayasinghe et al., 2017; Emmanuel et al., 2017). MGs have different sizes with their corresponding electric power capacities based on their scales such as mini (0.001–0.005 MW), small (0.005–5 MW), medium (5–50 MW) and large (50–300 MW) DG technologies (Jayasinghe et al., 2017). There are many opportunities for promoting the implementation of MG in Nigeria and the following have been identified:

Availability of renewable energy sources

In the context of the unfolding paradigm change in the energy sector, RE especially those that include solar and wind power have become eminent as an effective approach to resolve the problem of energy sustainability. Nigeria is rich in fossil fuels and has substantial potential for RE from wind, hydropower, and solar energy. It is however unfortunate that a

large portion of the clean energy potential has been utilized thereby subjecting the country to a situation of energy imbalance depriving its citizens of a dependable and sustainable electric power supply. Nigeria is naturally blessed with solar, wind, hydropower, and biomass energy sources. Apart from the solar energy which is present everywhere, others can also be found in reasonable quantities across the different geopolitical zones in the country.

Solar Energy: The application of solar energy from the sun to produce electricity can be achieved through the use of solar photovoltaic (PV) systems and concentrated solar power (CSP) systems. Compared to other countries in the world with high installed electrical power generation potential, Nigeria has high values of unexploited solar radiation potential for solar power generation as shown in Figure 3. As shown in Figure 4, the installed solar energy capacity in Africa showing the countries with the highest notable installed solar energy capacity in gigawatts (GW) is presented. It can be observed that the entire region of SSA is deficient regarding the availability of information concerning the installed capacity of solar energy for power generation. However, the opportunities presented by the availability of sustainable solar radiation in Nigeria can be exploited for increasing investment in solar power generation especially among the rural energy providers to enhance socioeconomic development.

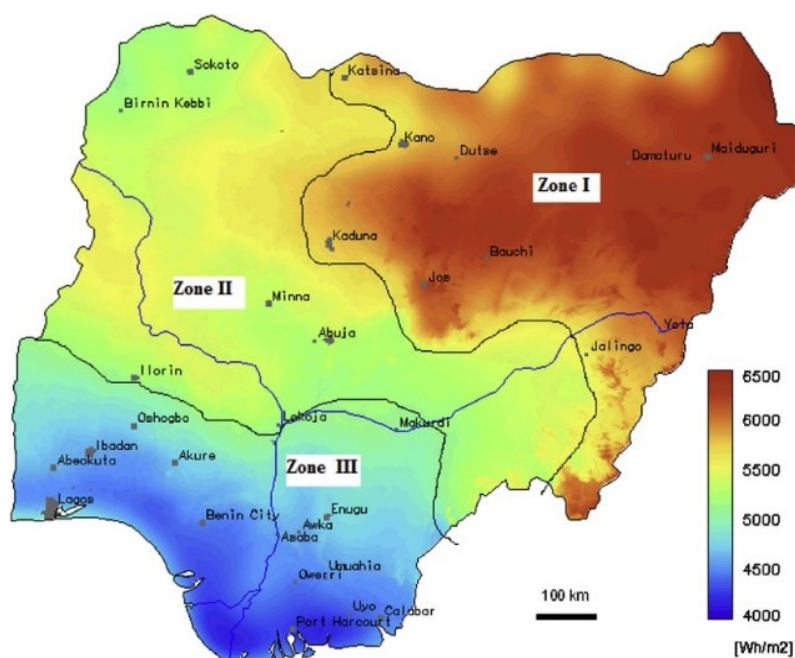


Figure 3: Solar radiation map in Nigeria (Ohunakin et al., 2014)

