INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 07 Issue 02 February 2024

DOI: 10.47191/ijmra/v7-i02-01, Impact Factor: 8.22

Page No. 417-428

Electrification through Renewable Energy in Nigeria an Exploration of Viable Technology Options Beyond Solar PV

Daberechi Emezue

Department of Mechanical Engineering, University of Lagos, Akoka, Nigeria

ABSTRACT: Nigeria has an electrification rate of 54%, with many of those who are connected to the grid experience severe power outages. The Energy Commission of Nigeria intends to address this challenge with the use of renewable technologies. This paper explores the viability of solar PV, biofuel, wind, and small-scale hydro as renewable energy options for electrifying Nigeria. I find that solar PV, biofuel and small-scale hydro show exciting potential in Nigeria, while wind energy has much less potential due to low wind speeds in the country. Ultimately, renewable technologies need to be considered based on the community in question, instead of attempts at a one-size-fits-all approach to electrifying every community in the country. However, hybrid systems combining various renewable technologies might just be the ideal solution to electrifying rural communities and getting the electrification rate in Nigeria to a hundred percent.

KEYWORDS: Renewable energy, Electrification, Sub-Saharan Africa, Solar PV, Biofuel, Wind, Hydro

1. INTRODUCTION

1.1. Background to electricity access challenge in Sub-Saharan Africa

Most of the 770 million people on earth without access to electricity live in Sub-Saharan Africa [1]. This makes it the most electricity-poor region in the world, accounting for the 10 least electrified countries in the world. According to the World Bank, only 48.4% of the population in Sub-Saharan Africa had access to electricity in 2020 [2]. Nigeria is the most populous black nation in Africa with an annual growth rate of 3.2% per annum [3]. Majority of Nigeria's power is generated through natural gas, with hydropower being the other source of power generation [4]. Despite being rich in crude oil, coal and natural gases, 45% of its population is not supplied with electricity [5]. Amongst the population of Nigerians supplied with electricity, many of them still rely heavily on diesel and petrol generators due to severe outages of electricity supply [4].

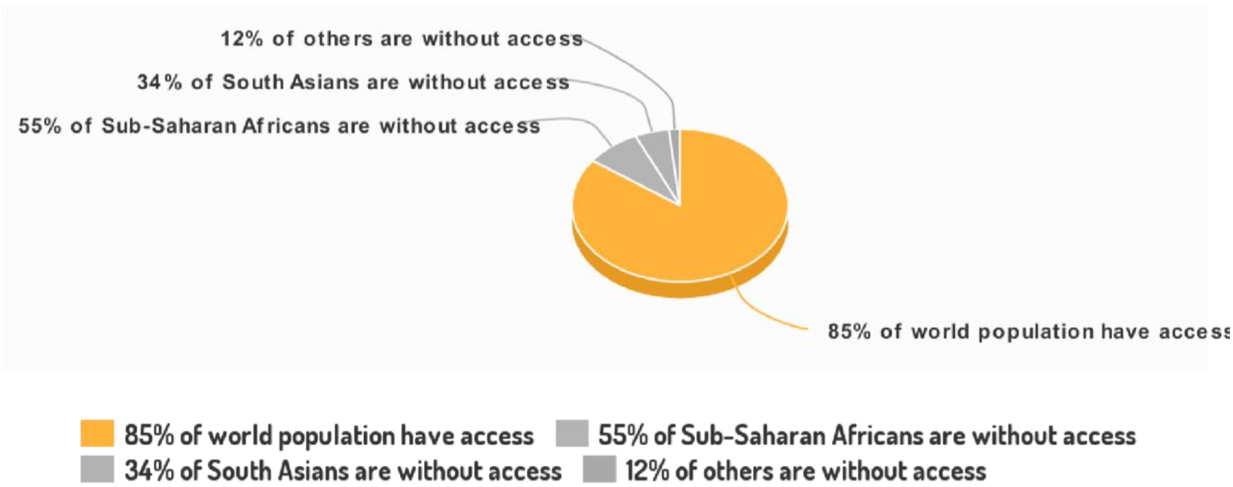

Figure 1. World electricity access and lack of access by region, 2012.

Source: [6].

The predominant means of generating energy around the world is by the use of fossil fuels which accounts for over 60% of the world's energy generation [7]. Fossil fuels are the main source of energy in Africa as many African countries are rich in crude oil, coal and natural gas [8]. In Nigeria, natural gas accounts for 86% of power generated [4]. Due to the inconsistency of power supply through the national grid in Nigeria, a good amount of electricity used in homes is self generated. In urban areas this energy is produced from running petrol or diesel powered generator sets [4]. It is estimated that the total generator sets market in Nigeria is the largest in Africa in terms of revenue [9]. As of 2018, over 60 million Nigerians owned a generator [10]. A survey of 262 people conducted in Obantoko, Ogun State, Nigeria showed that 91.2% of the studied population owned generators, while 92% of their neighbours did [11]. However, these generators have challenges that come with their use. One major challenge is the pollutants released from their exhausts after burning fuel [12]. A large amount of noise pollution is another effect of running generator sets. The study conducted in Obantoko showed that 70.9% of residents in this community complained that their own generator sets are too noisy, while 61 % complained of their neighbours' being too noisy [11]. With generators often running all through the night in residential areas, urban dwellers are also at risk of health challenges that come with its use [13], [14]. In rural settlements where there is no access to electricity, residents depend on fuel-wood for energy supply [15]. This means of generating power through fossil fuels and fuelwood are dominant sources of environmental pollution as carbon dioxide is emitted into the atmosphere.

Electricity access is directly linked to an increased standard of living as there is a positive long-run relationship between household electricity consumption and level of education, poverty rate, per capita income and life expectancy [16]. About 45% of Nigeria's population is off-grid [5]. A lack of electricity in rural off-grid areas hinders the ability of its dwellers to improve livelihoods, secure high-quality public services, and rise out of poverty [17]. In rural communities, there are various income-generating activities that can be vastly improved in efficiency with a supply of electricity, such as sewing, food processing and several other artisan activities. Electricity access also positively impacts the health of consumers as alternative means of illumination such as kerosene lanterns or candles which are sources of indoor air pollution and are also fire hazards are avoided [18]. Education can also see an improvement as children in these areas are able to study at all times of the day with the provision of electricity.

