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Renewable Energy Readiness in Nigeria: A Review Focusing on Power Generation

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Abstract

Six decades after independence, more than half of Nigeria's estimated 206 million people have no access to electricity. Meanwhile, outages, surges, and load shedding of power supply are common features of areas connected to the grid. These are attributable to insufficient generation, inadequate and poor transmission and distribution infrastructures. Consequently, many households and businesses have to rely entirely on expensive and environmentally-harmful diesel/petrol generators to meet their electricity demands. This paper presents a review of literature on Nigeria's renewable energy potentials for power generation, highlights the power sector policies and reforms since 2001 aimed at boosting electricity access, and the integration of renewable resources in the energy options. The research trends on renewable energy hybridization for power generation, the major renewable power system projects, and the key drivers and challenges of renewable energy utilization to meet electricity demands in Nigeria are also highlighted in this paper. The findings revealed that solar, wind, small hydro, and biomass resources are in abundance in Nigeria, and if fully harnessed can generate about 1,182.4 GWh of energy per day. More attention has been given to research on renewable-based rural electrification with an emphasis on the hybrid solar photovoltaic-diesel generator and hybrid solar photovoltaic-wind-diesel generator. In line with the National Renewable Energy and Energy Efficiency Policy (NREEEP), there is the need to integrate the solar, wind, biomass, and small hydro schemes in the energy mix, and also extend both research focus and deployment of renewable power systems to municipal and industrial areas in Nigeria.

Keywords

Renewable, grid, biomass, system collapse, fossil fuel

1.0 Introduction

Rural areas are made up of about 51% of the population of Nigeria, and the social and economic development of these areas has continued to be hampered by a lack of electricity supply (Adaramola et al., 2012). Power outages, power surges, brown-outs, poor voltage profiles, and load shedding remain common features even where there are grid extensions. For instance, despite the three on-grid hydropower and twenty gas-fired thermal power plants in Nigerian Electricity Supply Industry (Dunmand, 2016), the average dispatchable generation fell below 3,000 MW in 2018 (Ajayi, 2019), while the average output level of 2019 was 3,775 MW which is about 30% of the installed plants capacity of 12,522 MW (Ajayi, 2020). The long-standing bottlenecks to steady power supply from the grid are attributable to inadequate gas pipeline infrastructure and vandalism, gas supply shortages, inadequate reserves and maintenance of some generating units, congestion at the transmission and distribution interfaces (PSRP, 2018). More so, the radial nature of the country's transmission and distribution networks and their long extensions practically make them prone to faults (Dodo et al., 2020). The pathetic state of Nigeria's grid can also be pictured from the system collapse incidences. Thus, there were 647 system collapse incidences in Nigeria between 1987 and 2014 (Akinloye, 2016), and 36 more incidences between 2014 and 2017 (Uche et al., 2018). The national grid collapsed nine times in 2019 (Ajayi, 2020), and one of the incidences which occurred on 30th August placed the entire country in blackout for nine hours. In 2014, an average manufacturer in Nigeria experienced power outages five times per day and was supplied electricity for just six out of twenty-four hours (Osakwe, 2017). The privatized electricity distribution companies are not left out in lamentation as they alleged loss of about ₦395.43b revenues from January to August 2019 due to grid unreliability and distribution limitations (Okwe & Adeoye, 2019).

One should visualize the number of lives, economic and industrial activities that were affected during power outages. The inconveniences and economic misfortune that the power system failures from the grid impose on both domestic and industrial users are high and unendurable and have made the consumers pursue off-grid alternatives through petrol/diesel generators (Akinloye et al., 2016; Samuel et al., 2014). All types of firms and businesses in Nigeria experience power outages, necessitating most of them to own at least two generator sets as an alternative source of electricity (Odutola, 2018). About sixty million units of these generator sets have been deployed in Nigeria (Roche et al., 2017), with attendant emissions of poisonous gasses, noise, and high cost of fuel and transportation to mention but a few. MTN (one of the leading mobile telecommunication companies in Nigeria) owns and operates about six thousand diesel generator sets, resulting in $5.5 million annual expenditure on fueling of these generators to supply power to its base stations for 19 hours every day (Oyedepo, 2012). The manufacturing sector appears to be the worst hit. Every manufacturing firm in Nigeria uses between 100 and 300 liters of fuel or even more on daily basis to power generating sets due to frequent failure from the grid (Odutola, 2018). Over 80% of the Nigerian primary energy consumption is met by petroleum and diesel (Akorede et al., 2017), through captive power generating capacity evaluated to be as high as 14 to 20 GW, thus, surpassing the whole power sector's installed capacity (Renewable Energy Cooperation Programme, 2017). According to the Central Bank of Nigeria (CBN), Nigerians spend about $14 billion on generators and fuel annually (Olalekan, 2020); an evidence that power supply is not getting any better.

