International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 13, Issue 3 [March. 2024] PP: 159-168

Pathways to Sustainable Energy in Nigeria: A Review

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Abstract
Energy is a critical component of socioeconomic development and sustainable development in many nations today. Economic prosperity in a country is ensured by ecologically friendly, long-term, reasonably priced, and sustainable energy sources. Additionally, energy has a big influence on climate change, public health, and security and in most countries, the amount of energy used per person is closely connected to their standard of living. Nigeria, a lower-middle-income developing country, has shown that it is committed to increasing the share of renewable energy sources in the energy mix and to the global transition toward sustainable energy. This study aims to provide light on the numerous approaches to sustainable energy that are available in the country by reviewing them. This became necessary as many of Nigeria citizens have extremely limited access to energy. The study found out that numerous activities have not been made to realise these dreams as Nigeria is woefully underutilizing its wealth of naturally occurring renewable energy resources, which are essential to the country's sustainable growth.
Key Words: Energy, Sustainability, Renewable, Nigeria

Date of Submission: 16-03-2024 Date of acceptance: 31-03-2024

I. Introduction

The capacity to capture and utilize various energy sources has changed billions of people's living conditions since the beginning of the industrial era. This has allowed them to experience unprecedented levels of comfort and mobility and freed them up to carry out ever-more-productive tasks. This is because the modern world depends on an abundant supply of energy to undertake all economic operations, thus, make energy availability to be very important to the growth of any nation. Energy is essential for socioeconomic advancement and has favorable effects on national security, quality of life, and the eradication of poverty. Ramchandra and Boucar (2011) emphasized the connection between energy and the economy, as well as to public health, security, and the climate. Numerous areas of human life, including diet, health, education, technology, transportation, and communication, are impacted by energy (Oyedepo, 2013).

Studies have shown that the availability of energy has a significant impact on economic growth. For instance, Eleri (1993) emphasizes the expansion of an economy's function of a dependable, affordable, and enough energy supply in his recognition of energy as the backbone of great economies. As a result, highly industrialized economies rely largely on the supply of energy. Therefore, it is essential for any nation that wants to have a strong economy to ensure that it has a solid energy foundation for long-term growth. According to Borok, Agandu, and Morgan (2013), a country's current and future energy needs should be met by the energy base. Future energy systems must be created by managing natural resources sustainably, ensuring innovative production and consumption patterns, industrializing sustainably to support the development of resilient energy infrastructure, and properly and strategically planning the growth of the entire system. The shift to a sustainable energy source has drawn attention from all across the world due to growing worries about energy security and climate change.

The history of energy transitions over the past ten years has been studied (Smil, 2010), including those in the United States (Jones, 2014), Europe (Gales et al., 2007), and Asia (Allen, 2009). Many papers have been made about sustainable energy, but not many have properly addressed this from the viewpoint of a developing nation such as Nigeria. Long-term environmental sustainability is frequently eclipsed by more pressing concerns about energy access and affordability in countries where a sizable section of the population still lacks access to basic energy services.

1.1 The Concept of Sustainable Development and Sustainable Energy

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. The definition of "Sustainable Energy" can be interpreted in a variety of ways, but the one used in this study acknowledges both the importance of energy in social and economic growth as well as the effects it has on the environment. In light of the aforementioned, sustainable energy was defined through the three pillars of energy security, energy and quality of life, and energy and environment, which encompass the most pertinent sustainable development goals (SDGs) (see Figure 1). The trade-offs that nations will have to make when focusing on one area are highlighted by this visualisation, which also shows how the various aspects of sustainable energy are interconnected (UNECE, 2020).