The United Nations has the Sustainable Development Goal (SDG 7.1) to ensure access to affordable, reliable, sustainable and modern energy for all by 2030. With a large amount of Sub-Saharan Africa's poor living in dispersed rural settlements where the cost of extending the national grid connection is too costly, there is a need for decentralised energy technologies to serve these areas [19]. Renewable energy is often recommended as the ideal technology for these rural communities, with solar PV seen as the most attractive option in Africa. Thus, many countries in the continent have given priority to PV and have launched several PV projects. The United Nations Development Programme (UNDP) and the Energy Commission of Nigeria (ECN) drafted the Renewable Energy Master Plan (REMP) for Nigeria in 2005 [20]. The plan set an installed capacity target of 14,000 MW of renewable energy-based power generation by 2015. However, the International Renewable Energy Agency (IRENA) records that Nigeria's renewable capacity was only 2,153 MW as at 2020 [21], [22]. According to Akuru et al. [21], wind and solar energy projects to alleviate Nigeria's energy gap continue to fail or face delays. Akuru et al. gave the example of over 10 Independent Power Producers (IPPs) having issues with tariff structures after announcing that they would deploy 1.5 MW solar capacity in 2016. This has then led to construction delays and possible failure of these projects.

1.2. Objectives

The objective of this paper is twofold. To assess the:

(1) appropriateness of electrifying homes and communities in Nigeria with solar energy;
(2) viability of other renewable energy options in electrifying homes or communities in Nigeria.

1.3. Methods

To achieve the objectives outlined above, I conducted a literature review using secondary data from peer-reviewed publications using the Scopus database. I executed search strings covering the past 20 years, searching for "electrification of homes''. I then proceeded to refine the search results with the strings "renewable energy" and then "developing countries". The first search string "electrification of homes" produced 634 results. After refining with the strings "renewable energy" and "developing countries", I received 455 and 233 results, respectively. Afterwards, I sorted the results by the highest cited publications.

I also executed another search on Scopus, searching for "electrification" and refining with "renewable energy" and "africa" which produced 17875, 6873 and 1698 results, respectively. To get papers that focus on specific renewable technologies, I finally refined the results with "solar", "biofuel", "wind" and "hydro." This produced 1349, 126, 770 and 434 journals for "solar", "biofuel", "wind" and "hydro" search strings, respectively.

2. LITERATURE REVIEW

2.1. Solar PV as a renewable energy source in Nigeria

Solar PV has seen some success in Africa for several decades. A survey was carried out in the rural unelectrified community of Nyimba in Zambia [23]. An Energy Service Company had operated 100 Solar Home Systems (SHSs) from the year 2000 in this community. Although having to pay more for energy than before the installation of these 50 Wp solar home systems, clients were generally satisfied with the service provided after almost 3 years of service when the survey was conducted in 2003. The major advantage of the SHSs was the greater quality of light provided by solar lamps when compared to candles or kerosene lamps. This greater quality of light was especially advantageous in the education of their children as they were able to study more conveniently at night. Another benefit of these SHSs was the ability to power TVs and video sets which served as a means of entertainment. The study was able to show how attractive the energy services from these solar systems were. However, more than 40% of those surveyed commented on the low capacity of the systems.

Nigeria receives an abundance of solar radiation every year with an average of about 5.5 kWh/m^2/day. In a situation where solar systems with 5% efficiency are used to cover 1% of the country, an equivalent of 2.541 x 10^6 MWh of electricity can be generated daily [24]. This makes solar PV a very enticing prospect for solving the electricity crisis in the country. Yet, despite receiving such considerable amounts of solar radiation, considerations need to be made concerning the implementation of solar energy in a country whose priority is the long-term development of electricity systems with as low a cost as possible.

The Nigerian government has set clear targets under its National Renewable Energy Action Plan (NREAP) in exploiting its renewable resources potentials. The National Renewable Energy and Energy Efficiency Policy (NREEEP) 2015 aims for renewable energy to account for 16% of Nigeria's electricity consumption by 2030 [25]. The Energy Commission of Nigeria (ECN) estimates that solar PV can account for about 5.9% of this target. Rural solar PV projects began in Nigeria almost four decades ago. From as early as 1985, the Sokoto State Government financed the PV lighting project in Gotomo and Tunga-Buzu villages, which had a power output of 7 kWp [26]. In 1993, the ECN and the Sokoto Energy Research Centre executed the Kwalkwalawa PV-powered electrification scheme which provided power to a village of 60 households through a PV power plant [27]. The power output of this system which consisted of 204 solar modules, four 2.5 kW inverters and 28 deep cycle batteries was 7.21 kWp, and it had a total storage capacity of 4270 Ah. This project was created to serve as a model for future rural electrification projects through PV. The Rural Electrification Agency (REA) was launched in 2005 to provide electricity to off-grid communities in Nigeria. As at 2017, the REA had deployed several projects including twelve mini-grid projects ranging between 30 and 100 kW with a total capacity of 1,016 kW. It had also deployed over 19,130 units of Solar Home Systems [28]. Home Solar Systems are also used in urban communities in Nigeria. While they are costly to set up, their minimal maintenance, modularity and the fact that they do not produce noise makes them an alternative to generators.

According to Lahimer et al. [29], despite its technological advantages, PV is not a cost-effective option for electrifying off-grid communities because of its high capital cost. While worldwide costs of solar PV systems have decreased over the years, these systems remain quite expensive for many rural residents in Nigeria. With batteries required to maintain energy supply when there is little or low availability of solar radiation, the cost of a solar PV system only increases. From Baurzhan el's findings in 2016 [30], the initial investment cost of a 100 Wp solar PV system is sufficient to purchase a diesel generator of up to 1.2 kWp capacity. This means that much more power-hungry activities like water pumping, irrigation and several income generating activities become possible. Solar PV often fails to meet the energy requirement of communities beyond lighting and other low power applications. In fact, Baurzhan et al. share that the Deutsche Gesellschaft für Internationale Zusammenarbeit (GTZ) concluded that rural households buy SHSs for improved services such as longer TV viewing and better lighting quality, not because these SHSs actually reduce their energy costs. This ties closely to the point made by Karekezi et al. [19] that "the most successful renewable technologies in rural Africa are likely to be the ones that can generate income and facilitate the start-up of small micro-enterprises". With rural small and micro-enterprises needing about 100 - 1000 times the amount of energy a typical solar system can provide (40 - 100Wp), these systems are not a necessity for many rural dwellers. In the sections that follow below, I discuss alternative options to solar PV.

