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Exploring the Sectoral Development and Sustainability Potentials of Renewable Energy Resources in Nigeria

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A B S T R A C T

Energy is a crucial natural resource that is vital for the functioning and development of every nation. Nigeria is endowed with rich energy resources; however, hydrocarbon exploration and production have constituted its foremost source of energy and revenue. Over the last five decades, the oil and gas industry activities have had negative impressions on the environment, contributing to land degradation and the destruction of biodiversity. With the advent of the climate crises and other fossil fuels induced disasters, global energy consumption trends are making massive shifts to more eco-friendly sources of energy generation. This is due to the numerous benefits of renewable energy, including sustainable environmental development, enriched multilateral green development funding, climate change protection, poverty alleviation, and healthier and safer energy production conditions. Nigeria is not left out of this improvement as there have been various efforts for substitute means of power, exploring alternative energy sources and transitioning to renewable and clean energy for sustainability. This call for change in Nigeria has further been influenced by the stunning increase in fuel price and electricity tariffs and the need to limit fossil fuel usage and cut carbon emissions. This paper seeks to explore and reexamine the exploitation of Nigeria's renewable energy, offering current realities on the potentials, developments and sustainability of the resources and sector. The paper presents technical, financial and policy barriers as some limitations to harnessing the full potential of Nigeria's renewable energy to meet energy needs for optimal industrialization and to sustain its population. It reiterates that efficient, affordable and reliable environmentally friendly energy is crucial for sustainable development. It concludes that improved environmental awareness, advanced research and development in renewable energy technologies, effective policies, and international collaborations are required for sectorial development and to appropriately tap Nigeria's abundant renewable energy resources to meet its energy demands.

Keywords: Energy Resources, Environment, Nigeria, Renewable Energy, Sustainability

1. Introduction

Nigeria is blessed with abundant renewable and non-renewable energy resources. Energy does not play a simple role in the development of any country. The role of energy is so huge that there is no sector of the economy that does not require energy to create a value-added to whatever goods it produces or services it provides. This invariably is expected to improve the standard of living and reduce the poverty of the populace (Adeyanju et al., 2020). The sustainable economic growth of countries crucially depends on the long-term availability of energy from affordable, accessible, and environmentally friendly sources (Oyedepo, 2013). Energy is vital for the growth and socio-economic development of any region in the world, and it is fundamental to fulfilling essential needs in our societies. Lighting and heating a house, keeping a hospital open and operational, running a factory, lighting a street, providing potable water, etc., require energy. Since the services mentioned earlier are the indices by which a nation's progress and development are measured, the amount of energy consumed by a country at a particular instant of time largely determines its economic and social development (Sesan, 2008). The impact of energy on achieving the entire sustainable development goals (SDGs) such as zero hunger, quality education, good health facilities, decent work and economic growth and high literacy rates, among others, cannot be undermined. Many developed and developing nations have increased their productivity by increasing energy consumption. However, most of the energy sources used to realise this economic growth are fossil fuels associated with environmental hazards that have exposed the entire world to toxic substances (Akinwale and Ogundari, 2017).

Renewable energy is derived from naturally existing resources like wind, sunlight, geothermal heat, and tides constantly replenished. Each of these renewable sources has unique properties and characteristics influencing their usage. In 2012, the global energy consumption from renewable resources accounted for about 19% of the total energy used. Electricity generation in 2015 from renewable resources is about 23.7%, with hydropower accounting for 16.6%, while wind covered 3.7% and other new renewables were 3.4% (REN21, 2016). The national energy supply in Nigeria is principally from fossil fuels and firewood. The provision of electricity is primarily supplemented by private producers or individual electricity generators powered with fossil fuel for the privileged income groups. Over 90% of businesses and companies have private generators leading to high production costs (Omokaro, 2008). The present dependence on fossil fuels (petroleum) is not enough to meet the country's energy needs. Interest in renewable energy development in Nigeria is enhanced by factors including the recent increase in oil prices, unavailability of electricity to the majority of the population, and high cost

and energy losses associated with grid extension. Hindrances to renewable energy development in Nigeria, including technical and financial barriers, need to be overcome for its maximisation to be a reality (Sambo, 2009b). Sustainability is a crucial factor influencing the long-term viability of any energy resource, hence the need to drop reliance on fossil fuels. Nigeria is yet to fully harness its renewable energy resources, despite being blessed with their abundance. Nevertheless, the Nigerian government has taken a few steps to encourage renewable and alternative energy resources in different sectors of the economy (Akorede et al., 2017).

There is a global effort to reduce greenhouse gas (GHG) emissions to save the universe from the negative consequences. This necessitates exploiting alternative sources of energy that are clean and environmentally friendly, unlike conventional fossil fuels. Access to clean energy remains a leading challenge faced in Africa, and energy is fundamental to socio-economic development and poverty eradication. This provides vital services such as clean water, sanitation and healthcare, reliable and efficient lighting, heating, cooking, mechanical power, transport and telecommunications challenges. There is a strong relationship between poverty and access to energy (Akinwale et al., 2015). In Nigeria today, most of the inhabitants ranging from 60% to 70%, do not have access to a regular supply of electricity, and more than 60% of the Nigerians are living below the poverty line (NBS, 2016). Renewable energy provides a viable alternative to electricity generation against the current predominant use of fossil fuels. The leading purpose of this paper is to review the potential and sustainability of Nigeria's renewable energy resources and the development of the renewable energy sector. It examines the current status of renewable energy resources and their potential to meet Nigeria's energy demands to foster its socio-economic growth and environmental goals.

2. The Nigerian Contemporary Energy Settings

Nigeria is blessed with non-renewable energy forms like natural gas, crude oil and coal. However, the country is also endowed with renewable energy resources like wind, solar, biomass and hydro. One of Nigeria's primary energy considerations is electricity; however, the country has a low electricity uptake and is among the countries with the lowest consumption per capita in Africa, despite being the most populous country on the continent (Akinwale and Ogundari, 2017). The electricity sector in Nigeria primarily runs on gas and hydroelectricity. The Nigerian grid's estimated total installed generation capacity is 8,900 Megawatts (MW), out of which large hydro and thermal power plants accounted for 22% and 78%, respectively. There are three large hydro and seven thermal generating power stations in Nigeria (NBS, 2012). However, gas supply and distribution are not always reliable, and the functioning of dams is affected by erosion and other weather challenges (Dike and Gininwa, 2018). Fuelwood (50.45%) dominates the energy consumption mix in Nigeria, followed by petroleum products (41.28%) and hydroelectricity (8%). Coal, geothermal, nuclear, tidal, wind and solar energy are currently not part of Nigeria's energy mix (Vincent-Akpu, 2012). The energy utilisation pattern in Nigeria can be grouped into the household, industry, commercial, transport and agricultural sectors. Annually, the country consumes over 50 million metric tonnes of fuelwood used by over 60% of people living in rural areas and 80% of its population (Ibidapo-Obe and Ajibola, 2011). Table 1 below shows details of Nigeria's energy resource reserves.

Table 1 - Estimate of Nigeria's energy resource reserves.