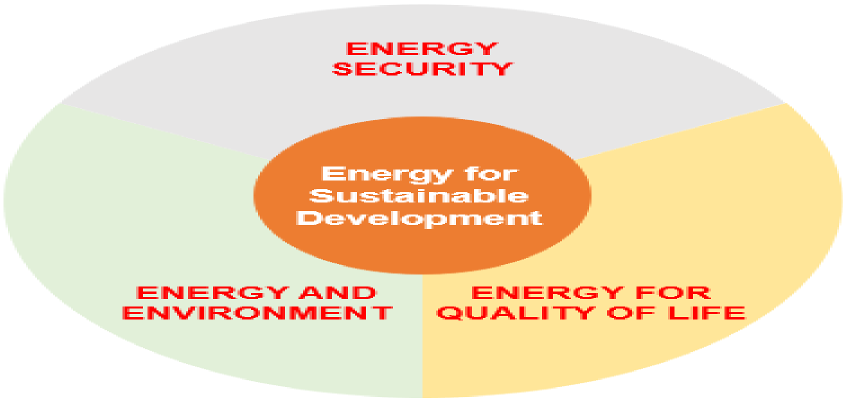

Figure 1: Energy for sustainable Development
Adapted from UNECE, 2020.

From a national perspective, the energy security pillar addresses the economic facets of energy security. It involves energy supply accessibility, as well as import, export, and transit issues. The Energy for Quality of Life pillar acknowledges the goal of enhancing citizens' quality of life by ensuring everyone has access to clean, dependable, and reasonably priced energy. The quality and cost of access to the broader idea of energy services are also included in this purpose, in addition to physical access to electrical networks. Quality of Life are currently not quantified using mathematical modeling and optimisation approaches, which presents a problem. It is also challenging to relate the benefits of clean energy, whether they are social or economic, to the energy options selected. The trade-offs between meeting the rising demand for energy, providing a clean environment and safeguarding humanity from climate change are represented by the third pillar of energy and environment.

II. MATERIALS AND METHODS

2.1 The Study Area

Nigeria is a country with a total size of 923,768 sq km (956,667 sq miles), and of 98.6% of the entire area, land makes up 351,649 sq miles (910,771 sq km). The country is organized into 36 states and the Federal Capital Territory (FCT) from six Geo-Political Zones. In addition, the country's topography, vegetation cover, and physical attributes range from lush rain forests in the south to flat, open savannah in the north, with a large number of rivers, lakes, and mountains dispersed throughout (Sambo et al 2015). In order to contain its resources, such a nation must make a lot of investments. The energy industry is one where this investment would be advantageous. Nigerians' quality of life would improve and productivity will rise with a daily supply of energy that is boundless.

2.2 Energy Situations in Nigeria

Nigeria has an abundance of commercial-grade crude oil, fossil fuels, and renewable energy sources (solar, hydro, wind, geothermal, and biomass), all of which will significantly enhance the nation's energy supply when combined. In Nigeria, there are numerous energy resources in large quantities. The nation is home to the sixth-largest crude oil reservoir in the world. A 36.2 billion barrel oil reservoir is thought to exist in Nigeria and over 5,000 billionm^3 of confirmed gas reserves is available in the country. The Niger Delta, Gulf of Guinea, and Bight of Bonny are where the majority of the oil and gas reserves are situated. With planned activities in the northeastern Chad basin, the majority of exploration efforts are concentrated in deep and ultra-deep offshore regions. The estimated reserves of coal and lignite are 2.7 billion tons, while the anticipated deposits of tar sands amount to 31 billion barrels of oil equivalent.

The indicated hydroelectricity plants are capable of producing 14,250 MW, according to estimates. Nigeria has abundant biomass resources that can be used for both conventional and modern energy needs, including the production of electricity [16]. Nigeria's energy potential and reserves are shown in Table 1. Table 1 lists Nigeria's conventional energy resources, including crude oil, natural gas, coal, tar sands, and hydropower, along with their respective reserves and energy output in billion tonnes. Tar sands account for the largest share of Nigeria's conventional energy at 28.4%, while crude oil and natural gas account for 21% and 24% of the country's total conventional energy, respectively. Hydropower has a 13.1% energy output, while coal and lignite have a 12.7% energy output.