2.2. Biofuel as a renewable energy source in Nigeria

Bioenergy production and applications have made great strides in more developed continents. As with many other things, Africa has been left lagging behind the rest of the world. With the continent being abundantly blessed with favourable climate, fertile soils and enormous land mass which are vital in driving the technology, it is pertinent for Africa to follow suit in the development of bioenergy. Biofuel is a non-fossil fuel derived biomass. Hoffmann et al. [31] defines it as a "renewable energy source produced from natural (bio-based) materials which can be used as a substitute for petroleum fuels". Biofuels can be produced from several processes; bioethanol can be produced from cellulosic materials, biomethanol can be produced from organic wastes, hydrogen can also be generated from organic wastes, and biodiesel can be produced from vegetable oils [32]. According to Adewuyi [33], bioethanol and biodiesel are the most sustainable forms of biofuel in Nigeria and there has been success in preliminary studies done with oil palm and cassava for the production of biofuel. Dahunsi et al. [8] also tells us that Jatropha curcas plantations–which is a biodiesel feedstock–exist across all geopolitical zones of the country. Bioethanol and biodiesel are considered as economically feasible and have been commercialised in some countries. For example, Malawi in the 80s began producing bioethanol from sugarcane molasses. This bioethanol then goes into a 1:9 ratio blend with gasoline for the purpose of transportation [8]. The National Renewable Action Plan (NREAP) has a target of biodiesel contributing to 17.45% of the national diesel and fuel-oil consumption by 2030 [25].

Biogas projects have seen success in rural counties in China. The Minhe Biogas project which is the largest chicken waste biogas energy plant in China has a 3 MW biogas generation plant. The plant consumes 300 t of manure and 500 t of waste-water daily to generate electricity for the local grid, with the leftover matter from the process used for fertiliser [34]. Adewuyi argues that the Nigerian waste system, if effectively managed, has the potential of generating sufficient energy to drive the economy and serve as means of employment. Likewise, Dahunsi et al. state that biogas generated from the annual 545 million tons of organic municipal wastes can potentially generate up to 173,458 MWh of electricity. Amuzu-Sefordzi et al. [35] make a similar argument, claiming that biomass-derived hydrogen energy has the potential to displace more than 240% of annual electricity consumption in Nigeria.

2.3. Wind as a renewable energy source in Nigeria

Wind energy is a technology that could be cost-effective and efficient in generating power when utilised. Lahimer et al. [29] claim that a study showed that stand-alone wind systems are preferable to stand-alone PV systems where both resources are abundant. However, it is site-specific as it is only feasible for use in locations with high wind speeds and thus is only cost-competitive in coastal regions of Africa. Seyedhashemi et al. [36] claim that in these regions it is likely even more economically advantageous than diesel systems. Just like with other forms of renewable technologies like solar PV and hydrokinetic technology, low or fluctuating resource availability reduces the ability of this technology to provide energy to power connected loads. Hence, batteries are required to complement this technology. In regions where wind speeds are low, a larger number of batteries will be required. This then significantly increases the cost of generating electricity.

Wind energy in Nigeria is at its infancy or almost nonexistent, with the International Renewable Energy Agency (IRENA) stating that Nigeria had generated 0 GWh of electricity through this technology at the end of 2019 [22]. When compared to other African countries like Egypt, South Africa, Morocco and Tunisia, the potential for wind energy in Nigeria is much lower. At the end of 2009, with installed capacities of 430 MW, 253 MW and 54 MW respectively, Egypt, Morocco and Tunisia led the continent in wind energy. In South Africa where wind speeds range from 4.0 - 5.0 m/s for most of the coastal regions and is approximately 8.0 m/s in some mountain regions, they had over 30,000 water pump systems utilising wind energy as at 2006 [37]. Nigeria however has much lower wind speeds with an annual average of 2.0 - 4.0 m/s at 10 m height [38]. Because of this, Seyedhashemi et al. [36] and Gabra et al. [39] conclude that in more central African countries like Nigeria, wind speeds are just too low for wind to be a suitable means of generating electricity.

Despite the challenges, such as low wind speeds in Nigeria, the Energy Commission of Nigeria (ECN) has made clear its intentions of developing the wind energy capacity and integrating it into the electricity supply mix of the country with the following policies and objectives stated in the National Energy Masterplan 2022 [38].

Policy focus and directions. The nation shall:

1. commercially develop its wind energy resource and integrate this with other energy resources into a balanced energy mix.
2. take necessary measures to ensure that this form of energy is harnessed at sustainable costs to both suppliers and consumers in the rural areas.
3. apply global best practices in the exploitation of wind energy resources.
4. encourage the utilisation of wind energy for agricultural purposes.

The corresponding objectives are to:

1. develop wind energy as an alternative energy resource.
2. develop local capability in wind energy technology.
3. use wind energy for provision of power to rural areas and remote communities far removed from the national grid.
4. apply wind energy technology in areas where it is technically and economically feasible.
5. encourage the utilisation of wind energy for agricultural purposes.

2.4. Small-scale hydropower as a renewable energy source in Nigeria

Small-scale hydropower (SHP) is another technology that can be considered in rural electrification whenever a suitable site is available. **Table 1** shows the classification of hydropower in Nigeria. It is similar to wind technology in rotor blade configurations and that their power outputs depend on flow speed. Lahimer et al. [29] claims that it can potentially be the most cost-effective means of rural electrification ahead of wind, PV and diesel generators.