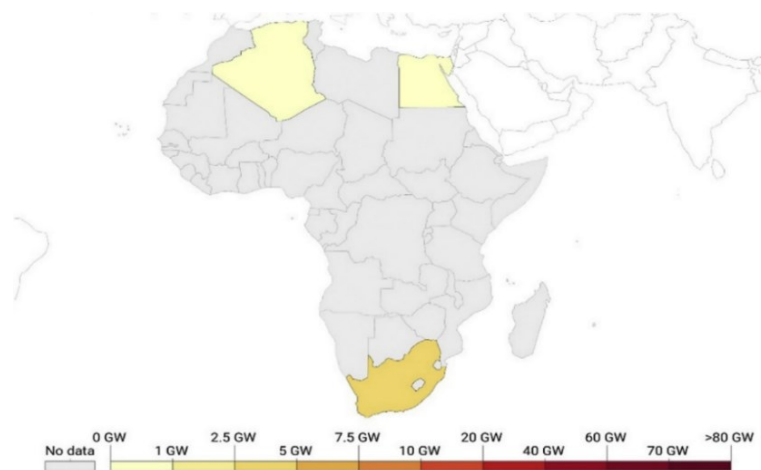


Figure 4: Installed solar energy capacity in Africa showing the countries with the highest notable installed solar energy capacity in gigawatts (GW) (Ritchie & Roster, 2023).

Solar PV systems have been used in the country for many decades. Over the past years, solar PV applications for MG have gained tremendous popularity (Anh, 2014). The popularity is because of the ease of coordination between the match in supply and demand side coupled with the technological simplicity for operation and maintenance. The potential of solar energy for electricity generation and the viability of the PV market in Nigeria has been investigated in many studies (Ohunakin et al., 2015; Enongene, et al., 2019). The National Agency for Science and Engineering Infrastructure (NASENI) has initiated efforts to support Nigeria's first solar PV manufacturing. The efficiency and cost of the solar panel produced locally by NASENI is expected to be as reliable as that imported from other countries into Nigeria thereby putting the local efforts of the government on competitive advantage. The cost of solar-powered MG systems has dropped considerably in the last few years, thereby making it a more economically reliable energy investment in addition to its ecosystem-friendly nature. Besides, the current expedition of solar PV system for implementation of MG in Nigeria, the potential of solar energy in the country can also be tapped for Concentrated Solar Power (CSP) technology for rural electrification. Presently, there is no available comprehensive data in Nigeria on the usage and performance of CSP for power generation. Still, there are possibilities of exploiting the technologies since they use direct solar thermal energy for electricity. Utilization of solar PV and CSP are parts of the environmentally friendly renewable energy technologies. Since there is abundant solar energy radiation in the northern part of Nigeria, there is a likelihood to support the use of CSP technologies for rural MG implementation in that region.

Biomass: In Nigeria, different categories of RES such as solar PV, biomass, wind, and hydropower are available for utilization for energy generation. Biomass is all types of biodegradable agricultural residues that can be used directly or indirectly for the production

of heat and power but mostly electricity. Biomass can be classified into wet and dry residual feedstock. Wet feedstock can easily be handled by any biochemical conversion method such as anaerobic digestion while the dry type is usually treated via a thermochemical conversion approach (gasification, combustion (incineration) and pyrolysis). The concept of biomass for power generation hinges on waste-to-energy technologies as shown in Figure 5. Municipal solid waste (MSW) from urban refuse dumps and agricultural crop post-harvest trash can be converted into useful economic consumption in the form of electricity and heat production. In addition to energy generation, biowaste products from the processing of biomass agricultural residues can also be used for the production of organic fertilizer for farm applications. Utilization of available biomass in Nigeria for power generation through MG technologies will assist the nation's power sector to explore the possibilities to confront the lingering problem of energy supply crisis in rural areas. However, the potential of biomass for rural electrification in Nigeria has been presented in many studies (Giwa, et al., 2017; Somorin et al., 2017; Mohammed, et al., 2014; Ibikunle et al., 2019; Rezaee et al., 2014).