Several undesirable characteristics stifle diesel generators as energy sources such as emission of gases (CO, NO, and NO_2) that are injurious to animals and plants, and also cause health problems in humans, fast diminution of fuel reserves, and rising evidence of global warming (Olatomiwa et al., 2016; Yimen et al., 2018). Therefore, finding alternative energy sources to meet the increasing energy demand while curbing adverse environmental consequences is becoming an essential task. Renewable energy sources, such as solar, wind, biomass, geothermal, and hydro, being free, infinite, locally available, and eco-friendly can constitute possible sources of alternative energy for electricity generation (Integrated Panel on Climate Change, 2012). Furthermore, they are energy sources with the advantage of generating power near load centers, thereby minimizing the losses in, and cost of transmission (Owusu & Asumadu-Sarkodie, 2016).

Renewable energy sources are characterized by uncertainty and intermittency. By using a conventional energy source infusion with renewable sources, the scheme turns out to be more reliable and cost-effective compared to reliance on a single renewable energy source (Olatomiwa, 2016). Blends of such different but complementary energy generation systems based on renewable, or mixed energy (renewable energy with a backup/standby bio-fuel/diesel generator) are known as hybrid renewable energy system (Brenna et al., 2016; Agajelu et al., 2013), and the grid formed by this system is referred to as a microgrid due to its scope when compared to the utility grid (Xu et al., 2019). A microgrid is a pool of loads and distributed generation units that function to improve the quality, reliability, and sustainability of the power system in a controlled manner, and can be operated in an on-grid mode or an off-grid mode (He et al., 2018). The driving factors for renewable energy systems development and deployment in locations with existing electrical grid infrastructure fall into three wide-ranging categories of energy security, economic benefits, and clean energy integration (Hirsch et al., 2018). In a deregulated electricity supply industry like Nigeria, the microgrid provides additional benefits to the local utility by providing dispatchable power during periods of peak demands, alleviation of distribution system upgrades, and boost in revenue generation.

In this paper, a review of the Nigeria's renewable energy potentials for power generation and an insight into the research direction of adopting renewable resources to meet the country's electricity demands are presented. It also highlights the key challenges hampering the deployment of renewable electricity projects, and the major issues of Nigeria's power sector planning, reforms, and polices targeted at improving the states of electricity supply.

2.0 Global Renewable Energy Outlook and Nigeria's Potential

The Global Wind Energy Council (GWEC) projected that the global wind market will rise by over 155% to reach 240 GW of total installed capacity by the end of 2012, with China projected to overtake the United States and the Organization for Economic Co-operation and Development (OECD) Pacific countries as a major producer of wind energy by 2050 with a figure of 1,660 TWh (Idris et al., 2012). Naturally obtainable solar energy strikes the earth's surface at the rate of 120 Petawatts, which implies that the amount of energy received from the sun in a day can fulfill the world's energy demand for more than 20 years (Khan & Arsalan, 2016). An estimated 937 TWh per year or 93% of Africa's economically viable hydropower potential remains unexploited, much of that is located in Nigeria, Gabon, Madagascar, Angola, Cameroon, Ethiopia, and Democratic Republic of Congo (in ascending order of capacity) (Eberhard et al., 2011). In April 2011, over 50 delegates from across the globe deliberated numerous issues at the International Renewable Energy Agency (IRENA) inaugural congress, including national initiatives for the development and deployment of renewable energy, energy access and security, and climate change (Singh et al., 2013). As of 2016, 173 countries set renewable energy development goals, and 146 countries had keyed into a wide range of motivating policies (Wang et al., 2018). In 2009, 82 countries used the wind to produce energy, and 49 countries increased their installed capacity (Emodi, 2016). The following subsections review some literature on renewable energy (hydro, wind, solar, and biomass) potentials in Nigeria.

2.1 Hydropower

Hydropower is derived from the potential energy available from water due to the difference in height between its storage level and the tailwater to which it is discharged. Power is generated by the conversion of this energy into electricity using a turbine at a usually high-efficiency rate. Hydroelectricity is one of the most mature forms of renewable energy, providing more than 16% of the world's electricity consumption from both small and large power plants (Gagliano et al., 2014). The National Renewable Energy and Energy Efficiency Policy (NREEEP) of 2015 classified hydropower as follows; Pico hydropower (less than 100 kW), Micro hydropower (between 100 kW and 500 kW), Mini hydropower (between 500 kW and 1 MW), Small hydropower (between 1 MW and 30 MW), Medium hydropower (between 30 MW and 100 MW), and Large hydropower (above 100 MW). The more predominant type according to different researches is of 10MW due to its structural costs and reduced environmental destruction in the form of land used for dam construction (Ogbuefi et al., 2018).