Table 1. Classification of hydropower in Nigeria

Hydropower category	Power range
Micro	0 - 500 kW
Mini	500 - 1000 kW
Small	1 - 30 MW
Large	> 30 MW

Source: [40]

Ebhota et al. [5] share that there are over 278 rivers around Nigeria identified as potential sites for micro and mini hydropower systems with a total capacity of 734 MW. A number of off-grid SHP projects by the Nigerian Electricity Supply Company (NESCO) exist in Plateau State with capacity ranges of between 3 and 40 MW [41]. Hydroelectricity is still underexploited in Nigeria despite its large potential. Small hydropower was first used in Nigeria in 1925, yet as of 2018, only a fraction of the estimated 3500 MW of exploitable small hydropower potential in the country has been tapped [37], [38], [41]. There is an urgent need to develop these surveyed potential SHP sites. As of 2012, the small hydropower schemes that existed in Nigeria are listed in **Table 2**.

Table 2. Existing small hydropower schemes in Nigeria

S/N	River	State	Installed capacity (MW)
1	Bagel I and II	Plateau	1.0 and 2.0
2	Bakalori	Zamfara	3.0
3	Kurra	Plateau	8.0
4	Lere I and II	Plateau	4.0 and 4.0
5	Oyan	Ogun	9.0

Source: [41]

Its advantages include low installation and maintenance costs and options for local manufacturing. This can be implemented in the form of hydrokinetic systems, which refers to hydroelectric systems which harness energy from flowing water. Meaning energy can be captured from waves, tides or rivers. Koko et al. [42] points out that "in rural areas with high water density, a small-scale hydrokinetic river system can generate electricity markedly cheaper than a small-scale wind system". It was shown in their paper that hydrokinetic power was cheaper than a wind system in a rural area of South Africa. Kusakana [43] concluded in their paper that using hydrokinetic-based hybrid systems reduces the cost and increases the reliability of both single energy systems like solar PV, wind and diesel generators, as well as hybrid systems combining the other technologies.

3. FINDINGS AND DISCUSSIONS

Cost is the main limiting factor in supplying power to rural communities. Ideally, grid connected power is the best means of electrifying these low-income communities. However, because rural communities are dispersed, have low population densities and have harsh terrain between them and mainland areas, it is just not profitable for distribution companies to build infrastructure to electrify these communities.

Diesel generators are the most cost effective solution for electrifying rural communities in Nigeria and certainly have a lower cost per unit of electricity than solar PV [30], [39]. Its relatively simple technology, easy installation and sufficient knowledge on maintenance makes it an attractive solution. It is however not the perfect solution for generating electricity as the fluctuating price of diesel fuel and the need for frequent maintenance serve as drawbacks to the use of this technology. Also, due to environmental degradation from the use of fossil fuels, the world is searching for alternative means of generating electricity, and this can be through renewable energy. Renewable energy is energy from naturally replenishing sources that do not get exhausted after use. This includes wind energy, solar PV, hydropower, etc.

Table 3. Estimate of Nigeria's renewable resources reserves

Renewable resource	**Estimated Potential Capacity/Reserves**	**Region with greatest potential for these resources**
Large hydropower	24,000 MW	Southern and Plateau areas of the country
Small hydropower (<30 MW)	3,500 MW	Southern and Plateau areas of the country
Fuelwood	13 million hectares	Savanna region of the country
Animal Waste	61 million tonnes/yr	
Crop residue	83 million tonnes/yr	Savanna region of the country
Solar radiation	3.5 - 7.0 $KWh/m^2/day$	Northern part of the country
Wind	2.0 - 4.0 m/s (annual average) at 10 m height	Jos and northwest geopolitical zone

Source: [38], [44]

Nigeria had a 38% target for the renewable energy share of the electricity mix in its grid connected generation for 2020 [22], [25]. Of the total 33,552 GWh generation in 2019, only 8,492 GWh was from renewables, with hydro and marine contributing 8,430 GWh of that. Solar and bioenergy contributed a mere 41 and 21 GWh, respectively. No other sources of renewable energy contributed to the power generation in 2019. This means that the renewable energy share of the electricity mix at the end of 2019 was only 25.3 %.

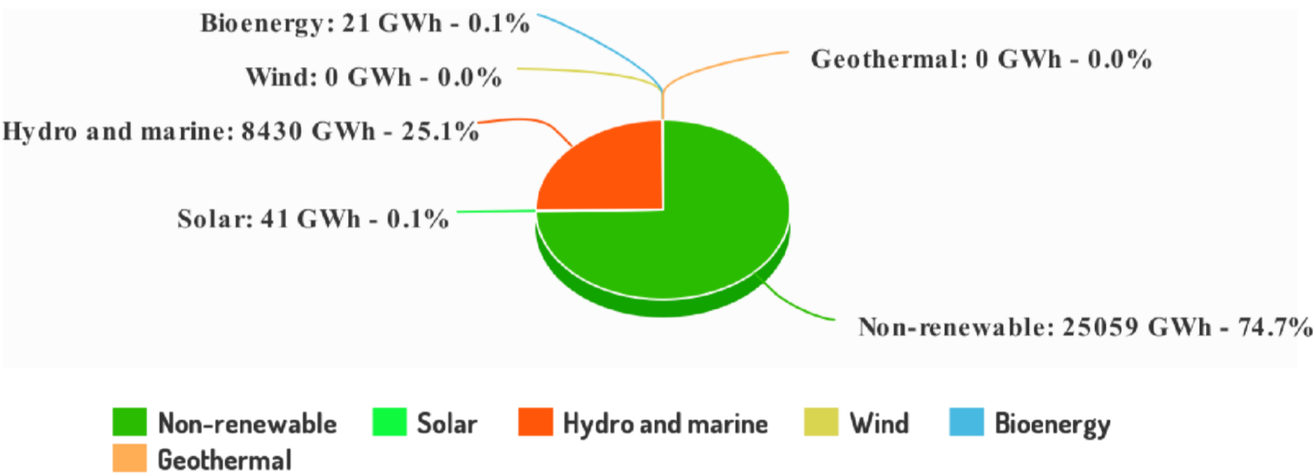

Figure 2. Nigeria's electricity generation in 2019.