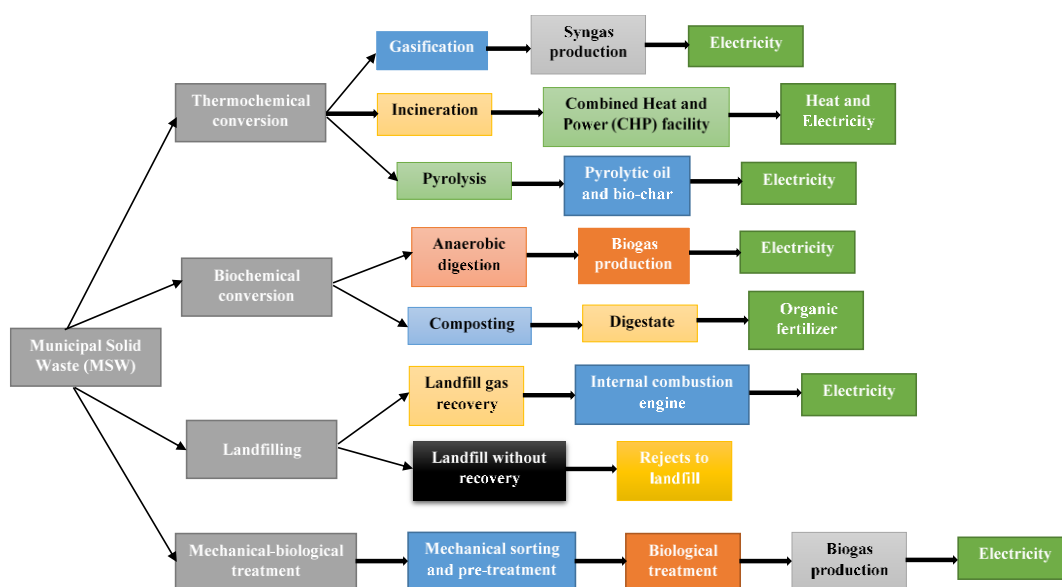


Figure 5: Waste-to-energy conversion technologies

Small Hydropower: Nigeria has very good potential for both large and small hydropower. Historically, before the discovery of crude oil, hydropower was primarily exploited for electricity generation in the country. Unfortunately, the hydropower development in the nation's power sector was later subjected to neglect due to the considerable use of fossil fuels because of the availability of plenty of natural gas for power generation. In the country, there are three major hydropower plants (Kainji, Jebba and Shiroro) all located in Niger State in Northcentral Nigeria. The total installed capacity of the large hydropower stations is less than 2000 MW. The potential capacity of both large and Small Hydropower

(SHP) in Nigeria is largely underutilization (Okedu et al., 2020). The sites of the SHP across the states in Nigeria are presented in Table 1. The application of SHP is an economically reliable clean energy mechanism, especially in remote communities where there are flowing rivers. Nigeria has hundreds of potential sites for Run-off-River (RoR) hydropower sites for harnessing renewable energy in rural communities. Figure 6 shows the schematic and the major components of a typical RoR hydropower plant. The key benefits of SHP are ecological and economic sustainability (Botelho et al., 2017; Schramm, et al., 2016). Using RoR technology has the additional advantage of the absence of a water reservoir for the operation of the turbine (Rotilio et al., 2017). The basic principle is such that flowing water passes through the hydropower turbine for power generation. The used water flows back into the river for reuse for other consumptions thereby depicting the power technology to be environmentally friendly. In locations where the RoR is not available throughout the year, storage of water to generate electricity becomes necessary.

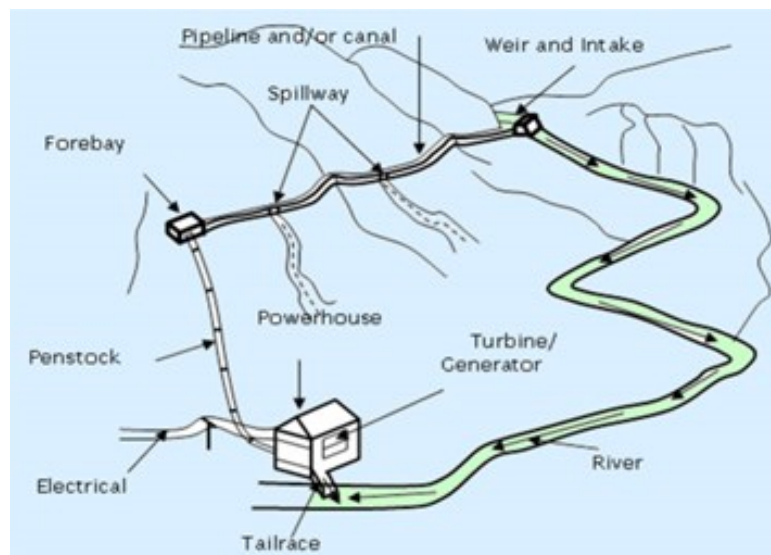


Figure 6: Layout of Run-off-the-River hydropower plant (Gogan & Ingersoll, 2023)