The four commissioned large hydropower stations in Nigeria are Shiroro (600 MW), Jebba (570 MW), Kainji (760 MW) and Bakolori (100 MW) (Aliyu et al., 2015). Thirty-two exploitable hydropower sites have been observed in Nigeria with a total installed capacity of 12.22 GW (Manohar & Adeyanju, 2009; Zarma, 2006). Ogbuefi et al. (2018) revealed that there are 286 sites spread across different locations in Nigeria with small hydropower potentials capable of generating 764.2 MW, out of which only about 4% has been utilized. Federal Ministry of Water Resources conducted surveys on some existing dam projects for hydropower, nineteen (19) of which have the prospects for hydropower generation with a total capacity of 3.56 GW (SE4ALL-AA, 2016). The small hydro potentials surveyed and captured in Renewable Energy Master Plan (REMP) enacted in 2005 are shown in Table 1. A total of 277 sites were surveyed in 12 states with prospects of generating 964.2 MW. For Nigeria to fully transit from the conventional to renewable energy, attention must focus on renewable energy exploitation like the small hydropower for sustainable development.

Table 1: Surveyed Nigeria's Small Hydropower Endowment (Renewable Energy Master Plan, 2012)

S/N	State	River Basin	Total Sites	Total Capacity (MW)
1	Rivers	Cross River	18	258.1
2	Benue	Lower Benue	19	69.2
3	Plateau	Lower Basin	32	110.4
4	Sokoto	Sokoto-Rima	22	30.6
5	Katsina	Sokoto-Rima	11	8.0
6	Taraba	Upper Benue	38	162.7
7	Bauchi	Upper Benue	20	42.6
8	Kaduna	Niger	19	59.2
9	Niger	Niger	30	117.6
10	Borno	Chad	28	20.8
11	Kano	Hadejia-Jamaare	28	46.2
12	Kwara	Niger	12	38.8
Total			**277**	**964.2**

2.2 Wind Energy Resources

The wind is another clean energy source that can be utilized for the generation of electricity. If there is a genuine commitment to wind dispersion and energy evolution keeps increasing globally at the same stride, by the year 2030 wind energy will be responsible for saving of virtually 23 billion tonnes of carbon dioxide, in addition to other benefits such as the prospects of new jobs running into millions (Diogenes et al., 2020). Out of the 125,728.6 km^2 of Nigeria's land area, 2% is seen to be extremely suitable, 23% are very suitable, and 75% are suitable areas for the siting of wind farms with Bauchi and Jigawa States taking the lead in potentials (Ayodele et al., 2018). The mean wind speed in the South and North lies between 3.0-3.5 m/s and 4.0-7.5 m/s respectively at 10 m above the ground using Weibull distribution in estimating the wind speed across Nigeria (Ajayi, 2010). The seasonal variations of wind characteristics for Jos in North-Central Nigeria within the period of 1971-2007 revealed the annual mean wind speed for the rainy season to be 8.3 m/s and dry season to be 9.1 m/s respectively (Ohunakin et al., 2014). Adedipe et al. (2018) accessed wind energy potential by utilizing four years' wind data sampled from one state capital (Warri, Enugu, Jos, Sokoto, Ikeja, and Calabar) in each of the six geo-political zones in Nigeria including Abuja. The annual wind speed at 10 m above the ground was found to vary from 2.3 to 3.4 m/s for sites along the coastal areas and 3.0-3.9 m/s for high land areas and semi-arid regions. Figure 1 is a map of Nigeria showing the average wind speeds of various states. Only twelve (Adamawa, Taraba, Gombe, Osun, Ekiti, Edo, Delta, Kogi, Bayelsa, Rivers, Ondo, and Abuja) of the 36 states including the federal capital territory (FCT) do not have favorable potentials for wind electricity schemes.

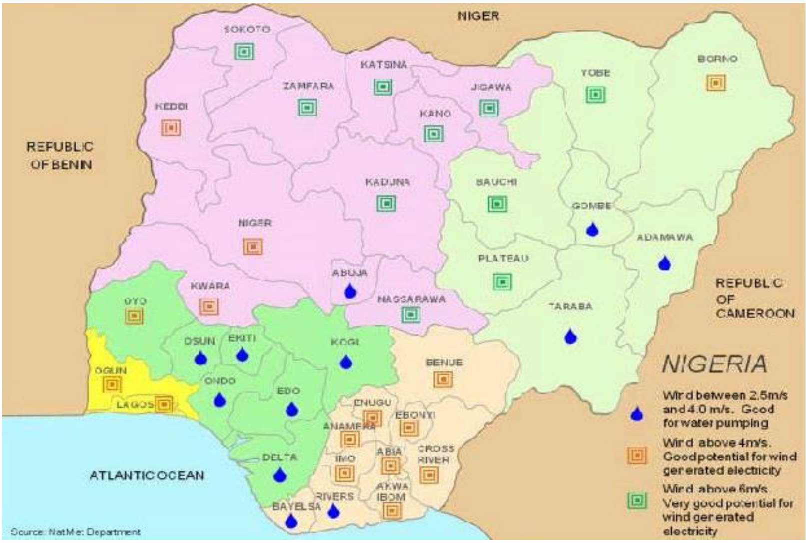

Figure 1: *Average wind speed distribution map of Nigeria (Alenoghena et al., 2014)*