Source: [22]

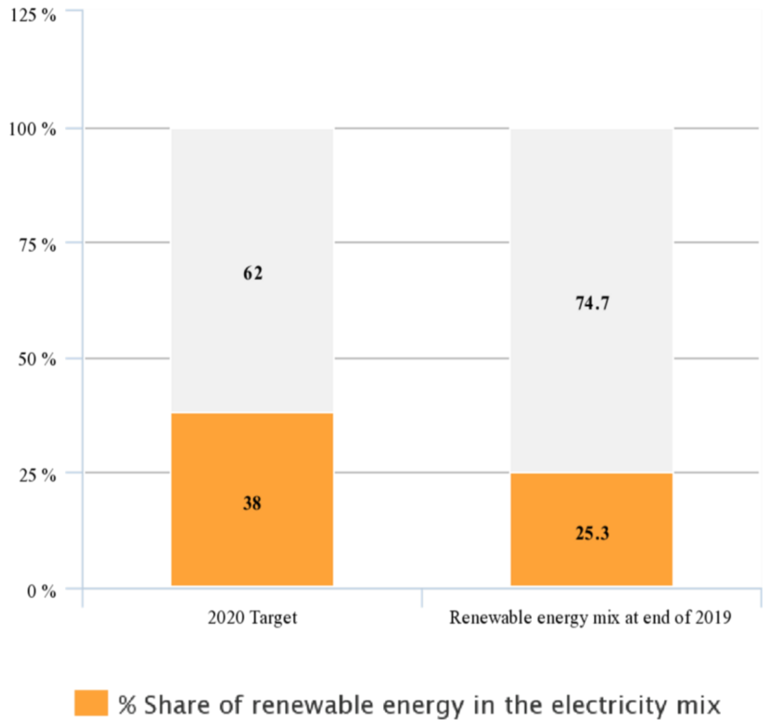

Figure 3. Nigeria's target for the renewable energy share of electricity mix in grid connected generation (including medium and large hydropower).
Source: [6], [22], [25].

The Energy Commission of Nigeria (ECN) has made clear its intentions of developing the renewable energy capacity of the country and integrating it into the electricity supply mix of the country. The National Renewable Energy and Energy Efficiency Policy (NREEEP) 2015 aims for renewable energy to account for 16% of Nigeria's electricity consumption by 2030 [25]. The ECN estimates that solar PV can account for about 5.9% of this target while hydropower, biomass and wind can account for about 7.07%, 2.78% and 0.25% respectively. They aim for renewable energy to account for 29% of grid connected generation and 40% of off-grid electricity generation by 2030. These targets as well as the barriers, policies and regulations for achieving them are stated in the National Renewable Energy Action Plan (NREAP) under the
National Energy Master Plan 2022 [38]. The latest version of this document was approved by the National Council on Power (NACOP) on the 14th of July, 2016. To achieve the country's target of renewable energy accounting for 16% of its electricity consumption by 2030, several policies and measures to promote the use of RE resources have been put in place. **Table 4** below outlines some of these measures and their expected results.

Table 4. Overview of policy instruments for RE in Nigeria

Name of the measure	**Grid or off-grid connected RE**	**Type of measure**	**Expected results**	**Target group**	**Start and end dates of the measure**
Feed-in Tariffs (FIT)	Grid connected	Regulatory	Increase generation of renewable electricity from 1MW to 5MW for PV and biomass, and from 1MW to 10MW for wind, small and medium hydropower plants	Primarily medium scale renewable electricity generation by Independent Power Producers (IPPs)	Start in 2016 with no end date defined.

Competitive Procurement Programme	Grid connected	Regulatory	Increase generation of renewable electricity from 5MW and above for PV and from 10MW and above for wind, small and medium hydro power	Primarily medium scale renewable electricity generation by energy companies	Start in 2016 with no end date defined.
GIZ-Nigerian Energy Support Programme: Capacity Building Component	Grid connected	Capacity Building	Develop professional and technical courses on renewable energy and energy efficiency	Working with National Power Training Institute of Nigeria and aimed at both public and private institutions of power sector	March 2013 March 2018
National Policy on Public Private Partnership (PPP)	Grid connected	Policy	Guidelines, policies, and procurement process for PPP	Collaborate with the States of the Federation to promote an orderly and harmonised framework for the development	2012 to date
				and market for PPPs	
National Renewable Energy and Energy Efficiency Policy (NREEEP)	Grid connected	Policy	Promote renewable energy and energy efficiency	Public and private sector	2015 to date
Soft loan	Off-grid	Financial	Assist with soft loans with low interest rates through the Bank of Industry	Small scale renewable energy generation companies	

Renewable Energy Subsidy and Grant	Off-grid	Financial	Provision of subsidy of up to 30% of initial costs of renewable energy utilisation facilities	Communities, enterprises, and individuals that embark on RE generation projects	
Rural Electrification Strategy and Implementati on Plan	Off-grid	Strategy/Pl an	Promote electricity in rural areas	Public and private sector	
National Biofuel Policy		Policy	To integrate the agriculture sector to the downstream section	Petroleum Industry	2007 to date

Source: [25]

There are potentials for the implementation of the renewable technologies explored in this paper in Nigeria. There are also challenges that exist with every form of these renewable technologies. Solar energy is very promising in Nigeria. The amount of sunlight received in Nigeria and much of Africa makes this technology extremely attractive and useful in solving its energy crisis. Hence, the Federal Government has put in place schemes, policies and targets to develop its potential in Nigeria. The Nigeria Electrification Project (NEP) is one of these initiatives that have been set in place under the Rural Electrification Agency to solve this crisis. This private sector driven initiative aims to supply electricity to rural communities through the deployment of mini grids and Solar Home Systems. As at the time of writing, this initiative claims to have supplied electricity to 3.8 million people in 680 thousand households [45]. Yet, despite the falling price of PV systems, many researchers believe solar PV not to be the ideal solution to electrifying Nigeria and Africa due to the fact that it cannot compete economically with existing grids or diesel generators [19], [29], [30], [46]. Furthermore, it also has little use beyond powering lighting and low power devices since PV systems for powering more powerful equipment are often too costly.