Wind Energy: Wind energy is one of the foremost renewable energy technologies that have gained tremendous advancement in the last few decades. In Nigeria, the potential of wind energy varies from one place to another depending on the existing wind speed in each site. The basic principle of operation of a wind power system is the conversion of the aerodynamic kinetic energy of blowing wind into rotational mechanical energy to generate electricity. Ohunakin & Akinawonu (2012) presented the assessment of wind energy potential and the economics of wind power generation in Nigeria. In another study (Adaramola et al., 2011), the estimation of electric power generation as well as the cost analysis of wind energy in North-central Nigeria is presented. Other researchers have also presented some useful developmental data for optimal site selection for investment as well

as the return on investment in wind power generation for developers in the country (Adaramola, et al., 2014). Going by the increasing power demand in Nigeria, the need to utilize wind energy for clean energy is important. The available mean wind speed in the country is in the range of 2.64 m/s to 9.83 m/s (Ohunakin et al., 2011) which is an indication to the worthy capabilities of meeting the requirements for generation of wind-based electricity.

Table 1: Summary of Small Hydro Power Plants in Nigeria (Igbinosun, et al., 2018)

S/No	State	Potential Sites	Cumulative Power Estimate (MW)
1	Adamawa	3	28.600
2	Akwa Ibom	13	-
3	Bauchi	1	0.150
4	Benue	10	1.306 (one site)
5	Cross River	5	3.000
6	Delta	1	1.000
7	Ebonyi	5	1.399
8	Edo	5	3.828
9	Ekiti	6	1.2472
10	Enugu	1	-
11	FCT	6	-
12	Gombe	2	35.099
13	Imo	71	-
14	Kaduna	15	25.000
15	Kano	2	14.000
16	Katsina	11	234.34
17	Kebbi	1	-
18	Kogi	2	1.050
19	Kwara	4	5.200
20	Nasarawa	3	0.454
21	Niger	11	110.580
22	Ogun	13	15.610
23	Ondo	1	1.300
24	Osun	8	2.622
25	Oyo	3	1.062
26	Plateau	14	89.100
27	Sokoto	1	-
28	Taraba	9	134.720
29	Yobe	5	-
30	Zamfara	16	-

Ongoing power sector reform

The Nigerian government has embarked on aggressive power sector development reform for the liberation of the nation's power sector from the grip of an epileptic power supply. The Nigerian Electricity Regulating Commission (NERC) was established in 2005 to make available the required regulatory framework to create an enabling environment for private investors and electricity consumers in the country. The road to the nation's power sector reforms started through the Electric Power Sector Reform Act (EPSRA) in 2005. The fundamental objective of EPSRA is to establish a technically viable electric power sector with the capability to eliminate the mismatch in the electricity demand and supply among all other requirements for the provision of reliable and secure electricity (Ayamolowo et al., 2029). Electricity consumers in Nigeria are not adequately served to match the potential capacities of their power demand thus leaving most of the populace in energy poverty. The nation's power sector is currently failing such that there is an exigent requirement for policy towards attaining a quality and adequately functioning electricity market in the country (Oseni, 2011). The existing electricity policy permits individuals to explore the possibilities of generating their electricity, therefore, the option of utilizing MG based on economic benefits for electrification in the country is essentially open to all.

It is no doubt fact that the successful deployment of MG for rural electrification in the entire region of SSA requires some sort of robust policy reform for survival. Until now, Nigeria is still building upon her energy policy to confront the prevalent incident of declining electricity generation capacity, aging infrastructure, poor energy management, minimization of environmental damages, weak transmission facilities, blackouts, power losses, poor power quality, poor maintenance culture, excessive use of fossil fuel power plants and overall power system gross inefficiency. The Nigerian government has developed policy strategies to encourage private sector participation, diversification of the energy sources for power generation and promotion of energy efficiency for sustainable development (Usman et al., 2015). Despite this, power sector reforms are still ongoing because the anticipated targets have not been achieved. The national electric power utility privatization programme is also in favour of MG deployment in the country. The current policy situations however present incredible opportunities for MG developers to exploit new power generation technologies and business models in the power sector to provide solutions. Over the years, Nigeria has made a huge investment in billions of dollars in the nation's power with little or no obvious impact. This situation is a serious concern to the government such that stakeholders in the power sector have chosen to embark on additional reforms. Consequently, the draft policy on MG of the present government might be an opportunity to deploy MG for the benefit of the nation's power sector.