2.3 Solar Energy Resources

The sun is the most readily and widely available renewable energy source capable of meeting the energy needs of the whole world (Liu et al., 2011; Oji et al., 2012). Solar energy can be utilized to generate electricity either by using concentrated solar power plants (CSP) such as Linear Fresnel collectors and parabolic trough collectors or by using photovoltaic modules (Ahmadi et al., 2018). Nigeria has an estimated 17.5 trillion MJ per day of solar energy incident on its total surface (Giwa et al., 2017). The estimated potential of solar energy in Nigeria with 5% device conversion efficiency is 5.0×10^{14} kJ of useful energy annually, equivalent to about 258.62 million barrels of crude oil production and about 420 TWh of electricity generation annually (Ndaceko et al., 2014). According to Olatomiwa et al. (2015) and Ohunakin et al. (2014), the solar radiation in Nigeria varies between 3.7 kWh/m^2 and 7.0 kWh/m^2 from the coastal regions to the Northern regions. The study conducted by Salisu et al. (2017) and Adaramola et al. (2014) estimated the country's mean solar radiation to be 5.25 kWh/m^2, with average sunshine hours of 6.25. Emodi (2016) also investigated the monthly average solar radiation of 28 sites cutting across Nigeria and found the locations in South-South to have the minimum mean solar radiation of about 3.748 kWh/m²-day while locations in the North-Eastern part have the highest solar radiation of 6.966 Wh/m²-day. Figure 2 shows a map of solar radiation distribution across Nigeria. States in Zone I have the highest solar radiation potentials followed by those in Zone II and Zone III respectively.

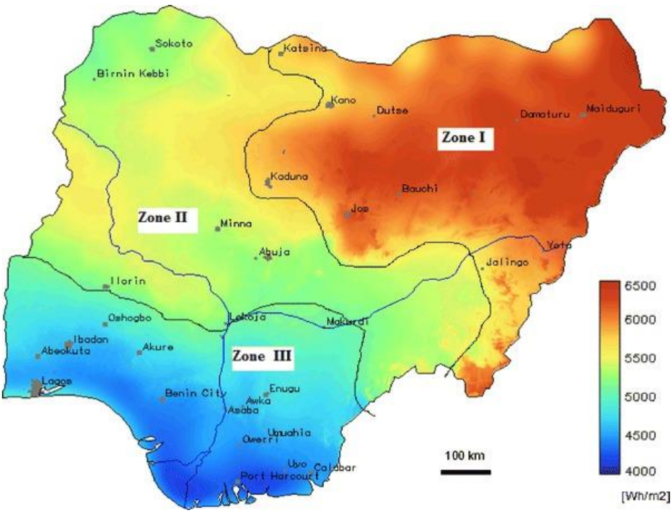

Figure 2: *Solar Radiation Map of Nigeria (Abam et al., 2014)*

2.4 Biomass Resources

Biomass is often used to describe any organic material obtained from plant and animal tissue (Ben-Iwo et al., 2016). Energy from biomass (bioenergy) is of increasing interest as an environmentally friendly alternative to energy derived from fossil fuels. Biomass materials can be converted into electric power through several methods such as by direct combustion, pyrolysis, gasification, or anaerobic digestion. Its resources include wood and woody plants and their wastes, crops, and residues, municipal solid wastes, animal wastes, sewage, waste from organic industrial processing and food processing, and aquatic plants and algae (Alidrisi & Demirbas, 2016; Ben-Iwo et al., 2016). Municipal solid wastes, animal wastes, crops, and residues, as well as forestry resources, are biomass resources abundantly available in Nigeria for producing biofuels that can be utilized to complement the existing electricity generation capacity (Agbro & Ogie, 2012). Nigeria's biomass resources are 200 billion kg/year with the potentials to generate 2.58 billion GJ of energy annually (Olanrewaju et al., 2019). The assessment of different types of biomass and bioenergy resources put Nigeria as having the potentials to produce

2.01 EJ of energy from the 168.49 million tonnes of agricultural residues and wastes generated annually (Simonyan & Fasina, 2013). Interestingly, timber alone has a prospect of generating 1.3 TWh of electricity from an approximated annual 1.8 million tonnes of wood wastes across Nigeria (Manohar & Adeyanju, 2009). As stated in the Renewable Energy Master Plan (2012), there are 18.5 million tonnes of municipal wastes, 245 million animal wastes, and 28.2 million hectares of arable lands for crops in Nigeria. The projection of the total potential of biomass in Nigeria in 2020 is about 7.2 EJ with the prospects to increase to approximately 29.8 EJ by 2050 (Sobamowo & Ojolo, 2018). Studies have been conducted to assess the potentials of biomass resources for energy/electricity production in specific cities and states in Nigeria such as in Ibadan (Ayodele et al., 2018), Lagos (Akinshilo et al., 2018), Ilorin (Ibikunle et al., 2019), and Ebonyi State (Nwofe & Ekpe, 2014) respectively.