Energy Source	***Reserves***
Oil	36.5 billion *barrels*
Natural Gas	187.44 trillion *scf*
Bitumen & Tar Sands	30 billion *barrels* of oil equivalent
Coal & Lignite	Over 4 billion *tonnes*
Nuclear	Not readily available
Large Hydropower	11,250 *MW*
Small Hydropower	3,500 *MW*
Fuelwood	13,071,464 *Hectares*
Animal waste	61 million *tonnes/yr*
Crop Residual	83 million *tonnes/yr*
Solar Radiation	3.5-7.0 *Kwh/m2-day*
Wind	2-4 *m/s* at 10m height

(**Source:** CBN Annual Report, 2007)

Table 1 shows a crude oil reserve of 36.22 billion barrels and 187 trillion Standard Cubic Foot (scf) natural gas. However, virtually nothing has been tapped from the 2.374 billion tonnes of coal and lignite. Nigeria's reserve is estimated at 11,250 MW and 3,500 MW for large and small hydropower. In addition, Nigeria has a reserve of 11 million hectares of forest and woodland and 72 million hectares of agricultural land wasteland. Daily, Nigeria produces around 227,500 tonnes of fresh animal wastes, which, if optimally used, is equivalent to 6.8 million m^3 of daily biogas production (Oyedepo, 2012).

Nigeria ranks among the less developed countries in the world as the electricity consumption per capita is approximately 142 kWh as of the year 2013, which is below that of Ghana (382 kWh) and Angola (227 kWh) in Sub-Saharan Africa, as shown in Figure 1, despite her potentials in the energy sector. Although most Nigerians live in rural areas out of reach of the national grid connection, those connected to the grid live below the poverty line and thus cannot afford to self-generate power for their houses (Akinwale and Ogundari, 2017). Despite the recent reform of the Nigerian electricity market, the gap between the electricity demand and supply continues to get broader yearly as industrialisation and the population increase. Less than 40% of Nigerians

have access to electricity (International Energy Agency, 2016), with only about 30% of their demands being met. Virtually all the members of the manufacturers association of Nigeria and many households depend mainly on self-generating diesel plants, which harm the environment.

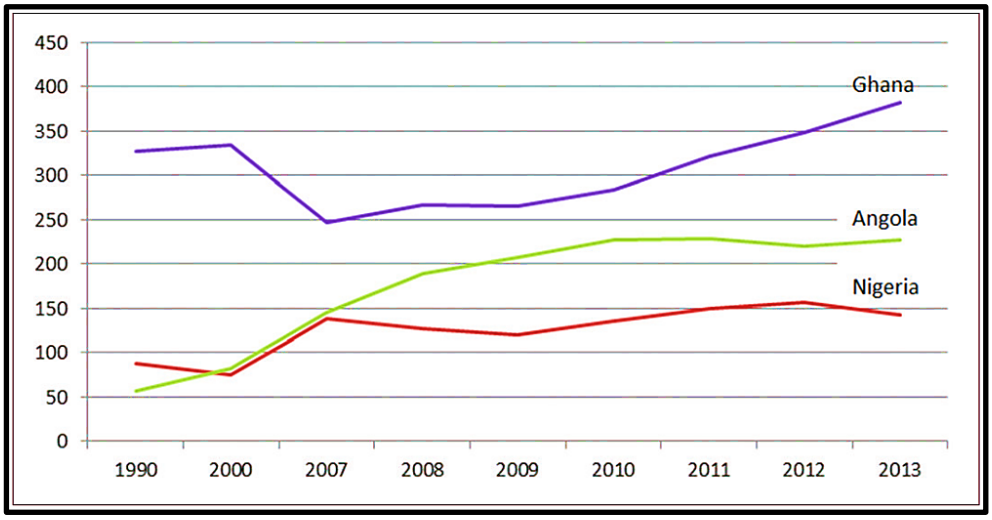

Fig. 1 - Electricity consumption (in kWh) per capita in selected Sub-Sahara African countries (**Source:** World Bank Development Indicators, 2017)

Despite Nigeria's abundant energy resources, the country faces an energy crisis from inadequate energy supply that is unable to meet growing demands. 91% of household energy consumption goes to cooking; lighting takes 6%, with 3% spent on essential electrical home appliances. To date, fossil fuels dominate the national energy supply in Nigeria. Renewable energy resources are grossly underutilised despite their availability in reasonable quantities (Oyedepo, 2012). Table 2 presents Nigeria's primary energy consumption by type (CBN Annual Report, 2007), and it is evident that while coal has been neglected for a long time, petroleum covers over 80% of the primary commercial energy consumed in the country. However, despite Nigeria's robust oil and gas sector, 58% of the population lacks access to electricity fueled by petroleum, which is abundant in the country (Akorede et al., 2017).

Table 2 - Primary energy consumption by type.

Types	**Percentage of Total**						
	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**Average**
Coal	0.03	0.03	0.03	0.03	0.05	0.05	0.04
Hydropower	11.93	14.20	17.39	12.04	17.03	23.90	16.08
Natural Gas	2.84	1.90	4.54	5.50	7.52	8.73	5.17
Petroleum Products	85.20	83.87	78.04	82.45	75.44	67.32	78.71

(**Source:** CBN Annual Report, 2007)

Currently, the Nigerian energy mix is 90% from fossil fuel, against the initial 50% from hydropower. The demand for energy in Nigeria by far outstrips supply leaving over 60% of the population without a reliable power supply (Dike and Gininwa, 2018). The massive reliance on conventional energy sources has done considerable damage to the environment and economy. The majority of our oil reserves and production at the current rate could not guarantee sustainable development in Nigeria (Nnaji et al., 2010). Consequent to the failure of fossil fuels to meet the current energy needs of Nigeria, there have been efforts to develop Nigeria's renewable energy sector. For Nigeria to meet its energy needs, it must look for alternative energy sources, especially for the rural populace, as renewable energy technology still has a significant unexploited potential to enable the country to meet its growing energy requirements. Unimpeded access to electricity is vital in meeting Nigeria's energy and other economic needs, while low access would promote energy poverty, engender poor economic growth and slow, sustainable development (Emodi and Ebele, 2016). It is evident that the electricity demand far outstrips its supply. Thus, exploiting alternative and cleaner options, such as renewable energy, to supplement the current electricity generation in Nigeria to meet the teeming population's demand becomes very important. If renewable energy is adequately harnessed and appropriately maximised, it could meet significant energy demand with less deteriorating environmental effects.

3. Methodology

This study employed a multiple approach system that purely involved the review of existing studies from both online and offline databases on energy resources and renewable energy. The data used for this article were systematically reviewed and obtained from the existing academic and industrial based literature to deliver a clear overview of current published research about the Nigerian renewable energy situation. For its core outcomes, discussions, statistics display and knowledge communications, this article explicitly adopts the most recent publications from globally acknowledged organisations and corporations. It principally dwelt on the collaborative data sources from the latest Nigeria Energy Profile updates of the International Renewable

Energy Agency (IRENA 2021) Statistics; United Nations Sustainable Development Goal (UN SDG) Database; United Nations Sustainable Development (UNSD) Energy Balances; United Nations Development Programme (UNDP); International Energy Agency (IEA 2016); World Bank Development Indicators (WBDI 2017); REN21 Renewables Global Status Report (2016); Energy Commission of Nigeria (ECN); Central Bank of Nigeria (CBN) Annual Report; Nigerian Energy Support Programme (NESP) and the Federal Republic of Nigeria - National Bureau of Statistics (NBS 2016).