Table 1: Nigeria Conventional Energy Resources and Reserve

Resources	Reserve	Resources in energy units (billion tonnes)	% total conventional energy
Crude oil	23 billion barrels	3.128	21.0
Natural gas	4293 billion m3	3.679	24.8
Coal and Lignite	2.7 billion tonnes	1.882	12.7
Tar sand	31 billion barrels of oil equivalent	4.216	28.4
Hydropower	10,000MW	1.954 (100yrs)	13.1
Total	Conventional/Commercial Energy resources	14.859	100%

Source: Enete & Alabi, (2011)

Table 2 lists Nigeria's non-conventional energy resources, including fuel wood, animal waste, crop residue, small-scale hydropower, solar radiation, and wind energy, along with their corresponding reserves and lifespans, the bulk of which are over 100 years.

Table2: Nigeria's non-conventional energy resources

Resources	Reserves	Reserves (billion tonnes)
Solar radiation	1.0kwm-2 Land area (peak)	
wind	2.0 - 4.0ms-1	
Small scale hydropower	734.2MW	0.143 (over 100years)
Crop residueandAnimal residue	144 million tonnes	3.024 (over 100 years)
Fuel wood	43.3 million tonnes	1.6645 (over 100 years)

Source: Enete and Alabi, (2011)

In order to increase the proportion of renewable energy to at least 13% by 2015, 23% by 2025, and 36% by 2030, the government established the Renewable Energy Master Plan in 2022. The plan which is behind schedule at the moment. Both carbon-intensive and renewable energy sources were intended to be used to meet the energy goal.

2.3 Energy Consumption Pattern in Nigeria

The world's current patterns of energy consumption demonstrate that Nigeria and other African nations have the lowest rates of consumption. The fast rising demand, however, which is typical of a developing economy, leaves Nigeria with an insufficient supply of usable energy. Nigeria's economy can be broken down into industrial, transport, commercial, agricultural, and residential sectors in terms of energy consumption patterns. About 65% of all energy used in the nation is consumed by the domestic sector. The underdeveloped state of all the other industries is partly to blame for this. Nigerian homes spend the most of their energy on lighting, cooking, and using electrical appliances. A startling 91% of household energy use is related to cooking, 6% to lights, and the remaining 3% to the use of common electrical gadgets like televisions and pressing irons. Fuel wood, charcoal, kerosene, cooking gas, and electricity are the main energy sources used for domestic and business purposes in Nigeria. Other, less frequent sources include sawdust, maize stalk leftovers from agricultural crops, cassava sticks, and, in severe situations, cow feces. Kerosene and gas are the main cooking fuels used by Nigerian city dwellers. Only a small percentage of people utilize gas or electric cookers for residential cooking, whereas the rest use kerosene stoves.

III. RESULTS AND DISCUSSIONS

3.1Pathways to Sustainable Energy in Nigeria

Exploring possible pathways for a sustainable energy change necessitates interdisciplinary expertise in the sophisticated technologies that power the change (Child et al., 2018), such as renewable energy, energy storage, waste to energy, electric vehicles, and energy efficient technology. According to estimates from BP (2018), 8.4% of the world's power production in 2017 came from renewable sources (excluding hydro). With a contribution of close to 50% to the expansion in worldwide power generation, renewables do contribute significantly to increase in electricity supply. In place of fossil fuels, many scholars advocated the use of renewable energy. Wind power is an economically viable alternative to fossil fuel-based power generation, according to Yang and Chen's (2013) analysis. Investments must be made in such a nation in order to sustainably utilize its resources. This is crucial because having an endless supply of electricity every day will improve living circumstances for Nigerians as well as productivity. The following are a few, if not all, of the pathways required for sustainable energy in the nation:

3.1.1 Creation of Large Hydropower plants Option

According to Akinbami (2001), the nation's entire hydroelectric power potential is thought to be around 8,824 MW, with a potential annual electricity generation output of more than 36,000 GWh. The 8,000 MW of this are made up of large hydropower technology (I.e. Kainji, Shiroro and Jebba hydropowers), and the final 824 MW are still made up of small hydropower technology. Currently, the country's big and small hydropower potentials have each been utilized to the extent of 24% and 4%, respectively. Adejumobi et al. (2013) surveyed and examined possible hydropower locations for a Nigerian rural electrification plan using hydrological data. Nonetheless, the authors discovered that the identified small hydropower (SHP) sources' theoretical electrical capacity, which ranges from 5.13 KW to 5,000 KW, was sufficient to meet the needs of the typical Nigerian rural community. According to Akinbami's (2001) assessment, Nigeria has a hydroelectric power potential of around 8,824 MW, with the ability to produce approximately 36,000 GWh of energy. After evaluating SHP development, Ohunakin et al. (2011) found that several obstacles still stand in the way of SHP development in Nigeria, making the government's efforts to diversify the nation's energy sources insufficient.