Table 2 shows the estimate of renewable energy resources excluding potentials for hydrogen, ocean, and geothermal energy according to the Energy Commission of Nigeria. About 1,182.4 GWh of energy per day could be generated from wind, solar, hydro, and biomass resources, and if fully harnessed through decentralized off-grid would considerably raise electricity access in Nigeria (Akhator et al., 2019).

Table 2: Nigeria's Renewable Resources (ECN-UNDP, 2005)

Energy Source	Capacity
Small Hydropower	734 MW
Large Hydropower	10,000 MW
Wind	2-4m/s at (annual average)
Solar	3.5-7.0 kWh/m^2-day
Biomass (non-fossil organic matter)	Crop residue – 83 million tonnes/year Fuelwood – 13,071,464 hectares Animal waste – 61 million tonnes/year

3.0 Nigeria Power Sector Planning, Reform and Policy

On three different occasions in 2016, the Portuguese power grid experienced 100% renewable energy (wind power, hydropower, solar photovoltaic, and biomass cogeneration units) to support the continuous operation of the national power load for several days (Yang et al., 2019). This landmark was credited to proper energy planning, viable market mechanisms, effective operation and control technologies, and adequate national transmission network planning. In Nigeria, there have been several plans, reforms, and policies targeted at increasing generation capacity and an overall improvement in electricity supply. A bird's eye view of those policies in the last nineteen years including those encouraging massive diversification into renewable energy developments is captured in Table 3.

Table 3: Highlights of Nigeria's Power Sector Planning, Reforms, and Policies (Nigerian Energy Sector, 2015; Renewable Energy Cooperation

Programme, 2016)

Policy/Reform	Year of Enactment	Major Highlight(s)
National Electric Power Policy (NEPP)	2001	Lays the groundwork for restructuring and privatization of the power sector.
National Energy Policy (NEP)	2003	Calls for efficient utilization of all forms of energy and recommended promotion for off-grid and standalone systems to supply electricity to remote locations of the country.
National Economic Empowerment and Development Strategy (NEEDS)	2004	Emphasizes the need for renewable energy agency and the importance of sustained determinations for rural electrification.
National Electric Power Sector Reform Act (NEPSRA)	2005	Provides legal and regulatory framework which led to the privatization of the government-owned electricity company and the process towards a fully liberalized electricity market.
Renewable Electricity Policy Guidelines (REPG)	2006	Plans expansion of renewable electricity market to at least 5% of total electricity generation and a minimum of 5 TWh of electric power by 2016.
Roadmap for Power Sector Reform (RPSR)	2010 and 2013 (Update)	Encourages the development of optimum power generation, transmission and distribution infrastructures, and settlement of liabilities and subsequent winding down of Power Holding Company of Nigeria (PHCN).
Vision 20:2020	2007	Targets 35 GW power capacity by 2020, by achieving 1% contribution from wind and solar respectively, and 20% from hydro to the nation's electricity generation mix, and putting in place 1 GW power generation capacity using biomass resources.
		Targets higher electrification rates, from 42% in 2005 to 60% in 2015 and

Renewable Energy Master Plan	2005 and 2012 (Update)	75% by 2025, of which renewable energy will account for 23% of the country's total electricity generation by 2025, and 36% by 2030.
National Renewable Energy and Energy Efficiency Policy (NREEEP)	2015	Addresses a wide range of issues such as renewable energy supply, utilization, pricing, financing, legislation, regulation, and standards. Energy efficiency and conservation; renewable energy project implementation issues; research and development; capacity building and training; gender and environmental issues; planning and policy implementation concerning renewable energy also form parts of the framework.
Multi-Year Tariff Order (MYTO) II	2015	Sets the feed-in tariff for new-entrant gas power plants, new-entrant coal-fired power plants, small hydropower power plants, land-mounted wind power plants, and solar power plants.
Draft Rural Electrification Strategy and Plan (RESP)	2015	Encourages a full menu of rural electrification options, grid, off-grid, mini-grid and standalone systems.
National Renewable Energy Master Plan (NREMP)	2016	Describes the operationalization of NREEEP and includes baseline data, information on renewable energy sources and technologies, various programs and activities in renewable energy in Nigeria, barriers to the development of renewable energy, and targets for 2020 and 2030 respectively.