Bioenergy in the form of bioethanol, biodiesel and biogas is a very promising form of renewable energy in Nigeria. However, the availability of land for growing feedstock and food security are serious considerations that come with the use of this technology. For example, a study was conducted in the village of Laela in Western Tanzania through surveys, focus group discussions and expert interviews [31]. The analysis aimed to evaluate the impact the use of sunflower and groundnut oils for local biofuel production had on development and food supply in the village. It was concluded that replacing food crops with biofuel producing crops is likely to increase hunger and existing economic gaps in the village. Extensive research is thus needed in potential rural sites for this technology to establish its viability in that community or village. For the urban communities in Nigeria, challenges to this technology exist in developing an effective waste management system that is able to convert municipal waste to biogas. Other challenges like high production cost, non-favourable government policies and technical knowledge can also harm the potential of this technology in Nigeria.

In the case of wind energy, due to the need for high wind speeds for wind systems to be competitive in cost with the grid and solar PV, this technology is not suitable for generating electricity in many parts of Nigeria.

While there are existing SHP schemes in Nigeria, this technology needs to be developed beyond its existing state as there is an abundance of flowing water bodies in the country. This technology can be used alongside other renewable energy technologies in hybrid systems to lower energy costs and increase the reliability of energy supply. Flow rate fluctuation is a key challenge faced by hydropower systems due to changing weather and climatic conditions in Nigeria. In dry season and monsoons, there could be little to no power provided by SHP systems. As a result of flow rises and falls, a stand-alone hydropower system can fail to meet its demand during these periods [29].

Various renewable technologies can be best implemented in various parts of the country and can serve varying purposes to different communities or villages across the country. Different communities might value the benefits and can better manage the challenges provided by certain technologies above that provided by others. Thus, case-based research needs to be made in evaluating the renewable technologies to be implemented in electrifying communities in Nigeria. I agree with the statement by Karekezi et al. [19] that “a renewable energy strategy that relies on a wider range of renewable technologies can ensure that the poor select the technology that best fits their comparative advantage as well as their incomes”.

4. CONCLUSION

Improving electricity access in Nigeria is of immense importance and is a major challenge. With about 45% of the country's population living off-grid and electricity supply being terribly unreliable to the grid connected population, the challenge of electricity access is one faced by the entire nation. Since reliable and cheap energy is a key driver of economic growth and improves the livelihood of citizens, Nigeria has worked on improving its electricity access, especially to its rural areas. The United Nations Development Programme (UNDP) and the Energy Commission of Nigeria (ECN) drafted the Renewable Energy Master Plan (REMP) for Nigeria in 2005 to coordinate the development and implementation of renewable energy in its energy sector. This development has caused organisations including the National Electricity Supply Company (NESCO) and the Rural Electrification Agency (REA) to develop schemes that have made some progress in generating electricity through renewable technologies [5], [41]. Nigeria has huge renewable energy potentials that have unfortunately been underutilised. Of the various forms of renewable energy sources available in Nigeria, solar PV has had the most capacity growth over the years. It also has the largest electricity generation target above small hydro, wind energy and biomass [22], [38]. However, because of the high cost of this technology and its typically low power application, other renewable technologies need to be considered in solving the nation's electricity crisis.

Bioenergy shows a lot of potential in Nigeria. Bioethanol, biodiesel and biogas are possible biofuels that can be successfully produced in the country. The presence of abundant land mass and favourable climate means that feedstock to produce bioethanol and biodiesel can be grown. Likewise, municipal wastes can be used to generate biogas.

The effectiveness and economic advantage of small hydro energy is highly subjective to the particular area or community considered. Even in areas where there is an abundance of flowing water, the technology's strong reliance on weather and climatic conditions and its resource dependent power output is something to consider [43]. The case of wind technology is similar to small hydro in that it is highly dependent on weather conditions, however the potential for wind is even much less than small hydro in most parts of Nigeria.

Hybridization of some of these renewable technologies can create a scenario where one or more technologies serve to compensate for the disadvantages of the other(s) and fill in the gap for energy shortages from one or more sources. This is a solution that the renewable energy developers in Nigeria should put into consideration as they seek to develop these technologies and solve the electricity crisis in the country.

ACKNOWLEDGEMENTS

I would like to express my deepest appreciation to my supervisor, Dr. Nehemiah Sabinus Alozie for guiding my research throughout the programme.

Words cannot express my gratitude to my family, especially my older brother, Chukwuma Emezue, for financing my academic journey so far. Finally, I'm extremely grateful to God for making this opportunity possible and allowing me to complete this paper.

REFERENCES

1) ‘World Energy Outlook 2021 – Analysis’, *IEA*. https://www.iea.org/reports/world-energy-outlook-2021 (accessed Aug. 30, 2022).
2) ‘Access to electricity (% of population) - Sub-Saharan Africa | Data’. https://data.worldbank.org/indicator/EG.ELC.ACCS.ZS?locations=ZG (accessed Aug. 30, 2022).
3) A. I. Akinyemi and U. C. Isiugo-Abanihe, ‘Demographic dynamics and development in Nigeria’, *Afr. Popul. Stud.*, vol. 27, no. 2, p. 239, Mar. 2014, doi: 10.11564/27-2-471.
4) T. R. Ayodele, A. S. O. Ogunjuyigbe, O. D. Ajayi, A. A. Yusuff, and T. C. Mosetlhe, ‘Willingness to pay for green electricity derived from renewable energy sources in Nigeria’, *Renew. Sustain. Energy Rev.*, vol. 148, p. 111279, Sep. 2021, doi: 10.1016/j.rser.2021.111279.