3.1.2 Installing Mini-Hydro Power Plants Option

Water is a resource that has been utilized for a variety of reasons, according to Ohunakin (2011). More than 97% of all electricity produced from renewable sources and around 22% of all electricity produced globally come from hydropower, the majority of which is SHP (small hydro-power) under 10 MW. Hydropower is the largest source of renewable energy. Mini-hydro power plants are water flow structures built next to rivers, streams, or irrigation canals that operate at a constant pace in relation to the in-stream flow necessary to preserve the ecosystem. They are power stations whose output is less than 10 MW (Megawatt). SHP has been in use in Nigeria since 1923, 45 years before Kainji, the nation's first sizable hydropower plant, was put into service. With only three States of the Federation operating the schemes, SHP technology is still in its infancy today (Ohunakin, 2011). Although, there is greater demand than ever for it as it makes a resurgence because the Federal Government of Nigeria was urged to take into account off-grid technology mini-hydro power plant stations as an efficient remedy to Nigeria's electricity shortage in June 2018 by the Russian nuclear energy organization Rosatom. Rosatom claims that the construction of mini-hydro stations would improve the country's population's access to energy because it is known that the small water streams required for such projects are dispersed throughout the nation, particularly in the southern region. By sending the water to these plants to generate power, the nation's flooding problem might be resolved.

Figure 2: Nigeria Waterways
Source: SAFTY4SEA

3.1.3 Biomass Option

The term "biomass" describes organic material that has energy stored in it from photosynthesis. In the recent two decades, it has risen to become one of the most widely used renewable energy sources, second only to hydropower for the production of electricity. It is a clean energy innovation. Due to its low cost and indigenous status, it is such a commonly used source of energy that it makes up about 15% of the world's total energy supply and as much as 35% in developing nations, primarily for cooking and heating. Globally, bioenergy is receiving more attention as a substitute for finite fossil fuels. According to Duku et al. (2011), a biomass's appropriateness as a possible feedstock for the generation of bioenergy depends on a variety of factors, including its moisture content, calorific value, fixed carbon, oxygen, hydrogen, nitrogen, volatiles, ash content, and cellulose/lignin ratio. According to Sokan-Adeaga AA et al. (2015), biomass accounts for around 78% of Nigeria's primary energy supply. The term "biopower" or "biomass power" refers to electricity generated from biomass fuels. Diji, 2013). Vegetables may be carbonized to make coal, which can be used as fuel to power electric plants and solve the problem of gas shortages in power plants. Biomass is widely used in Nigeria at all levels of production. Examples include using charcoal to cook traditional meals, using charcoal to press iron, using coal as a fuel in industries, using tree leaves to make paper, etc.

3.1.4 **Methanol Fuel Technology Option**

Carbon monoxide is hydrogenated to create methanol. Additionally, it is mostly made by distilling wood, and its primary basic materials are oxygen and hydrogen. The abundance of hydrogen in the atmosphere and its favorable ecological and economic effects are key factors in the technology's success. Similar to how gasoline or diesel is used in internal combustion engines, methanol, a liquid carrier of hydrogen, is a fuel utilized in fuel cells. Olah (2006) makes the case that storing energy in the form of methanol might end our reliance on fossil fuels and turn carbon dioxide from a global warming liability into a crucial raw material for a methanol-based economy, despite the fact that it is not as sustainable as bio power or solar power. Methanol is simple to use, store, and move about. This cutting-edge fuel cell technology doesn't need to refine the fuel before using it to generate electricity from liquid methanol. No contaminants are released, and the only by-products of the fuel cell are pure water and carbon dioxide (NASA/JPL-Caltech 2011). The Direct Methanol Fuel Cell concept was developed by JPL (Jet Propulsion Laboratory), which also made substantial contributions to all other aspects of the technology.