4.0 Trends of Research on Renewable Energy Hybridization for Power Generation in Nigeria

Renewable energy development in Nigeria is still at its sprouting stage. With the approval of the National Renewable Energy and Energy Efficiency Policy (NREEEP), there is hope that renewable energy development will gain more momentum. Economic, social, and environmental feasibility assessment of the energy mix and optimum configuration of the system components for beneficiary sectors are important aspects to consider before reasonable financing and consequent development and deployment of any renewable energy project. Table 4 takes a cursory look at 42 different articles on feasibility evaluations, and optimal system configurations of hybrid renewable power supply in Nigeria. Figures 3 and 4 show graphically the focus of the researchers in terms of the study location and the hybrid system configuration as deduced from Table 4.

Table 4: Research Trends on Hybrid Renewable Power Supply in Nigeria

S/N	Reference	Case Study	Hybrid System Architecture
1.	Oladigbolu et al. (2019)	Rural area	Solar PV-DG
2.	Salisu et al. (2019	Rural area	Solar PV-WT-DG
3.	Esan et al. (2019)	Rural area	Solar PV-DG
4.	Adaramola (2014)	Rural area	Grid-Solar PV
5.	Adesanya & Schelly (2019)	Small scale industry	Solar PV-DG
6.	Ayodele et al. (2019)	Microfinance Bank	Solar PV-DG
7.	Jumare et al. (2019)	City center (residential area)	Solar PV- BG-WT
8.	Olatomiwa et al. (2018)	Rural Health Clinic	Solar PV-WT-DG
9.	Muhammad et al.(2017)	Academic Building	Solar PV-WT
10.	Eziyi and Krothapalli (2014)	Rural area	Solar PV-BG
11.	Chiemezuo et al. (2018)	Rural area	Solar PV-BG
12.	Anene et al. (2017)	Rural area	Solar PV-WT-DG
13.	Oluseyi et al. (2014)	Rural area	Solar PV-WT-DG
14.	Ohijeagbon et al. (2019)	Metropolitan area	Solar PV-WT
15.	Ajao et al. (2011)	Metropolitan Area	Solar PV-WT
16.	Adaramola et al. (2012)	City Centre (residential area)	Solar PV-WT-DG
17.	Olatomiwa et al. (2015)	Rural Area (Clinic)	Solar PV-WT-DG
18.	Ariyo et al. (2018)	University Senate Building	Solar PV-WT-DG
19.	Ndukwe et al. (2019)	Rural area	Solar PV-DG
20.	Agajelu et al. (2013)	City Centre (Residential building)	Solar PV-DG
21.	Dioha and Kuma (2018)	Residential buildings	Rooftop solar PV
22	Olatomiwa (2016)	Rural Health Clinics	Solar PV-WT-DG
23	Shuaibu et al. (2019)	University	Solar PV-WT-DG

24	Babatunde et al. (2019)	Base Transceiver Stations	Solar PV-DG
25	Ramunenyiwa et al. (2020)	Base Transceiver station	Solar PV-WT-FC
26	Modu et al. (2018)	Metropolitan residential buildings	Solar PV-DG
27	Ajayi et al. (2014)	Rural area	Solar PV-WT-DG
28	Anayochukwu et al. (2014)	Rural Base transceiver station	Solar PV-DG
29	Mas'ud (2017)	Rural area	Solar PV-WT-DG
30	Jumare et al. (2019)	Metropolitan Area	Solar PV-WT-DG
31	Ozigis et al. (2019)	University	Mini-hydro-DG
32	Diemuodeke et al. (2016)	Rural area	Solar PV-DG
33	Oyedepo et al. (2019)	Rural areas	Solar PV-WT-DG, Solar PV-DG, WT-DG
34	Anayochukwu et al. (2013)	Base transceiver station	Solar PV-DG
35	Olatomiwa et al. (2015)	Base transceiver station	Solar PV-WT-DG
36	Ani (2016)	Rural area	Solar PV-DG
37	Omogoye et al. (2016)	Rural area	Solar PV-DG
38	Oviroh & Jen (2018)	Base Transceiver stations	Solar PV-DG
39	Bukar et al. (2017)	Rural area	Solar PV-DG
40	Bashir and Modu (2018)	Rural area	DG, Solar PV, Solar PV-DG, Solar PV-WT
41	Omogoye et al. (2015)	Rural area	Solar PV-DG
42	Anayochukwu et al. (2013)	Rural Health Facility	Solar PV-DG

DG = Diesel Generator, WT = Wind Turbine, PV = Photovoltaic, FC = Fuel Cell, BG = Biogas Generator