Support by government agency

The Rural Electrification Agency (REA) of Nigeria is empowered by law to promote rural electrification under the Federal Ministry of Power. REA was established in 2005 by the EPSRA but inaugurated in 2006. The agency is saddled with the responsibility to plan and implement activities concerning rural electrification projects in the country. The agency is expected to conduct all its activities in line with the nation's Rural Electrification Strategy and Implementation Plan (RESIP). Though governments at all levels have the desire to create equitable access to electricity in the country irrespective of geographical location such an endeavour is very difficult to achieve (Yetano et al., 2020). REA has the mandate of the government to make provision for electricity in rural areas to maximize socioeconomic and environmental benefits via off-grid electrification. REA is also tasked with the burden of stimulating innovative concepts towards rural electrification in the country. Painstakingly, it has been the sole agency directly promoting the development of MG for rural electrification with economic development objectives in the country. Moreover, the opportunity of multiple funding schemes available to the agency is a convincing advantage for its anticipated success in the implementation of MG projects in the country. REA secures its funds from fines obtained by NERC, donations from international energy support agencies, and government at different levels, benefits accrue from the Rural Electrification Fund (REF), donations from intended large-scale business owners, government special intervention funds, a certain percentage from the annual income obtained by NERC from electric power licensees. The present promotional efforts of the REA towards standalone power generation are a way forward into the future of MG development in the country. With these funding sources being controlled by REA, there may be the possibility to facilitate the entrance of new market participants from government, private sectors, and local communities into rural electrification development projects in the country.

Challenges of Micro-Grid Development in Nigeria

Many challenges are usually encountered during the implementation of MG in different phases of deployment procedures. For a very long time, the nation's energy development initiatives have been suffering from implementation complexities. Mismatched demand and supply of electricity have created different negative consequences in the generality of the economy of the country. Therefore, the thought of applying MG utilizing RES as a long-term viable solution to the energy crisis in the country is long overdue. The possible challenges affecting the actualization of efficient deployment of S-MG technologies for sustainable power generation in Nigeria are presented in the subsection below.

Legal Issues and regulatory uncertainty

The development of an effective legal and regulatory framework is necessary for the conceptualization and development of MG. Some key legal issues are considered important

for MG power generation and distribution to customers. Presently, there is no clear legal and regulatory framework for existing MG pilot projects in the country. Unlike Singapore (Wouters, 2015; Chang, 2017), there are certain regulatory structures to determine the establishing rule and operational context of the existing electricity market structure for the implementation of MG. A major regulatory uncertainty today in Nigeria is the absence of laws enabling the connection of MG to the TGs. In this case, it may be difficult for MG developers among the Independent Power Producers (IPPs) to connect their power system equipment to the national grid (Oyewunmi, 2014). Given this problem, it is thus important that any legal framework in support of MG development in the country must specify the national standardized requirements for grid-connected operations. In addition, for the nation to get involved in a vibrant MG investment, policymakers must investigate the tendencies to eliminate duties on renewable power technologies for a convenient period for energy developers. The challenge in legal issues and regulatory uncertainty is also connected to the reluctance of the nation's policymakers to completely support renewable energy development based on the weak status of the current power system infrastructure in the country. This possibly will continue to slow the progress of the country in the pursuit to transit towards a clean energy development mechanism.

Lack of sustainable MG business models

In the context of a sustainable electricity market, the structure of business models for MG is very important and depends on several issues among which are reliability of the technology used and cost savings. The initial cost of investment in MG is an expensive project scheme. Where there are good business models, there are tendencies to lower upfront costs and reduce the associated financial risk on the development of MG projects. In some countries where MGs are widely deployed for power generation, existing business models adequately pinpoint some important business issues such as Power Purchase Agreements (PPA), ownership models, and financing agreement schemes (Ogunnubi et al., 2017). In a good business model, it is possible to remove financial barriers by a way of opening opportunities for mixed ownership. A sustainable MG business model can help to grow the core business focus, improve de-carbonization initiatives, and enhance the market segment for the project. The costs of purchasing MG power assets, automation facilities and control system components are quite expensive such that the return on investment may not be as quick as possible. Therefore, the development of effective business models for MG operators is very crucial to ensure that the operators and users are allowed with manageable expenses. This can be achieved through effective technology evaluation and energy policy (Hanna et al., 2017). Unfortunately, it is understandable that Nigeria is currently far away from the reality of developing sustainable business models with reliable financial savings for the operators and the potential MG energy users. The challenge of the lack of sustainable MG business models needs to be resolved by using proactive

technological development and a sustainable financing forum approach. The most reliable means of financing the MG project is by involving multiple stakeholders from the federal government designated agencies, state governments, local governments with joint concerned local communities and project developers.