4. Position of Nigeria's Renewable Energy Sector

Renewable energy sources are abundant in Nigeria and have for long been a part of the country's energy mix, though in a fundamentally essential way. The most adopted primary energy source for rural dwellers in Nigeria is fuelwood. More recently, large hydropower has been added as a renewable energy source, contributing around 32% to Nigeria's national electric grid supply (Akorede et al., 2017). However, the country's adoption of modern renewable energy sources like solar photovoltaics, small hydropower, wind, and competent biomass is relatively recent. This section of the article looks into the status of renewable energy resources and the development of the renewable energy sector in the country.

4.1 Structure

Hydroelectric power (HEP) has been one of the renewable energy sources of great significance since the beginning of the twentieth century. It produced about one-fourth of the world's electricity and supplied power to more than one billion people. HEP plants are unceasingly gaining importance as a renewable and non-polluting source of electricity generation (Olukanni and Salami, 2012). Hydropower emerges from converting the potential energy of water into electricity by water turbines and electric generator systems (Aliyu et al., 2018). The potential of hydropower depends on the amount of available water and suitable terrain. Nigeria is equitably gifted with large rivers and some natural falls. Small rivers and streams in Nigeria are split into 11 River Basin Authorities, some of which retain minimum discharges all year round (Riti and Shu, 2016). The country has three primary hydropower plants at Kainji, Shiroro, Jebba power stations (760 MW, 600 MW and 560 MW, respectively) totalling 1,900 MW (Olukanni and Salami, 2012). The fourth hydropower station is owned by a private utility service company, the Nigerian Electricity Supply Corporation (NESCO) Limited and is located at six different sites in Plateau State with a total potential of just 21 MW (Mohammed, 2013).

Nigeria has an estimated total technically exploitable large-scale hydropower (LHP) potential of over 12,000 MW, which is capable of producing 36,000 GWh of electricity annually. However, its small-scale hydropower (SHP) has an estimated yearly potential of 3,500 MW. The country's current hydropower generation accounts for around 14% of its hydropower potential and represents about 30% of the total installed grid-connected electricity generation capacity (REN21, 2016). Hydropower is currently the country's largest renewable energy source. Much hydro potential is yet to be harnessed with more growth and development for the renewable energy sector through this medium. Due to its abundance and generally available recognised technology, hydro-energy has the most potential for development in rural areas of Nigeria. Small-scale hydro is mainly a run of river, thereby requiring no construction of large dams and reservoirs (Ohunakin, 2011). This is a convenient substitute for fossil fuels since it can provide on-demand electricity without storage or backup systems. It is also, in many cases, cost-competitive with fossil-fuel power stations and diesel-generated power. Rivers are spread across Nigeria, with the potential hydropower installations that can serve the urban, rural and isolated communities. A large amount of the untapped hydropower potential (12,190 MW) has been identified around the country (Table 3). However, most of the small hydropower (SHP) potential has not even been exploited (Akorede et al., 2017).

Table 3 - Nigeria's hydropower potentially identified locations and their capacities.

Location	River	State	Potential Capacity (MW)
Mambilla	Danga	Taraba	3,960
Lokoja	Niger	Kogi	1,950
Makurdi	Benue	Benue	1,060
Onitsha	Niger	Anambra	1,050
Ikom	Cross	Cross River	730
Zungeru I	Kaduna	Niger	500
Zungeru I	Kaduna	Niger	450
Yola	Benue	Adamawa	360
Gurara	Gurara	Niger	300
Katsina-Ala	Katsina-Ala	Benue	260
Beli S.E.	Taraba	Kano	240
Donka	Niger	Adamawa	225
Afikpo	Cross	Ebonyi	180
Afikpo	Cross	Ebonyi	180
Garin Dali	Taraba	Taraba	135
Gembu	Dongo	Taraba	130
Karamti	Kam	Taraba	115
Sarkin-Danko	Suntai	Taraba	45

Kiri	Gongola	Adamawa	40
Oudi	Mada	Benue	40
Richa I	Mosari	Nassarawa	35
Gwaram	Jama'are	Adamawa	30
Ifon	Osse	Ondo	30
Kashimbila	Katsina-Ala	Benue	30
Korubo	Gongola	Adama/Taraba	25
Kura II	Sanga	Kano	25
Richa II	Dafo	Kano	25
Mistakuku	Kurra	Plateau	20
Kura I	Sanga	Kano	15
Kafanchan	Kongum	Kaduna	5
Total			**12,190**

(**Source:** Akorede et al., 2017)

The existing SHP installed capacity in Nigeria is 39.0 MW; however, Nigeria's small and large hydropower potential stands at 3,500 MW and 11,235 MW, respectively (Oseni, 2012). The Federal Government provided a documented guide to exploring small hydropower, thereby indicating the need for collaborative multi-sectoral efforts. However, participation has increased more in fossil-based sources than hydropower and other renewable sources for private sector involvement (Akorede et al., 2017).

Table 4 - Existing small hydropower (SHP) schemes in Nigeria.

River	State	Installed Capacity (MW)
Bagel I	Plateau	1.0
Bagel II	Plateau	2.0
Ouree	Plateau	2.0
Kurra	Plateau	8.0
Lerre I	Plateau	4.0
Lere II	Plateau	4.0
Bakalori	Sokoto	3.0
Tiga	Kano	6.0
Oyan	Ogun	9.0
Total		**39.0**

(**Source:** Akorede et al., 2017)

Hydropower projects in many countries had brought socio-economic development such as flood control, irrigation, tourism, local employment and skills development, rural electrification and the expansion of physical and social infrastructure such as roads and schools; holistically, these projects have opened up the interior areas of the country to economic development. (Akinwale and Ogundari, 2017). Moreover, aquatic resources like rivers, waterfalls, and streams with high potentials for hydropower, if properly harnessed, will provide the most affordable and accessible option to off-grid electricity services, especially to the rural communities.

4.2 Solar Power

Nigeria lies within a high sunshine zone, thereby enjoying abundant sunshine and enormous solar energy potential. The country is enriched with solar energy and has a 6.5 hours annual average daily sunshine, extending from 4 hours in the coastal areas to 9 hours at the northern extremes. Nigeria's estimated average daily solar insolation varies between 4.0 kWh/m^2 at the coastal latitude and 7 kWh/m^2 at the far North (REN21, 2016). Adopting the appropriate technology, solar radiation is viable for electricity generation in vast parts (Shaaban and Petinrin, 2014). Solar power involves technologies of generating electricity from the energy of the sun. Solar systems provide electricity for rural dwellers, homes, hospitals, schools, and businesses. Globally, solar energy is abundant and has a vast potential for a cleaner climate environment. Nigeria sits in the tropics, with its landmass stretching between latitudes 5° South and 15° North of the equator. The country has yearly sunlight of almost 290 days, estimated at 5.5 kWh/m^2/day, which shows abundant sunshine availability and is a positive indicator that Nigeria is viable for investment in solar energy resource development (Akinwale and Ogundari, 2017). Table 5 represents the estimated solar energy possible in different cities across Nigeria for both horizontal and optimal inclined solar P.V. modules. The yearly sum of estimated electricity achievable from 1 kWp P.V. module at horizontal solar irradiance ranges from 1,703 kWh (far North) to 1,166 kWh (far South). Northern Nigeria exhibits the most substantial potential for solar electricity, with Maiduguri having the highest yearly average daily global irradiance. Meanwhile, there is a reduction of solar radiation towards the country's central parts.