5) W. S. Ebhota and P. Y. Tabakov, 'The place of small hydropower electrification scheme in socioeconomic stimulation of Nigeria', *Int. J. Low-Carbon Technol.*, vol. 13, no. 4, pp. 311–319, Dec. 2018, doi: 10.1093/ijlct/cty038.
6) B. Lohani *et al.*, 'REN21. 2015. Renewables 2015 Global Status Report (Paris: REN21Secretariat).'
7) S. Rahman and A. de Castro, 'Environmental impacts of electricity generation: a global perspective', *IEEE Trans. Energy Convers.*, vol. 10, no. 2, pp. 307–314, Jun. 1995, doi:10.1109/60.391897.
8) S. O. Dahunsi, O. O. Fagbiele, and E. O. Yusuf, 'Bioenergy technologies adoption in Africa: A review of past and current status', *J. Clean. Prod.*, vol. 264, p. 121683, Aug. 2020, doi:10.1016/j.jclepro.2020.121683.
9) A. Babajide and M. C. Brito, 'Solar PV systems to eliminate or reduce the use of diesel generators at no additional cost: A case study of Lagos, Nigeria', *Renew. Energy*, vol. 172, pp. 209–218, Jul. 2021, doi: 10.1016/j.renene.2021.02.088.
10) T. Kemabonta and M. Kabalan, 'Using What You Have, to Get What You Want – A Different Approach to Electricity Market Design for Local Distribution Companies (DISCOs) in Nigeria', in *2018 IEEE Global Humanitarian Technology Conference (GHTC)*, Oct. 2018, pp. 1–2. doi:10.1109/GHTC.2018.8601910.
11) A. Azodo and S. B. Adejuyigbe, 'Examination of Noise Pollution from Generators on the Residents of Obantoko, Ogun State, Nigeria', *ASIAN J. Eng. Sci. Technol.*, vol. 3, pp. 31–41, Mar. 2013.
12) O. Oguntoke and A. Adeyemi, 'Degradation of urban environment and human health by emissions from fossil-fuel combusting electricity generators in Abeokuta metropolis, Nigeria', *Indoor Built Environ.*, vol. 26, no. 4, pp. 538–550, Apr. 2017, doi: 10.1177/1420326X16629818.
13) N. Singh and S. C. Davar, 'Noise Pollution-Sources, Effects and Control', *J. Hum. Ecol.*, vol. 16, no. 3, pp. 181–187, Nov. 2004, doi: 10.1080/09709274.2004.11905735.
14) M. S. Hammer, T. K. Swinburn, and R. L. Neitzel, 'Environmental Noise Pollution in the United States: Developing an Effective Public Health Response', *Environ. Health Perspect.*, vol. 122, no. 2, pp. 115–119, Feb. 2014, doi: 10.1289/ehp.1307272.
15) O. Oguntoke, B. O. Opeolu, and N. Babatunde, 'Indoor Air Pollution and Health Risks among Rural Dwellers in Odeda Area, South-Western Nigeria', *Ethiop. J. Environ. Stud. Manag.*, vol. 3, no. 2, Sep. 2010, doi: 10.4314/ejesm.v3i2.59833.
16) M. C. Ezeh, U. C. Nwogwugwu, and O. N. Ezindu, 'Impact of Household Electricity Consumption on Standard of Living in Nigeria', *J. Energy Technol. Policy*, Feb. 2020, doi:10.7176/JETP/10-1-05.
17) International Energy Agency, International Renewable Energy Agency, United Nations, World Bank Group, and World Health Organization, *Tracking SDG7: The Energy Progress Report 2018*. World Bank, Washington, DC, 2018. doi: 10.1596/29812.
18) I. A. Olanrele, A. I. Lawal, S. O. Dahunsi, A. A. Babajide, and J. O. Iseolorunkanmi, 'The impact of access to electricity on education and health sectors in Nigeria's rural communities', *Entrep. Sustain. Issues*, vol. 7, no. 4, pp. 3016–3035, Jun. 2020, doi: 10.9770/jesi.2020.7.4(30).
19) S. Karekezi and W. Kithyoma, 'Renewable energy strategies for rural Africa: is a PV-led renewable energy strategy the right approach for providing modern energy to the rural poor of sub-Saharan Africa?', *Energy Policy*, vol. 30, no. 11–12, pp. 1071–1086, Sep. 2002, doi:10.1016/S0301-4215(02)00059-9.
20) U. B. Akuru and O. I. Okoro, 'Renewable energy investment in Nigeria: A review of the renewable energy master plan', in *2010 IEEE International Energy Conference*, Dec. 2010, pp. 166–171. doi:10.1109/ENERGYCON.2010.5771668.
21) T. Kemabonta, A. Geoffrey, O. Apena, and S. Uzzle, 'What Went Wrong And How Can We Fix It: Renewable Energy and Mini-Grid Policies in Nigeria', in *2019 IEEE PES/IAS PowerAfrica*, Aug. 2019, pp. 76–80. doi: 10.1109/PowerAfrica.2019.8928648.
22) International Renewable Energy Agency, 'IRENA/Statistical_Profiles/Africa/Nigeria_Africa_RE_SP', Sep. 2021. [Online]. Available: https://www.irena.org/IRENADocuments/Statistical_Profiles/Africa/Nigeria_Africa_RE_SP.pdf [23]
23) M. Gustavsson and A. Ellegård, 'The impact of solar home systems on rural livelihoods. Experiences from the Nyimba Energy Service Company in Zambia', *Renew. Energy*, vol. 29, no. 7, pp. 1059–1072, Jun. 2004, doi: 10.1016/j.renene.2003.11.011.
24) J. O. Ojosu, 'The iso-radiation map for Nigeria', *Sol. Wind Technol.*, vol. 7, no. 5, pp. 563–575, Jan. 1990, doi: 10.1016/0741-983X(90)90065-A.
25) 'Nigeria National Renewable Energy Action Plan (NREAP).pdf', INTER-MINISTERIAL COMMITTEE ON RENEWABLE ENERGY AND ENERGY EFFICIENCY (ICREEE). [Online]. Available: https://www.se4all-africa.org/fileadmin/uploads/se4all/Documents/Country_PANER/Nigeria_National_Renewable_Energy_Action_Plans_.pdf