Through her previous Minister of Science and Technology, Dr. Ogbonnaya Onu, the Federal Government of Nigeria contemplated using methanol fuel technology to produce energy. The technical committee for the program to implement methanol fuel technology was launched by the minister at the time in August 2018. The former Minister claimed that, given the widespread usage of methanol fuel throughout the world and Nigeria's plentiful natural gas resources, it was high time for Nigeria to follow suit. In Nigeria, 25% of natural gas is flared, which has a severe impact on the social lives of those who reside close to the location of crude oil extraction. It is possible to capture this gas and turn it into methanol. so increasing the nation's energy supply and generating riches and enjoyable prospects.

3.1.5 Solar Energy

Due to the fact that solar PV can generate energy for self-consumption, it is known as a PROSUMER technology. In solar energy technology, the device converts sunlight directly into electrical energy. According to Okoro (2014), Nigeria's technological solar energy potential is estimated to be 15.0 x 10^{18} J of useable energy per year with a 5% device conversion efficiency. According to the country's current yearly fossil fuel production, this translates to around 4.11 x 10^{10} liters of crude oil or 258.62 million barrels of oil equivalent. The annual electricity production from this will likewise be close to $4.2\text{x}10^5$ GW/h, which is over 26 times the nation's current annual electricity production of 16,000 GW/h. As effective as they are, the PV systems can be used for effective production of power in Nigeria, particularly in the northern region due to its terrain. This can be used to balance a bit energy producing sources in the northern part of the country. This is so because majority of energy sources in Nigeria are concentrated in the southern part of the Nigeria, see figure 2a and 2b.

Nigeria's average annual global horizontal irradiation ranges from 1,600 to 2,200 kWh/m2, with the northern region of the country experiencing the highest values (over 2,000 kWh/m^2). These results indicate the country's strong potential for solar resources. IRENA projects that the nation has 210 gigawatts (GW) of technological potential for solar photovoltaic (PV), even though only 1% of the available land can be used for project development (IRENA and AfDB, 2022). Located largely in northern Nigeria, where direct normal irradiance is highest, concentrated solar power (CSP) has a potential of about 88.7 GW, making it a very major energy source (Ogunmodimu, 2013). Numerous indigenous researchers have been involved in the topic of solar energy. According to Chineke and Igwiro (2008), Nigeria receives an abundance of solar energy, with daily solar radiation ranging from 5.25 kWh/m2/day in the northern region to 3.5 KWh/m2/day in the southern region. According to Okoro and Madueme (2004), the annual incidence of solar energy on land is 2,300 kWh/m2, so that Nigeria receives roughly 2.100 × 10el2 kWh of energy annually. Oji et al. (2012) discussed the viability of using solar energy in Nigeria to generate power.