Table 5 - Estimated electricity generation from 1kWp P.V. module in selected Nigerian cities.

City	Latitude (North)	Longitude (East)	Optimal Inclination Angle (º)	Yearly Averaged daily radiation kWh/m^2/day)	Annual Electricity Generation (kWh)
Sokoto	13°3'25"	13°3'25"	0	5.21	1,426
			15	5.34	1,462
Maiduguri	11°49'59"	13°9'0"	0	6.22	1,703
			16	6.4	1,752
Abuja	9°4'0"	7°28'59"	0	5.26	1,440
			15	5.39	1,476
Ilorin	8°29'29"	4°32'40"	0	5.13	1,404
			14	5.23	1,432
Ibadan	7°23'47"	3°55'0"	0	4.61	1,262
			14	4.71	1,289
Enugu	6°27'9"	7°30'37"	0	4.75	1,300
			12	4.82	1,319
Port-Harcourt	4°47'5"	7°0'19"	0	4.26	1,166
			11	4.31	1,180
Total				**71.64**	**19,611**

(**Source:** Akorede et al., 2017)

The lowest recorded solar irradiance is at the far South in Port Harcourt. At minimum solar P.V. modules with 10% conversion efficiency covering a 1 hectare (10,000 m^2) surface area will generate total annual energy of 1.166 GWh. If solar collectors or modules cover 1% of Nigeria's landmass, there is a possibility of generating 1850 × 103 GWh yearly of solar electricity, which is over 100 times the country's current grid electricity consumption level. The Energy Commission of Nigeria (ECN) has supervised several pilot projects and studies carried out by the National Center for Energy Research & Development (NCERD) and the Sokoto Energy Research Center (SERC), thereby having several PV-water pumping, solar-thermal and electrification systems installed. These systems support solar crop drying, solar cooking, solar chick brooding and solar incubators. In other cases, they are helpful in areas including water pumping, power supply for schools, village electrification, rural clinics and traffic lighting (Nigerian Energy Support Programme, 2015). The Nigerian government also started operation "Light up Rural Nigeria" to provide constant electricity supply to the rural areas through an off-grid system. The first phase extends the solar-powered initiative to remote parts of the country not connected with the national grid (Akinwale and Ogundari, 2017). As a result, more people, especially the rural dwellers that do not have access to electricity, are expected to benefit from this, thereby enhancing the development of the renewable energy sector through solar power and contributing to sustainable development and environmental goals.

4.3 Biomass

Biomass is any material that once was living and can be utilised for energy production (Ahmad and Tahar, 2014). It is usually plant-derived organic matter and animal wastes available for energy generation. Nigeria's biomass resources are forage grasses, crops and shrubs, animal wastes, and wastes arising from forestry, agriculture, municipal, industrial activities, and aquatic biomass. Sweet sorghum, sugarcane and maise constituted the most promising feedstocks for biofuel production (Nnaji et al., 2012). Other feedstock substrates suitable for an economically feasible biogas production include water lettuce, water hyacinth, dung, cassava leaves, processing waste, urban refuse, solid waste, agricultural residues, and sewage. It can be used as solid fuel and converted to liquid or gaseous forms for electric power generation, heat or fuel using different technologies (Rahman et al., 2011). A measure of Nigeria's biomass potential is the total land under vegetation available for agriculture. The biomass energy resources of Nigeria is estimated to be 144 million tonnes/year, with an established production of around 227,500 tons daily of fresh animal waste. Since around 0.03 m^3 biogas is generated from 1 kg of fresh animal waste produced, 6.8 million m^3 of biogas can be potentially produced every day from only animal waste in Nigeria (National Bureau of Statistics, 2016).

Plant biomass can be utilised as a fuel for small-scale industries. Anaerobic bacteria could also ferment to produce a cheap fuel gas (biogas). Biogas production from agricultural residues municipal and industrial waste does not compete for land, water, and fertiliser with food crops, as with bioethanol and biodiesel production. It will thus reduce the menaces posed by these wastes (Riti and Shu, 2016). Also, with increasing urbanisation and industrialisation, the annual generated municipal solid waste (MSW) will remain on the rise. Thus, biogas production from these wastes constitutes a viable means of reducing the nuisance of urban wastes in many cities. Figure 2 illustrates the monthly amount of MSW generated in a few major cities in Nigeria (Ogwueleka, 2009). It shows that an annual potential of 10.98 million metric tonnes of MSW can be generated from these nine cities.

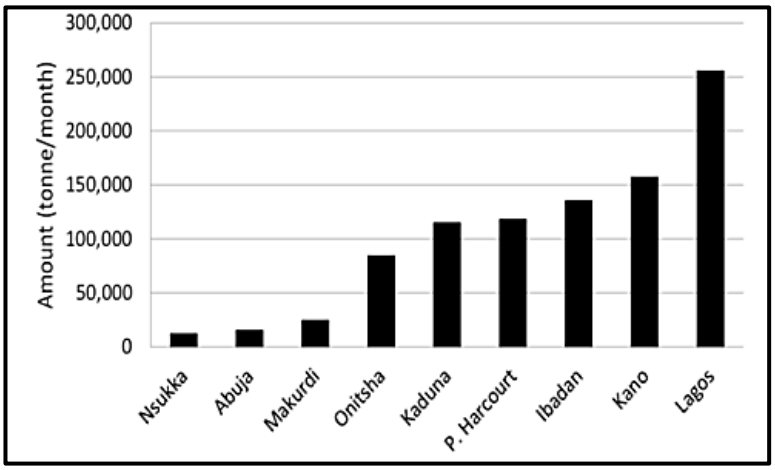

Fig. 2 - Monthly MSW generated in nine major cities in Nigeria (**Source:** Ogwueleka, 2009)

It is estimated that Nigeria consumes about 43.4×10^9 kg of fuelwood annually. Over 60% of Nigeria's population depends on fuelwood for cooking and other domestic uses. Fuelwood consumption is worsened by the widespread use of inefficient cooking methods, which is still open fire. This traditional method is not sustainable as the fuelwood consumption rate far exceeds the replenishing rate, thus resulting in desert encroachment, soil erosion and loss of soil fertility. The rural dwellers should be enlightened to use improved wood-burning stoves to reduce fuelwood consumption by 50%. Also, the government should work towards providing modern high-efficiency bioenergy, which involves utilising more convenient solids, liquids and gases as secondary energy carriers to generate heat, electricity, combined heat and power, and transport fuels for various sectors (Ogwueleka, 2009). Some significant research has been done on a reactor design that would lead to process optimisation in developing anaerobic digesters. Sawdust and wood wastes are other significant resources for energy generation from biomass (Nnaji, 2012). Biomass utilisation as an energy resource is currently limited to the thermal application as fuel for cooking and crop drying. The Nigerian government should ensure that power generation through biomass does not affect food production as land usage and crops become competitive between food and energy production.