26) O. U. Oparaku, 'Photovoltaic systems for distributed power supply in Nigeria', *Renew. Energy*, vol.25, no. 1, pp. 31–40, Jan. 2002, doi: 10.1016/S0960-1481(00)00203-2.
27) H. N. Yahya and A. S. Sambo, 'Solar photovoltaic-powered village electrification at Kwalkwalawa in Sokoto State', *Renew. Energy*, vol. 6, no. 3, pp. 307–309, Apr. 1995, doi:10.1016/0960-1481(95)00028-I.
28) RURAL ELECTRIFICATION AGENCY, 'REF Call 1', *Rural Electrification Agency*, Apr. 12,2021. https://rea.gov.ng/ref-call-1/ (accessed Jul. 12, 2022).
29) A. A. Lahimer, M. A. Alghoul, F. Yousif, T. M. Razykov, N. Amin, and K. Sopian, 'Research and development aspects on decentralized electrification options for rural household', *Renew. Sustain. Energy Rev.*, vol. 24, pp. 314–324, Aug. 2013, doi: 10.1016/j.rser.2013.03.057.
30) S. Baurzhan and G. P. Jenkins, 'Off-grid solar PV: Is it an affordable or appropriate solution for rural electrification in Sub-Saharan African countries?', *Renew. Sustain. Energy Rev.*, vol. 60, pp. 1405–1418, Jul. 2016, doi: 10.1016/j.rser.2016.03.016.
31) H. Hoffmann, G. Uckert, C. Reif, F. Graef, and S. Sieber, 'Local biofuel production for rural electrification potentially promotes development but threatens food security in Laela, Western Tanzania', *Reg. Environ. Change*, vol. 15, no. 7, pp. 1181–1190, Oct. 2015, doi:10.1007/s10113-014-0596-x.
32) A. H. Demirbas and I. Demirbas, 'Importance of rural bioenergy for developing countries', *Energy Convers. Manag.*, vol. 48, no. 8, pp. 2386–2398, Aug. 2007, doi: 10.1016/j.enconman.2007.03.005.
33) A. Adewuyi, 'Challenges and prospects of renewable energy in Nigeria: A case of bioethanol and biodiesel production', *Energy Rep.*, vol. 6, pp. 77–88, Feb. 2020, doi: 10.1016/j.egyr.2019.12.002.
34) Z. Bie and Y. Lin, 'An Overview of Rural Electrification in China: History, technology, and emerging trends.', *IEEE Electrification Mag.*, vol. 3, no. 1, pp. 36–47, Mar. 2015, doi:10.1109/MELE.2014.2381606.
35) B. Amuzu-Sefordzi, J. Huang, D. M. A. Sowa, and T. D. Baddoo, 'Biomass-derived hydrogen energy potential in Africa', *Environ. Prog. Sustain. Energy*, vol. 35, no. 1, pp. 289–297, Jan. 2016, doi: 10.1002/ep.12212.
36) H. Seyedhashemi, B. Hingray, C. Lavaysse, and T. Chamarande, 'The Impact of Low-Resource Periods on the Reliability of Wind Power Systems for Rural Electrification in Africa', *Energies*, vol. 14, no. 11, p. 2978, May 2021, doi: 10.3390/en14112978.
37) M. Shaaban and J. O. Petinrin, 'Renewable energy potentials in Nigeria: Meeting rural energy needs', *Renew. Sustain. Energy Rev.*, vol. 29, pp. 72–84, Jan. 2014, doi: 10.1016/j.rser.2013.08.078.
38) 'National Energy Masterplan (NEMP)', Energy Commission Of Nigeria. Accessed: Aug. 12, 2022. [Online]. Available: https://www.energy.gov.ng/Energy_Policies_Plan/APPROVED_NEMP_2022.pdf
39) S. Gabra, J. Miles, and S. A. Scott, 'Techno-economic analysis of stand-alone wind micro-grids, compared with PV and diesel in Africa', *Renew. Energy*, vol. 143, pp. 1928–1938, Dec. 2019, doi: 10.1016/j.renene.2019.05.119.
40) 'DRAFT NATIONAL RENEWABLE ENERGY AND ENERGY EFFICIENCY POLICY(NREEEP)', Energy Commission Of Nigeria. Accessed: Aug. 12, 2022. [Online]. Available: https://www.energy.gov.ng/Energy_Policies_Plan/natonal_renewable_energy_and_energy_efficienc y_policy.pdf
41) A. Omojola and O. Oladeji, 'Small Hydro Power for Rural Electrification in Nigeria', *Am. J. Sci. Eng.*, vol. 1, pp. 29–34, Jan. 2012.
42) S. P. Koko, K. Kusakana, and H. J. Vermaak, 'Micro-hydrokinetic river system modelling and analysis as compared to wind system for remote rural electrification', *Electr. Power Syst. Res.*, vol. 126, pp. 38–44, Sep. 2015, doi: 10.1016/j.epsr.2015.04.018.
43) K. Kusakana, 'Techno-economic analysis of off-grid hydrokinetic-based hybrid energy systems for onshore/remote area in South Africa', *Energy*, vol. 68, pp. 947–957, Apr. 2014, doi:10.1016/j.energy.2014.01.100.
44) A. T. Brimmo, A. Sodiq, S. Sofela, and I. Kolo, 'Sustainable energy development in Nigeria: Wind, hydropower, geothermal and nuclear (Vol. 1)', *Renew. Sustain. Energy Rev.*, vol. 74, pp. 474–490, Jul. 2017, doi: 10.1016/j.rser.2016.11.162.
45) 'About NEP – Nigeria Electrification Project'. https://nep.rea.gov.ng/about-nep/ (accessed Aug. 18, 2022).
46) N. Wamukonya, 'Solar home system electrification as a viable technology option for Africa's development', *Energy Policy*, vol. 35, no. 1, pp. 6–14, Jan. 2007, doi: 10.1016/j.enpol.2005.08.019.

There is an Open Access article, distributed under the term of the Creative Commons Attribution – Non Commercial 4.0 International (CC BY-NC 4.0) (https://creativecommons.org/licenses/by-nc/4.0/), which permits remixing, adapting and building upon the work for non-commercial use, provided the original work is properly cited.