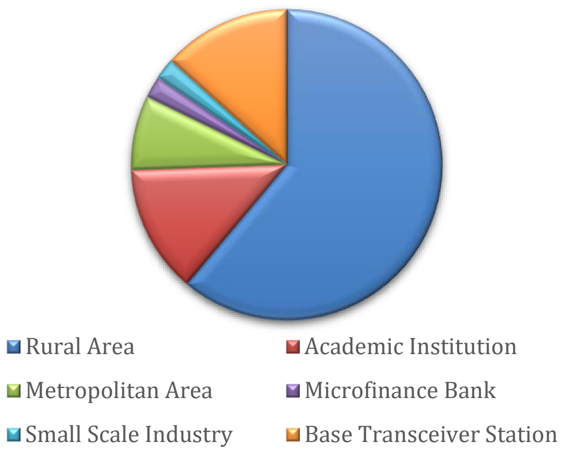

Figure 3: *Case study representation*

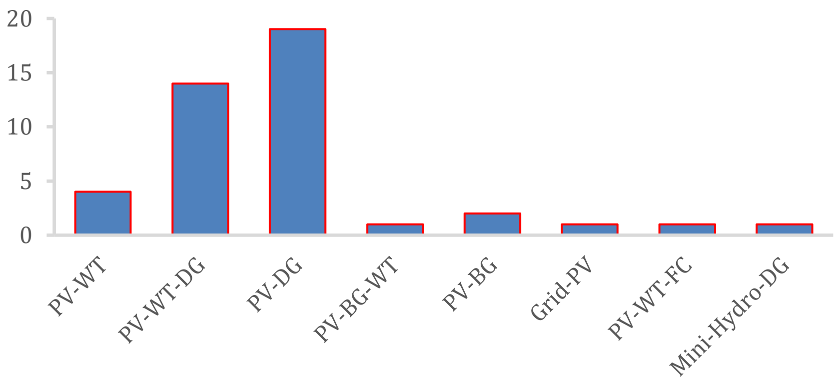

Figure 4: *Hybrid System Configuration*

As seen in Figure 3, 61% of the papers focus on rural areas, 13% of the papers delved into cases in universities and base transceiver stations respectively. Microfinance bank and small-scale industry each has just 2%, while 8% of the papers focus on residences in Metropolitan areas. There has been more concentration on renewable-based rural electrification while other areas/sectors such as the municipal and commercial or industrial areas are lagging. It is also clear from Figure 4 that the attention of the researchers is more on hybrid solar PV-DG and hybrid solar PV-WT-DG. The integration of small/mini/micro hydropower and biomass resources in the energy mix has not attracted enough research attention. Meanwhile, only one case focuses on the grid-connected renewable energy system.

5.0 Major Renewable Power Generation Projects in Nigeria

Nigeria does not have a comprehensive renewable electricity project database since there is no synergy among the key energy players (Energy Commission of Nigeria, Rural Electrification Agency, Federal Ministry of Power, Federal Ministry of Science and Technology, private donors, and similar Agencies of the state governments) (Ohunakin et al., 2014). Therefore, it is difficult to keep track of all the renewable electricity projects in the country. Currently, apart from the conventional large hydropower (Kainji, Jebba, and Shiroro) which supplies the grid, there is no other grid-connected renewable power system in Nigeria. Energizing Education Programme of Rural Electrification Agency (REA) implemented 7.1 MW solar hybrid power systems at Bayero University Kano (REA-BUK, 2019), and 2.8 MW at Alex Ekwueme Federal University, Ndufu Alike-Ikwo (FUNAI), Ebonyi State with a similar target for the remaining federal universities in the country (REA, 2019). The REA, under its Energizing Economy Initiative (EEI), enumerated 340 economic clusters comprising 81,691 shops across the country with the energy demand of about 3-4 GW (REA-EEI, 2019). The pilot projects under this initiative were implemented at Sabongari Markets in Kano State, Ariaria Markets in Abia State, and Sura Shopping Complex in Lagos State.

Zungeru hydropower (700 MW) and Mambilla hydropower (3.05 GW) projects are expected to add to the pool of grid electricity when completed. The existing wind electricity projects are 100 MW wind farm in Plateau State (SE4ALL-AA, 2016), and 10 MW wind farm in Katsina state (SE4ALL-AA, 2016; Okoronkwo et al., 2016). Despite the abundance of varieties of biomass resources, the waste-to-energy project has not been given necessary consideration in Nigeria. The small hydro schemes in existence in Nigeria have a total installed capacity of 38 MW and are on Ouree, Kurra, Bagel I, Bagel II, Lere I, Lere II, Tiga, and Bakolori rivers (NREEEP, 2015), and Oyan rivers (Zarma, 2006). The majority of the solar photo-voltaic installations in Nigeria are owned and operated by government agencies for vaccine refrigeration, street lighting, water pumping, office lighting, and community lighting (Akorede et al., 2017). Some of the existing solar electricity projects in Nigeria are 7.2 kWp village electrification at Danjawa Village, Sokoto State; 5.5 kWp solar photovoltaic plant at Laje, Ondo State; 3 kW solar PV mini-grid in Talasse General Hospital, Balanga LGA, Gombe State; 5 kW Solar PV Plant in Nassarawa State; 3 kW Solar PV Plant at Gassol LGA in Taraba State; 3 kW Solar PV mini-grid at Igu Community Bwari, FCT (Zarma et al., 2017). Rural Electrification Agency recently implemented solar hybrid systems to power critical loads such as ventilators, lighting, cooling equipment, and intensive care units of four Corona Virus Diseases isolation centers (Rural Electrification Agency, 2020). Abdullahi et al. (2017) listed 35 solar electricity projects (with a total installed capacity of 5,109.9 MW), while Ohunakin et al. (2014) enumerated 59 solar-based rural electrification projects at various locations in Nigeria.