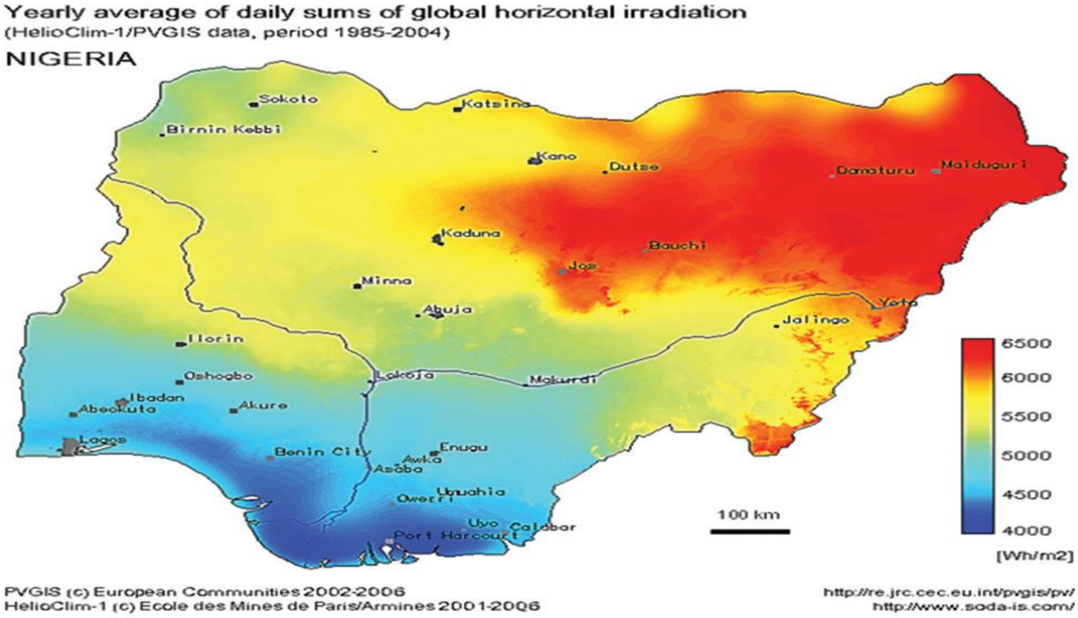

Figure 2a: Nigeria's Yearly average of Daily Sun
Source: SODA-IS

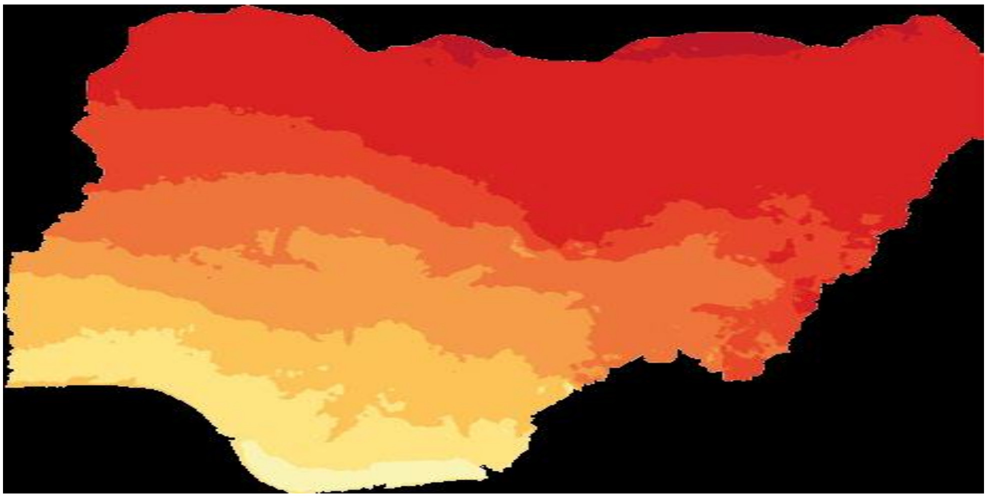

Figure 2b: Average annual global horizontal irradiation in Nigeria
Source: IRENA, 2022.

Shehu (2012), however, conducted a survey among solar sellers and residents of Northern Nigeria, and the findings indicated that a sizable portion of the population would be open to switching to solar energy in exchange for financial incentives. Moreover, according to Chineke and Igwiro's (2008) research, Nigeria receives a lot of solar energy that can be used for good. The country receives an average of 5.25 kW h/m^2/day of solar radiation annually, which is a lot more than can be used for nothing. From 3.5 kW h/m^2/day in the coastal regions to 7 kW h/m^2/day in the northern limit, this varies. Around 6.5 hours of sunshine per day are thought to be the national average. With a solar energy intensity of 1,934.5 kW h/m^2/year, Nigeria's entire land area receives an average of 6,372,613 PJ/year (or around 1,770TW h/year) of solar energy each year. This is around 120,000 times more electrical energy than the Power Holding Company of Nigeria (PHCN) produces on an annual basis. The total final energy consumption for Nigeria in 2030, as projected by the Energy Commission of Nigeria (ECN) (2011), is approximately 23 times the amount of solar energy currently accessible, even with a 10% conservative conversion efficiency. It is imperative to provide the country's unreliable energy sector with a sustainable source of power supply through solar energy in order to advance the country's development trend.