4.4 Wind

The wind is an effect of heating the earth's surface by the sun. Significant exploration of wind energy has not been made in Nigeria as the major wind energy systems in existence are abandoned due to inappropriate potential evaluation, operations and management (Oyedepo, 2012). Wind energy generation potential depends on wind availability, and understanding the site-specific nature of wind is crucial in planning wind energy projects (Sambo, 2008). The wind speed average is about 2.0 m/s annually (coastal region) and 4.0-5.12 m/s at 10 m height (extreme North) for Nigeria. Currently, wind energy contribution to nationwide consumption of energy has stayed at minimal, having no commercial plants connected to the national grid from wind power (Riti and Shu, 2016). Wind energy technologies convert the energy from wind for practical purposes such as pumping water, grinding grain, charging batteries and generating electricity, among others. The primary technical parameter that determines the economic success of a wind turbine system is its annual energy output. However, the most essential and sensitive parameter is the wind speed which increases with height above the ground (Sambo, 2008). There is a high potential for wind energy in Nigeria, especially in the North. However, only a few shreds of evidence of small wind power plants for water pumping and village electrification exist in Northern Nigeria. There are constraints such as the site's location, public resistance, technological incapability of the local people, acoustic noise emission and bird's life. Therefore, it is important to conduct a comprehensive environmental impact analysis before setting up the wind turbine to avoid these problems (Akinwale and Ogundari, 2017).

Table 6 - Nigeria's renewable energy resources reserves.

Resource	**Reserves**
Large Hydropower	10000MW
Small Hydropower	734MW
Fuelwood	13071464 has (forest land 1981)
Animal waste	61million tonnes/yr
Crop Residue	83million tonnes/yr
Solar Radiation	3.5-7.0kWh/m2-day
Wind	2-4m/s (annual average)

(**Source:** Energy Commission of Nigeria, ECN and United Nations Development Programme UNDP, 2005)

Nigeria is bestowed with abundant renewable energy resources such as solar, wind, biomass and large and small hydropower potentials (Table 6). However, the penetration level of renewable energies is still deficient in Nigeria. Although the initial investment cost of some of these renewable energy sources may be high, the maintenance costs of most of them are relatively low.

5. Obstacles of Nigeria's Renewable Energy Sector

The renewable energy sector faces many challenges in Nigeria, and these constraints have occasioned a lack of commercialization of the sector. Below are some of the barriers and challenges.

5.1 Reliance on Fossil Fuel

Nigeria's economy depends largely on the oil and gas industry. Hence, oil and gas remain the backbone of its power sector. Besides the Middle East countries, Nigeria is recognized as one of the leading oil and gas exporting nations due to its relative abundance in oil and gas products (Onoh and Ndu-Okereke, 2018). However, the current relatively low cost of petroleum fuels remains a significant barrier to deploying alternative energy sources, and consequently, it remains a threat to renewable sources of electricity generation. The availability of local subsidies in petroleum fuels poses a barrier to electricity generation from renewable resources, suggesting that renewable energy sources of electricity will remain expensive and unaffordable if fossil fuel power generation subsidies persist (Aliyu et al., 2018).

5.2 Inability of Consumers to Pay for Electricity

The inability of consumers to pay for electricity provided by investors is a primary concern in Nigeria. Most consumers cannot afford the price of electricity at a competitive rate. This situation is further aggravated by Nigeria's culture in that public goods are not meant to be paid for by the citizens (Amadi, 2014). The poverty rate in Nigeria has contributed to this as most citizens would prefer to be under blackouts than starve for their meals. Consequently, many consumers cannot afford payments for renewable energy, enabling cost recovery and return on investment. This situation distinguishes Nigeria from developed economies where consumers can afford the cost of electricity (Huhta et al., 2014). The main design issue in the support for renewable energy is who pays the incremental cost. In developed economies, the cost of funding investment in renewable energy is socialized by passing it to the consumers through electricity consumer bills. Therefore, bearing the cost of the decarbonization of the energy sector is ultimately passed to the consumers in developed economies (Banet, 2012). The price of electricity is a determinant factor in attracting investors. If the price of electricity is such that consumers cannot afford it, the demand will fall. This makes pricing the most sensitive aspect of the power sector reform (Adaralegbe, 2009). It could be argued that cost-reflective pricing impacts the poor and may raise political challenges in developing countries such as Nigeria. Therefore, the major challenge is how the government will strike a balance in meeting the investors' costs and that of the consumers (Dike and Gininwa, 2018).

5.3 Insecurity and Vandalism

Frequent acts of vandalism and insecurity represent a deterrent to successful business operations and management in Nigeria (Ohunakin et al., 2014). For example, operations of Boko Haram and militants have been active in the Northern and Southern regions of Nigeria, respectively, with notable infrastructural damage. This greatly affects investments potentials in such areas from local and foreign companies in renewable energy technology or installations that can be easily vandalized or destroyed (Ogunmodimu and Okoroigwu, 2019). Also, the fear of people falling out of business by accepting renewable energy sources constitutes a social barrier (Akuru et al., 2017). This makes it impossible or limits people's thinking in accepting the change.

5.4 Grid Access and Connection Issues

The entry of renewable energy into the Nigerian market is very challenging in that access to the network, and the grid operates on the principle of non-discrimination. Renewable energy generation should be given priority to feed the grid (Irukera and Isiekwena, 2009). Electricity cost from renewable energy sources is lower than that of fossil fuel will be determined by factors such as the support mechanism provided, the grid connection procedure and the price of transmission (Bellantuono, 2010). The absence of provision for priority connection of renewable energy to the grid remains a significant barrier in Nigeria. It is suggested that renewable energy be prioritized due to its environmentally cleaner nature than fossil fuels. Further, most investors will want to guarantee that the renewable energy they generate will be connected to the grid. Renewable energy generators will be discouraged if, having the necessary support, they cannot reap the benefits of the electricity generated connected to the grid (Dike and Gininwa, 2018).

5.5 Inadequate Legal Framework for Funding

A significant obstacle to developing renewable energy projects in Nigeria is the absence of a comprehensive framework for financing. In a capital-constrained economy such as Nigeria, where there is high competition for scarce capital, renewable funding projects is challenging (Dike and Gininwa, 2018). Investment in renewable energy is faced with challenges in the Nigerian business environment, which is characterized by low credit ratings and low availability of capital for investment. New renewable energy projects could be financed by loans with high-interest rates, strict covenants, and other securities. In Nigeria, the situation has been complicated by local financing in the financial services sector, which is still evolving. A legal framework providing investment funding to investors as a palliative subsidy for indigent consumers would make the difference (Dike and Gininwa, 2018).

5.6 Infrastructure and High Investment Cost of Renewable Energy Projects

Although renewable energy sources are now globally more affordable in developed countries, the initial investment required for renewable energy installation in developing countries remains a significant barrier to its development (Sen and Ganguly, 2017). The high initial cost of installing renewable energy technology remains a primary barrier in Nigeria. Also, infrastructure constraints, which cut across the sector value chain, i.e. generation, distribution and transmission, remains a significant challenge (Ogunmodimu and Okoroigwu, 2019). Furthermore, renewable energy technology requires huge start-up capital compared to other conventional energy alternatives. However, it is the most cost-effective in terms of operational and maintenance costs. Nevertheless, renewable energy technology businesses face the problem of restricted access to capital in the absence of specialized funds for renewable energy investment (Efurumibe, 2013).