Poor social awareness

Most of the local people in remote communities in the country are not adequately informed on the impact of MG projects on sustainable power generation. They are not acquainted with the working principles of MG due to a lack of initiatives and programmes to convince them to embrace the project. Stakeholders in the nation's power sector and the investors' interactive forum with the prospective energy consumers in local communities can be initiated to create awareness. This can increase community involvement in the planning and development of MG projects thereby removing different sorts of social barriers. Local communities need to be adequately informed to have better insights regarding the possible business opportunities and other socioeconomic impacts of the projects. Although there could be a general understanding of the benefits of electrification using MG projects, the local people may not have better knowledge of other the extended positive impacts. A high level of social sensitization of the rural dwellers may enable better decision-making concerning maximum project benefits. In addition, the involvement of the local community in the planning and implementation of MG through social interactions could also unlock significant business model optimizations, exhibit accountability and enhance understanding among the stakeholders.

High cost of investment

Traditionally, the cost of establishing a renewable energy MG is usually a key challenge compared to an independent diesel-base electric power system. In most cases, financing scheme for MGs is the major constraints as the payback period is not usually in economically manageable situations as expected. Industrial and commercial establishments are the major patronage of MG in some countries due to their potential to handle the financial aspect of the projects. Therefore, effective financing of an MG project becomes a serious issue due to some significant barriers. It is however possible for MG projects to be the most cost-effective option in some cases depending on the financing scheme, tax rebate and subsidies. Moreover, where it is practically expensive for developers of MG projects, care must be taken towards adequate planning to break high-cost barriers (Dayo, 2008). A sustainable engineering design portfolio of the MG projects can reduce cost savings. Where the means of cutting project costs become difficult, developers can explore the option of tapping from donors and government agencies. Government financial support in the form of MG development incentives or grants may be required to develop a community-based MG project in Nigeria. This is because of the high cost of energy that rural dwellers in

developing countries cannot afford. Furthermore, commercially viable tariffs and tax rebates may also be needed to provide a least-cost solution to the electricity needs of the rural communities. In Nigeria, apart from the burden of high upfront costs required for developing MG projects, there is also the challenge of inflation of contracts and manipulation of electricity tariffs by the stakeholders. Efforts by the government to subsidize the cost of electricity for the benefit of poor people are often not achievable due to financial corruption among the stakeholders. This challenge has brought detrimental effects to the expected performances of the nation's power sector. To achieve effective MG development in the country, there will be a need for proactive and prudent involvement of the Rural Electrification Agency (REA) in dealing with grants, loans, and credit boosts from government agencies.

Lack of skilled manpower and technical capability

Generally, there is a shortage of quality skilled manpower in Nigeria. This is one of the reasons why almost all the power projects in the country are executed by foreign companies. Some of the power projects implemented in the country are either abandoned or are compelled to operate below their installed capacity because of poor technical handling of operation and maintenance. In most cases, the local engineers and technicians are either not properly trained or lack the requisite technical capacity to accomplish the necessary operation and maintenance. Therefore, it is obvious that the country has no adequate skilled manpower expertise with the capability to install, maintain and upgrade or achieve capacity expansion of the power systems whenever desirable. The lack of skilled manpower and technical capacity in Nigeria is directly a function of poor capacity building (Sambo, 2009). The nation's administrative system gives more priority to individuals with intimidating paper qualifications rather than technical know-how. This has negatively affected the expected success in the nation's technical sectors more conspicuously in the power industry. Nigeria has a long-standing history of unstable power supply and frequent blackouts resulting from poor handling of the technical affairs in the nation's power sector. This situation persists even after the privatization of the power sector which was anticipated to bring about the expected change in service delivery. Expert knowledge is highly required for the planning, design, modelling, and operation of MG systems utilizing renewable energy (Ebhotu & Tabakov, 2018). It is certain that where the required level of expertise is lacking, the reliability and lifespan of the MG project could be at stake. Skilled manpower knowledge is required to accomplish a successful design capability of an MG project. The technical design of an MG project is vital since it can affect the operational structure of the project. The design of an MG project should be planned to adapt to some socioeconomic characteristics of the local community which the project is intended for. This will ensure that technological consideration alone is not given much priority as most rural

communities may have some specific socioeconomic adaptation that can influence the success of their energy projects.