3.1.6 Wind Energy Resources Option

According to Sambo (2005), the total amount of wind energy that may be exploited is at 10M height and ranges from 8MWh/yr in Yola to 51MWh/yr in the Jos plateau areas and 97MWh/yr in Sokoto. Strong indicators of the potential for wind energy are these numbers. Numerous indigenous researchers have also looked at the availability of wind energy resources in Nigeria with the goal of putting them to use if there is a chance that they would be needed. In 1992, Adekoya and Adewale conducted an analysis of the wind speed data from 30 sites in Nigeria to determine the yearly mean wind speeds and power flux densities, which range from 1.5 to 4.1m/s and 5.7 to 22.5W/m^2, respectively. In contrast to Ngala et al. (2007), who used the Weibull distribution and 10-year (1995 to 2004) wind data to analyze the statistical potential of wind energy in Maiduguri, Borno State; Fagbenle and Karayiannis (1994) carried out a 10-year wind data analysis from 1979 to 1988, taking into account the surface and upper winds as well as the maximum gusts. Utilizing wind energy conversion technologies for the State's supply and generation of electricity, a cost-benefit study was also carried out.

Wind speeds in southern Nigeria are generally lower than in the northern region, with the exception of coastal and offshore areas (Emodi and Yusuf, 2015; Idris, Ibrahim and Albani, 2020). Nigeria's offshore wind potential is not currently estimated. Adekoya and Adewale (1992) conducted a wind energy research in Nigeria, analyzing data from 30 stations with power flux densities and wind speeds that ranged from 5.7 to 22.5 w/m2 and 1.5 to 4.1 m/s. Other indigenous wind energy researchers include Fagbenle and Karayiannis (1994), Ngala et al. (2007), and Mnse and Ojo (2009). Felix et al. (2012) assessed the wind energy potential in Nigeria and outlined the requirements to be fulfilled before the wind generator can be connected to the current grid.

Each of these studies demonstrates that there are numerous opportunities for the country to harvest wind for the production of electricity, particularly in the core northern states, the mountainous regions of the central and eastern states, as well as the offshore areas, where wind is abundantly available all year long. The challenge is for the nation to consider how to channel resources toward building wind farms in various areas and zones that have been identified as having the potential to generate wind energy.