5.7 Political Barrier

Currently, the Nigerian government lacks the political will to develop a regulatory framework, standards and provision of incentives to enable it to make a significant change or advancement in the nation's energy usage from conventional to renewable energy sources (Abdullahi et al., 2017). This implies that the Nigerian government is not doing enough to transition to renewable energy; therefore, embracing energy from 100% renewable sources are highly hindered by political will (Akuru et al., 2017). Political obstacles constitute a significant roadblock to implementing successful renewable energy policies in Nigeria (Elum and Momodu, 2017).

5.8 Lack of Adequate Renewable Energy Data

Adequate information is a key to sustainable energy development. Poor access to adequate data or information on renewable energy has been a significant barrier to effective policy and decision making in Nigeria (Akuru et al., 2017). For example, ascertaining the total number (wattage) of solar P.V. installations operational across the country is very difficult. In Nigeria, the absence of data recording stations constitutes an impediment to renewable energy development. Feasibly, inaccurate statistics and a lack of access to relevant data constitute a significant barrier to the development of renewable energy in Nigeria (Sen and Ganguly, 2017).

5.9 Policy Barrier

In Nigeria, policy issues constitute barriers to renewable energy; although multilateral initiatives involving Power Africa, the World Bank, the Nigerian government and the private sector are set to address challenges of relevance within the energy sector, the efforts made are insufficient and slow-paced (Emodi and Ebele 2016). The government has introduced several projects to expand hydro and thermal sources, but their investments are low compared to existing targets and deficits. A significant barrier affecting renewable energy development is the lack of appropriate and inconsistent policy implementations (Amigun et al., 2008). Increased responsiveness and policy effectiveness are required to foster renewable energy technologies (RETs) in Nigeria (Oyedepo et al., 2018). To achieve different renewable energy development initiatives, the objectives of the Nigerian energy policies, such as mobilising private resources at the community levels, must materialise (Elum and Momodu, 2017). Besides the stated barriers to renewable energy development in Nigeria, the power sector was solely managed and controlled by the government until 2013 without the private sector participation. Although the sector is now privatised, it is operated more like a monopoly venture than most countries in developed countries, where the participation of private investors is encouraged through the provision of attractive feed-in-tariff programmes (Kost et al., 2013). In Nigeria, potential private investors are often confronted with non-attractive feed-in-tariff and energy policies (Ohunakin et al., 2014). Promotion and continuous advancement of active private participation in the entire power process from generation to the distribution of renewable energy in Nigeria will promote improvements in the development of the renewable energy sector and provide a solution to the country's electricity supply challenge.

6. Sustainability Potentials of Nigeria’s Renewable Energy Resources

For an energy source to be renewed, its harvesting, conversion and use would occur sustainably and avoid negative impacts on the people and natural environment. However, the renewable energy reality in Nigeria will be dependent on adequate government policies, financial and technical capability and public acceptance for their installation. Renewable energy resources abound in Nigeria but have not been fully exploited (Akinwale and Ogundari, 2017). The scenario-based model of the International Atomic Energy Agency (IAEA) was employed to design the demand structure of the Nigerian energy sector in four scenarios. This was carried out in a bid to aggressively address the lingering energy crisis faced in the country and was named Model for Analysis of Energy Demand (MAED). It evaluates future energy demands based on medium to long term socio-economic, technological, and demographic development scenarios. These combinations give an overall picture of future energy demand growth. Similarly, another model called MESSAGE, i.e. the Model for Energy Supply Strategy Alternative and General Environmental impacts, also developed by IAEA, was used to estimate the supply strategy for meeting the energy demand in Nigeria. MESSAGE combines technologies and fuels to map energy flows from supply to demand. The four scenarios used were reference growth, high growth, optimistic I and optimistic II with average G.D.P. growth of 7%, 10%, 11.5% and 13% per annum, respectively (Sambo, 2009b).

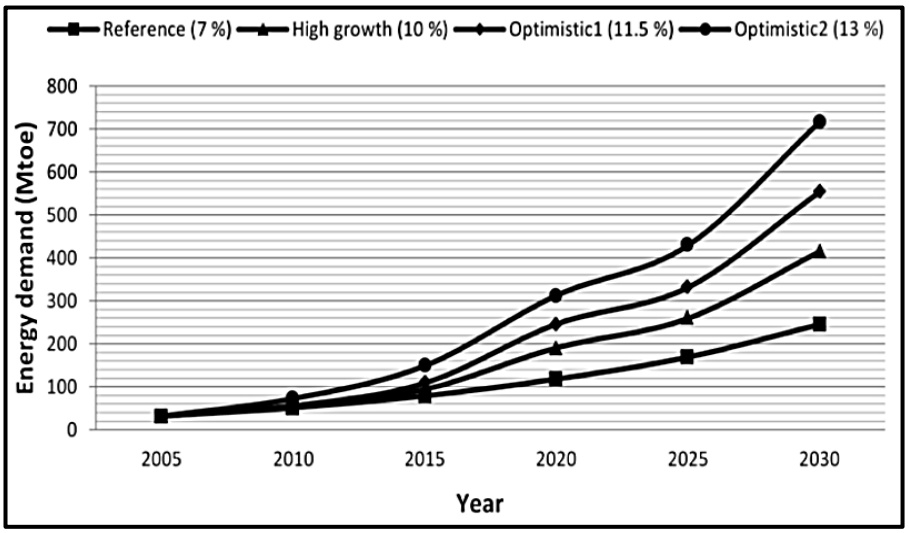

Fig. 3 - The energy demand projections for the four economic growth scenarios. (**Source:** Energy Commission of Nigeria, 2008)

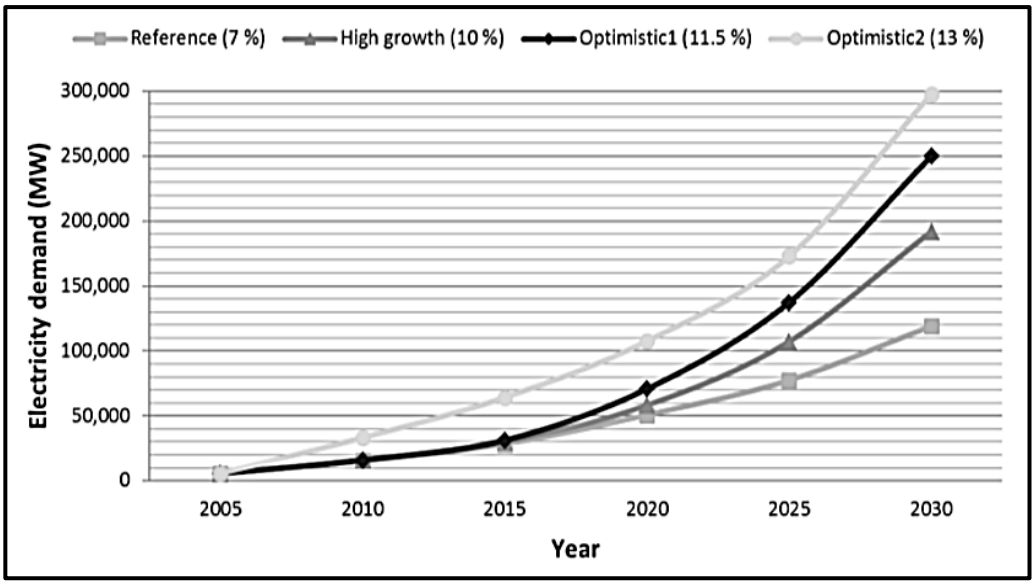

Fig. 4 - The Electricity demand projections for the four economic growth scenarios. (**Source:** Energy Commission of Nigeria, 2008)

The projected energy demand and corresponding electricity demand for the country from 2005 through 2030, using the previously mentioned MAED model, are depicted in Figures 3 and 4, respectively. Similarly, Table 7 presents the projected electricity supply by fuel mix for Nigeria for the reference growth scenario.