Absence of compliance with standard codes

In designs, installations and operations of electrical systems, compliance with standard codes is strongly recommended in line with international practices. Effective compliance with all necessary code rules provides connections to electrical systems that are free from dangerous situations such as electric hazards. In advanced and emerging countries, compliance with electrical safety standard codes enjoys legal backing whereas that is not the situation in Nigeria. Apart from the failure of the country to adopt the International Standard Codes, in most electrical project works, there is also the absence of a framework for the National Electrical Code (NEC) in the country. IEEE and IEC Standard are the generally used International Codes for the design and implementation of MG projects across the world (Seifi, et al., 2013; Arndt & Puto, 2010). Hence, for reliability, safety and network security purposes, stakeholders in the nation's power sector must begin the preparation for the adoption of Standard International Codes or the development of national standard codes for enforcement of safe electrical practices. Additionally, when the country decides to embark on its national standard code, authorities empowered by law inspect for compliance to ensure that minimum standard requirements are not compromised.

Constricted market potential

The present situation in the electric power industry in Nigeria is such that the market structure is characterized by a series of challenging situations. Before the emergence of EPSRA in 2005, the electricity market structure was highly monopolistic under the control of the defunct National Electric Power Authority (NEPA). After the power sector reforms, the nation's power sector was unbundled into independent generation, transmission and distribution companies with each segment controlling its market autonomy but subject to regulation by the Nigeria Electricity Regulatory Commission (NERC). There were six generations, one transmission and eleven distribution companies after the transformation from NEPA to the Power Holding Company of Nigeria (PHCN). Backed by a legislative framework, NERC was created in the context of the EPSRA. Even with the development of EPSRA, there is no enabling market potential for MG in Nigeria. The investment opportunity must first be considered to scale the MG investment in Nigeria. The existing energy market scheme should be reviewed such that its key focus on bulk electricity trading alone under the control of the Nigerian Bulk Electricity Trading (NBET) can be discouraged. A financially worthwhile and market-oriented should be created for MG development in Nigeria to grant opportunities for viable revenue streams from tariffs and balances financial subsidies and operational expenses (Okonkwo et al., 2021).

Weak research and development

Research and Development (R&D) in MG usually involves a multidisciplinary team of researchers to conduct systematic analysis while implementing sustainable MG projects. Sustainable R&D is a major driver for the planning and implementation of MG in any part of the world. More advancements in MG emerge from time to time because of R&D. Based on the sensitive nature of MGs, especially their capability to utilize DERs, there are possibilities to encounter some difficult challenges. It is consequently necessary to have a strong R&D background for handling the various aspects required for the efficient design of MGs, implementation, operation and maintenance. In Europe, there are many existing MG R&D centers like the Kythnos Island MG (Greece), the Residential Demonstration at Mannheim-Wallstadt (Germany) and Continuon's MV/LV facility (Netherlands). Apart from these MG R&D-funded projects by the EU authority, there are many other scattered MG projects for R&D in the United States and China (Romankiewicz et al., 2014; Hossain et al., 2014; Ton & Smith, 2012). Unfortunately, the R&D in Nigerian tertiary institutions and scientific agencies is very weak with limited capacity to foster development in the nation's power sector. Since intensive and dedicated research work is required for the development of sustainable MG, it is therefore important that robust efforts are needed from the combination of academic institutions, government agencies and the industrial sector. In MG, information and communication technology are highly required to realize the intelligent behaviors of the energy system and fulfill other expected roles of the power system. The necessary scientific and engineering capability for R&D needed for the design and development of indigenous MG in Nigeria is lacking considering the complexities of the technologies.