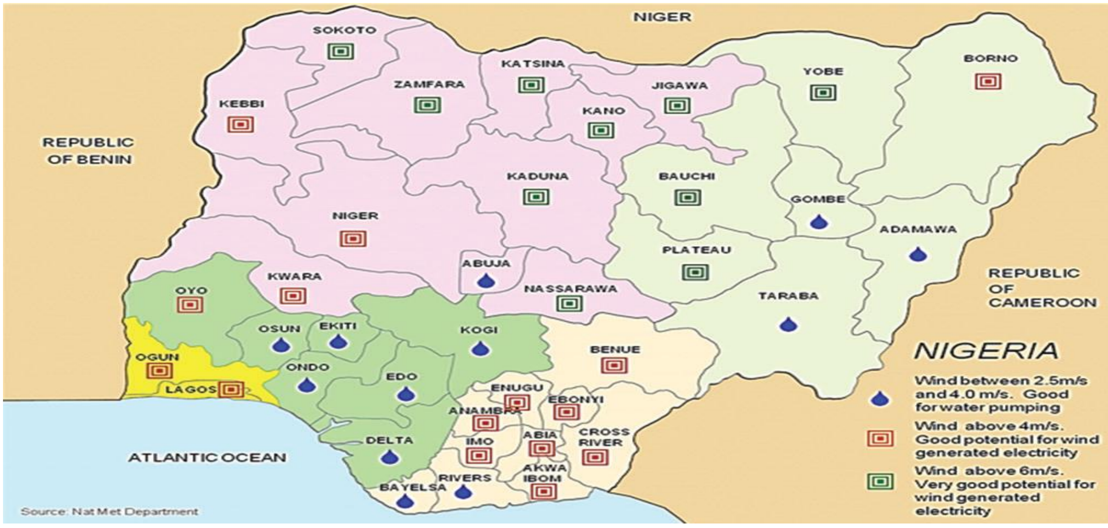

Figure 3: Wind energy location in nigeria
Source: NEENIGERIA

3.1.7 Waste to Energy Option

According to Akinbami et al. (2001), sewage, water lettuce, water hyacinth, manure, cassava leaves, urban garbage, solid waste (including industrial waste), and solid waste are the specified feedstock substrate for a financially viable biogas program in Nigeria. The following is a list of the authors' opinions: About 227,500 tonnes of fresh animal waste are produced everyday in Nigeria. Nigeria may produce roughly 6.8 million m^3 of biogas daily if 1 kilogram of fresh animal waste yields 0.03 m^3 of gas. In addition to all of this, it has been projected that the nation produces 20 kg of municipal solid garbage per capital per year. All these can be use to generate power for the country so as to boast energy availability. For instance in countries such as Sweden now leads the world in the production of energy from waste, with the Czech Republic, Denmark, Norway, and Finland following it in that order. By efficiently resolving the issue of over-reliance on landfills and assisting in meeting inhabitants' energy and heating demands, waste can be used as energy (Braw, 2018). More than 60% of waste is already recycled mostly for energy in Austria and Germany, and other Western European nations are not far behind.

3.1.8 Nuclear Energy Option

Every energy source has benefits and disadvantages in terms of sustainable development. The analysis of the characteristics of nuclear energy within a framework for sustainable development demonstrates that the strategy used by the nuclear energy sector is generally consistent with the core objective of sustainable development, which is to pass along a variety of resources to succeeding generations while minimizing environmental impacts.

Uranium has several advantages for security of supply, including its high energy density (1 tonne of uranium has the energy density of 14 000–23 000 tonnes of coal), ease with which stocks may be maintained, and the vast geographic distribution of uranium deposits. Environmentally damaging uranium mining methods from the past are no longer permitted. Impacts on people and the environment are minimized by modern extraction and processing techniques. Despite the belief of some that uranium is a limited resource with limited supply, the two prior eras of aggressive investigation (1940s and 1970s) prompted by rising demand led to the discovery of resources well in excess of projected needs. The idea that nuclear energy's contribution to sustainable development is lessened by accident risk and radioactive waste is one of the most common objections to it. A responsible management of nuclear power programs has a very low safety risk and far less negative effects on the environment and public health than other sources of energy, especially when it comes to emissions and air pollution, as shown by more than 50 years of experience in OECD member nations.

Considering the utilization of nuclear energy, radioactive waste is likely the most crucial issue. The amount of ultimate waste has been reduced, and next-generation reactors will burn fuel even more effectively. However, there is still garbage that needs to be dealt with, and long-term storage is now the most secure and practical approach. Although such trash must be handled carefully, above-ground storage in custom-made barrels has been done for the past 50 years with excellent success and no harm to the environment. In Nigeria, there is availability of uranium for nuclear power as revealed by studies. Nigeria has also earmarked two sites for take off of nuclear power but work have yet to commence on the sites.

IV. CONCLUSION

This study has looked into the potentials for sustainable energy future for Nigeria. From above analysis, research has largely shown that the only way to end energy poverty is through sustainable energy development. An effective, dependable, decentralized energy system built on a clean energy source is necessary for the economy to experience sustainable energy development. Energy efficiency and renewable energy have a relationship or connection; they are the two cornerstones and basis of sustainable energy. Nigeria is endowed with a wealth of energy resources, including renewable energy and fossil fuels. Nigeria today faces energy poverty as a result of the inefficient use of its resources by the nation particularly the renewable energy sources. To reduce the disparity between the supply and demand of energy, this study promotes the appropriate use of energy resources resources in Nigeria along with increased energy efficiency. It was found that no energy efficiency policy had been started and that numerous government initiatives on the development of renewable energy were not being properly implemented. The government must implement procedures that support the development of renewable energy sources, diversify the nation's energy mix by incorporating renewable energy into it, and establish national energy efficiency regulations.

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