Table 7 - Projected electricity supply by fuel mix for 7% growth.

Scenario	**2010 (MW)**	**2015 (MW)**	**2020 (MW)**	**2025 (MW)**	**2030 (MW)**
Coal	0	2,393	6,515	9,305	15,815
Gas	13,555	23,617	37,733	56,086	85,585
Large Hydro	3,702	4,962	6,479	9,479	11,479
Small hydro	40	90	140	227	701
Nuclear	0	0	3,530	7,005	11,872
Solar	5	10	34	75	302
Wind	0	126	1,471	3,019	5,369
Total Supply	**17,303**	**31,197**	**55,903**	**85,196**	**131,122**

(**Source:** Energy Commission of Nigeria, 2008)

From Table 7, a total of 55,903 MW was targeted for the year 2020. It is, however, unfortunate that Nigeria's combined electricity capacity and generation for both non-renewable and renewable energy for the year 2020 was 13154 MW (International Renewable Energy Agency, 2021). This value is

approximately equal to 24% of the target. Judging by this development, it would be tough to achieve the country's electricity supply projected for 2030 (131,122 MW). The contribution of renewable energy resources for the targeted electricity generation is shown in Table 8. The primary renewable energy resources expected in the reference growth scenario are large and small hydropower, solar and wind energy.

Table 8 - Target for renewable energy contribution to electricity generation in Nigeria.

Resource	**2010 (MW)**	**2015 (MW)**	**2030 (MW)**
Large Hydro	1,930	5,930	48,000
Small Hydro	100	734	19,000
Solar P.V.	5	120	500
Solar Thermal	0	1	5
Biomass	0	100	800
Wind	1	20	40
Total RE	2,036	6,905	68,345
Total Energy Resources (RE)	16,000	30,000	192,000
Percentage of RE (%)	**13**	**23**	**36**

(**Source:** Renewable Energy Master Plan for Nigeria, ECN, 2005)

The sustainability of energy resources is hugely dependent on the availability of such resources and how efficient it is or would be. Important factors for consideration include how affordable *it is* for the population, the reliability of the resources and whether their exploitation has no negative or a highly minimal harmful effect on the environment. Despite the current energy situation in the country, Nigeria's renewable energy resources, if maximally and appropriately exploited, could significantly fix the current energy issues. According to the latest International Renewable Energy Agency (2021) statistics, the Nigeria renewable energy sector has enormous potential to sustain its citizens, especially for household usage.

Table 9 - Nigeria's total primary energy supply (TPES) in 2018.

TPES	**2018**
Non-renewable (T.J.)	1 637 987
Renewable (T.J.)	4 954 442
Total (T.J.)	6 592 429
Renewable share (%)	**75**

(**Source:** International Renewable Energy Agency, IRENA, 2021)

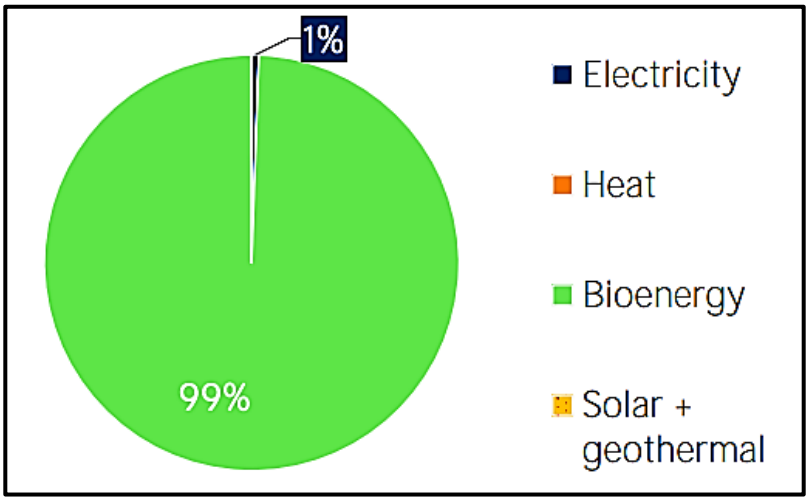

Figure 6 - Percentage of renewable energy consumption by source in 2018. (**Source:** International Renewable Energy Agency, IRENA, 2021)

Table 9 and Figure 6 show the renewable energy consumption by source in 2018 according to the latest Nigeria Energy Profile as of 29th September 2021, documented by the International Renewable Energy Agency (IRENA). Bioenergy, largely woodfuel, accounts for the highest renewable energy consumption at 4,526,138 Terajoules (T.J.), while electricity share is 25,214 TJ at only 1% against 99% bioenergy. These statistics reveal that Nigeria's renewable energy is yet to be adequately harnessed for electrical consumption, and the country is principally dependent on fossil fuels for electricity.

Table 10 - Renewable energy consumption by sector in 2018.

Consumption by Sector	**2018**
Industry (T.J.)	179,813
Transport (T.J.)	0
Households (T.J.)	248,356
Other (T.J.)	123,184
The renewable share of TFEC **Total Final Energy Consumption (TFEC %)**	**79.7**

(**Source:** International Renewable Energy Agency, IRENA, 2021)

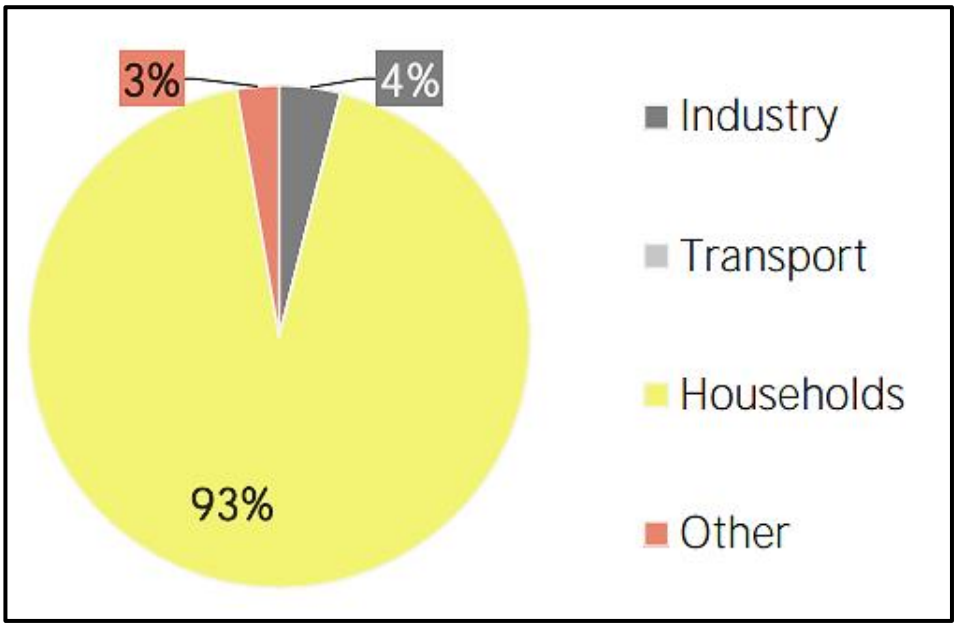

Figure 7 - Percentage of renewable energy consumption by sector in 2018. (**Source:** International Renewable Energy Agency, IRENA, 2021)