Discussion of Results and Findings

Going by the review conducted, it is impossible to bring up a clean energy discussion in the absence of a conversation about climate change. Burning fossil fuels for energy produces a lot of greenhouse gases, which cover the atmosphere and weaken the ozone layer. Compared to non-renewable energy sources, renewable energy sources are more widely accessible. To reduce the dependency of the country on fossil fuel exploitation for energy production, governments have begun to invest in clean and alternative energy initiatives including wind farms, solar energy and hydropower but far below the expected level due to several challenges. To improve the quality of life for present and future generations, especially the rural inhabitants, there is a need to invest in clean energy technologies for sustainable development. Making the switch to renewable energy will make the country greener, poverty reduction, promote opportunities for economic development and provide employment. Additionally, it will lessen the amount of fossil fuels importation thereby freeing up money for more infrastructural development. The cost of renewable energy is lower than that of non-renewable since the price of renewable energy has decreased in the

last few decades (Mohammed et al., 2022). It is now advantageous for the economy as well as the environment to move away from fossil fuels and invest in renewable and clean energy sources. Now that businesses have begun to make the transition and are enjoying the benefits of their decision, it is time for individuals, organizations, and the country to follow suit. Investing in renewable energy offers long-term economic benefits by significantly benefiting not only the financial status of the investors but also the lives of people worldwide, as everyone has an economic stake in the battle against climate change. To achieve effective investment in the clean energy business in Nigeria to secure long-term economic benefits, the identified challenges highlighted in the framework of this study must be resolved.

Conclusion and Recommendations

With a population of over 200 million people, the available power capacity from the national grid is not sufficient to cater for the energy demand in the country. Currently, the installed power capacity is about 10,000 MW while the operational available capacity is below 6000 MW. This problem has left millions of people, particularly the rural populace in an energy crisis. However, Nigeria has a vast quantity of renewable and non-renewable energy sources. The incident of poor access to energy in the country has created tremendous challenges to the economic situation of the country. The resultant effects on the socio-economic well-being of the citizens are obvious from a poverty perspective. The existing model of electric power generation in the country is highly concentrated on the use of large-scale fossil power plants such that the extension of the power networks to the rural areas is economically not feasible. Therefore, embracing the opportunities presented by the emerging technological concept of MG application for power generation is a viable alternative. The uses of MG facilities for rural electrification present a substantial opportunity for the entrant of new investors into the electricity market in Nigeria. Besides, it will also help the country to exploit the benefits of tapping her RE sources for sustainable development based on suitable economic design and stakeholders' support. Consequently, the review presented herein shows that the application of MG technology for power generation is fast becoming a wide-ranging approach and solution-based for the electrification of off-grid communities. In addition, it also has the benefit of grid-connected opportunity thereby increasing the reliability of power supply. However, the country needs to embark on some important measures to overcome some of the challenges highlighted in this study to be able to deploy renewable energy-based MG technologies in a sustainable approach. Subsequently, the following recommendations are thereby stated:

- **Increasing the Level of Awareness:** In Nigeria, the level of awareness on clean energy generation is very disappointing. The public populace especially the illiterate has very limited orientation on the implementation of renewable energy for the supply of clean and sustainable electricity to domestic households. A typical

Nigerian household relies on electricity from the grid network for their socioeconomic activities. However, recently, the awareness of the opportunity to use solar energy to compensate for poor energy supply from the national grid is gradually increasing such that some electricity users now understand the utilization of small-scale solar for the cost of energy reduction in their homes. In this case, energy stakeholders will need to increase the awareness of investment in clean energy supply. This can be achieved through a proactive effort from the government and stakeholders through educational institutions and media propagation (Nwofe, 2014).

- **Enhancement of Technological Capability:** Some technological mechanisms required for the design, development and implementation of clean energy are not readily available in Nigeria (Agbo et al., 2021). From this perspective, more efforts are required to equip the citizens with the required technical know-how to reduce the level of the nation's dependency on the knowledge of foreign experts. Aggressive deployment of research laboratories and renewable energy skill training centers in the country must be prioritized.
- **Provision of Financial Subsidy:** In recent times, there has been a reasonable reduction in the price of renewable energy equipment such as solar PV systems due to increasing market demand. However, because most Nigerians are financially constrained coupled with the negative influence of the high exchange rate of the Naira to the Dollar, it is thus difficult for them to purchase and install solar PV power systems due to the high initial cost of investment. These challenges have conditioned the citizens to fall back to firewood and other cheap fuels for their energy supply notwithstanding the consequential climate change impacts and health implications. Hence, it is recommended that the government make provision for financial subsidy in the support of clean energy investment to lower the cost of investment and increase affordability.

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