6.0 Key Drivers and Challenges of Renewable Energy Development in Nigeria

The Nigerian population keeps increasing at a faster rate, so also electricity demands. The supply from the grid has proven to be inadequate to satisfy these increasing demands. The environmentally harmful and high running costs are major disadvantages of fossil-based generators. The abundance of renewable resources and other associated benefits make them potentially most suitable as an alternative source of electricity in Nigeria. The major factors that should trigger interest in renewable electricity in Nigeria are clean energy integration (reduction of carbon dioxide footprints and other harmful gases associated with the use of fossil-based generators), job creation and opportunities, energy security, and economic benefits.

The National Renewable Energy and Energy Efficiency Policy (NREEEP) targets 60 MW (2015), 2,031 MW (2020), and 10,334 MW (2030) of grid-connected renewable electricity using solar, wind and biomass resources (NREEEP, 2015). Five years later, the target for 2015 is nowhere accomplished. The Implementation of medium or large-scale renewable electricity projects is capital-intensive with a long payback period. Sourcing for funds for these projects unless with some forms of government's intervention appears to be an enormous challenge.

Renewable energy adoption for power generation in Nigeria is facing the challenges of lack of a framework for sustainability, lack of political will to diversify into clean energy, poor research, and developmental culture, lack of access to wide-ranging technology, high and exorbitant import rates, and lack of support for local manufacturing. The general barriers to harnessing wind resources for power generation in Nigeria are outlined by (Ajayi, 2010; Adedipe et al., 2018). Mohammed et al. (2013) and Wojuola and Alant (2017) outlined the hindrances in the utilization of renewable energy technologies in Nigeria to include technological lag, financial corruption, economic uncertainty, negative opinions or poor level of awareness, lack of technical knowledge of renewable energy technologies, deficient political will, and bureaucratic ineffectiveness.

7.0 Conclusions and Recommendations

This paper examines the potential of renewable energy resources in Nigeria. Major issues of the various reforms, plans, and policies enacted by the federal government since 2001 aimed at boosting the electricity supply have been highlighted. Published articles that delved into cases in Nigeria were reviewed to establish the research direction in conducting viability assessment of adopting hybrid renewable energy systems to serve the electricity demands of the country. Major existing renewable power system projects and key drivers and challengers hampering the development and deployment of renewable power systems were also highlighted. This study has succeeded in revealing that; Nigeria possesses vast renewable energy resources, and if fully harnessed can satisfy the electricity demands of the entire country while going a long way in reducing the environmentally-harmful gas footprints associated with the fossil-based generators. In other words, Nigeria is positioned perfectly for investment in renewable energy technologies, especially as it continues to struggle for reliable and sustainable electricity supply with some power plants currently under construction and overhauling, and the privatization of the distribution and generation subsectors of the electricity supply industry since 2013. The trends of research have shown that the attention of authors is more on off-grid renewable-based rural electrification with an emphasis on hybrid solar PV-diesel generator, and hybrid solar PV-wind-diesel generator due to ease of access of the solar and wind resources at the study locations. Thus, there has been very little research efforts on the commercial-scale or industrial-scale hybrid renewable energy system in Nigeria. Furthermore, apart from the conventional large hydropower schemes contributing to the pool of grid electricity, the rest of the renewable energy schemes are in off-grid mode and are either standalone solar PV or hybrid solar PV-diesel generator. Energy security, economic benefits, and clean energy integration are major factors that should trigger credible research interests and investments in renewable power development not only for rural communities but municipal and industrial areas. Therefore, with the abundance of renewable energy resources across the country, there is a need to extend research focus to municipal and industrial areas, and also include biomass and small hydropower schemes in the energy options. The government needs to show more commitments by putting in place the necessary framework that will encourage sound investments in renewable power generation. For instance, waivers on taxes or its complete relaxation for certain periods, provision of funds, and other incentives to private sectors by the federal government are ways to slope up the development and deployment of renewable power systems. This will also go a long way in reducing the consumer's tariff.

8.0 References

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