Table 10 and Figure 7 show the renewable energy consumption by sector in 2018 according to the latest Nigeria Energy Profile by International Renewable Energy Agency (2021). Household usage consumes the most renewable energy, accounting for 248,356 TJ, followed by industrial consumptions at 179,813 TJ (4%) and others taking 123,184 TJ (3%). These statistics reveal that 93% of Nigeria's renewable energy goes to households, and household activities and usage primarily consume renewable energy resources. However, Nigeria has yet to incorporate renewable energy into its transportation systems.

Table 11 - Electricity capacity and generation of Nigeria's energy resources in 2020.

Capacity in 2020	**MW**	**%**
Non-renewable	11,002	84
Renewable	2,153	16
Hydro/marine	2,111	16
Solar	28	0
Wind	3	0
Bioenergy	10	0
Geothermal	0	0
Total	**13,154**	**100**

(**Source:** International Renewable Energy Agency, IRENA, 2021)

From Table 11 showing the electricity capacity and generation of Nigeria's energy resources in 2020, it is clear that Nigeria is still largely dependent on Non-renewable resources for electricity generation. Even with the combined use of renewable resources and fossil fuels, it could not meet the total of 55,903 MW (Table 8) that was targeted for the year 2020 (International Renewable Energy Agency, 2021). Renewable energy accounts for 16% of electricity capacity and generation for 2020, and Non-renewable covers 84% (Table 11).

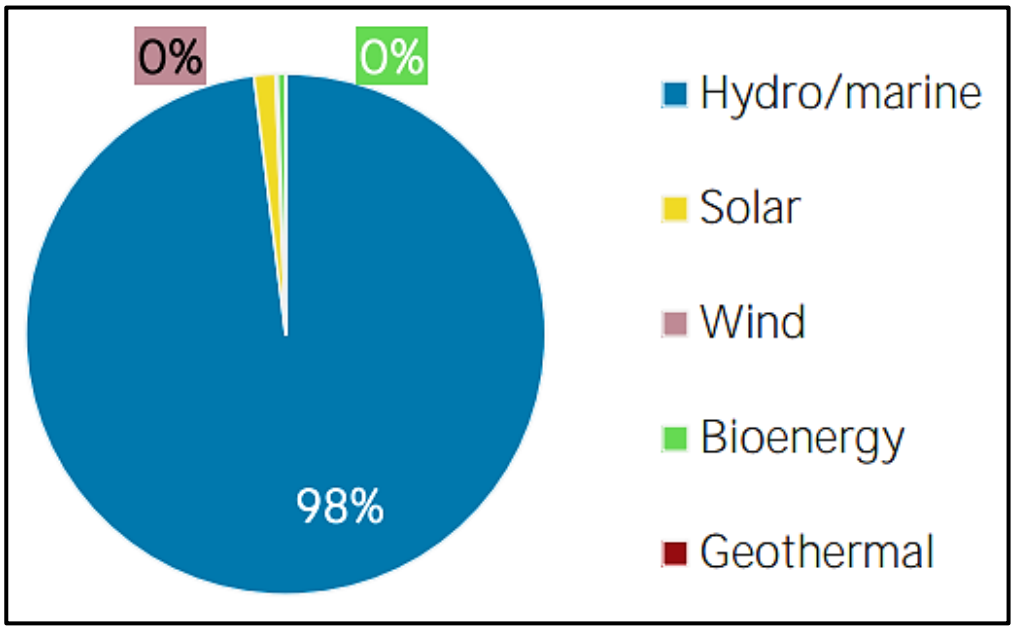

Figure 8: Percentage electricity generation of Nigeria's renewable energy in 2020

(**Source:** International Renewable Energy Agency, IRENA, 2021)

Figure 8 shows that only Hydropower is currently utilised for electricity generation as it represents 98% of the electricity generation of Nigeria's renewable energy in 2020 (International Renewable Energy Agency, 2021). With the current developments and realities of Nigeria's renewable energy sector, it is clear that renewable energy resources alone cannot sustain the entire population and every aspect of the country's economy. Renewable energy is yet to adequately penetrate Nigeria's commercial sphere, and serious efforts by the government and the private sector are needed to promote the deepening of the sector for sustainable development and to meet the country's energy needs.

7. Conclusion

Exploring and developing renewable energy sources will aid the government's effort in reducing environmental degradation and the country's input to global carbon emissions. Although the initial cost of installing renewable energy equipment is high, the life cost is competitive with conventional energy sources (Riti and Shu, 2016). Government should ensure that fiscal and non-fiscal incentives are put in place for private investors willing to invest. The development of renewable energy services should be linked to many other sectors such as agriculture, small scale industrial enterprises or millennium goals. If implemented in line with these activities, they will have a greater likelihood of success to ensure sufficient demand for the energy services providers and attract funding (Vincent-Akpu, 2012). Moreso, it will be influential to the socio-economic development of the country and the improved societal well-being. The utilization of multiple renewable energy sources in the energy mix will enable the country to meet its energy demand due to increase and improved standard of living, industrialization, and the growing population (Awogbemi and Komolafe, 2011).

It is a fact that renewable energy technologies, especially those that can be locally manufactured, require subsidies only in the initial stages. They can become financially sustainable in short to medium term after a certain level of technology dissemination has been attained, and subsidies would be gradually withdrawn. Nigeria needs an integrated policy and robust implementation strategy to facilitate the rapid diffusion of renewable resources in the nation's energy mix (Dike and Gininwa, 2018). The current flow of information on renewable energy technologies is inadequate; demonstration projects on various energy forms should be established widely so that services' performance and efficiency would be exhibited. This will sensitise the public and assist in creating markets for the renewable energy system. The need for capacity building at the institutional and personnel level to acquire technical, organizational, and managerial skills required for increased renewable energy development should be identified (Akorede et al., 2017).

Activities including technical, entrepreneurial and managerial skills development training programmes and courses in renewable energy technologies should be introduced in order to develop Energy Service Companies for rural areas. The existing Research and Development centres and technology development institutions should be adequately strengthened to support the shift towards increased renewable energy utilization (Nigerian Energy Support Programme, 2015). Finally, Nigeria is endowed with abundant renewable energy resources; successful investment in the development of renewable energy will result in job creation, climate protection, technology development, poverty alleviation and achieving environmental goals. Nigeria's renewable energy resources could be harnessed alongside energy efficiency to stimulate economic growth, social development, and energy sustainability.

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