

# Potentials for alternative energy in Nigerian cities and remote communities

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**Abstract.** The energy sector of Nigeria's economy constitutes a critical challenge. This sector has defied all efforts for its reform and restoration largely due to ineffective and poor policy implementation. In the 20th century, oil was the main driving force in global geopolitics and the main force behind massive industrialization. However, oil is moving in a downward trend. In its place will be an array of technologies, in the form of alternative energies with long term prospects. The standard of living of a given country can be directly related to per capita energy consumption but energy crisis is on the increase due to population and improved standard of living especially in developing cities. The aim of the study is to identify alternative energy potentials for Nigeria in view of her current energy challenges. The methodology applied in this study include case studies and review of existing literature on the subject. Identified energy crises include, incessant power outage, shortage and scarcity of petroleum products, high electricity bill, vandalization of pipelines and oil installations. The paper discussed the energy crises in Nigeria, the potentials of alternative energy technologies, and the challenges of its development for Nigerian cities and recommends that renewable energy and energy efficiency are necessary factors to achieve sustainable development in Nigeria.

## 1. Introduction

Nigeria's reliance on fossil fuels has been beset by a slew of challenges in recent years coupled with energy shortages and supply limits in both urban and rural areas. The array of energy issues includes incessant power outages, shortage and scarcity of petroleum products, high electric bills, vandalization of oil installations, high cost of foreign exchange rate, under-utilization of natural gas and other energy resources such as coal, wind etc. These according to survey have affected how reliable power and energy are distributed and marketed to a large number of households, businesses, and manufacturing consumers across the country. The rural population depends on fuel wood and charcoal for their daily heating needs and the sale of these commodities are uncontrolled in the private sector. Famuyide et al. [1], reported on government's policy to subsidize the pricing of petroleum products consumed locally including electricity. However, the experience of citizens has been skyrocketing pump price and electric tariffs. Electricity is viewed in this study as essential for facilitating crucial developmental infrastructures such as the availability of water, education, medical care, communications, and information technology. Additionally, energy powers productive endeavours including mining, manufacturing, farming, and business ventures.

Since post-independence era, there have been various government interventions to improve energy production and supply in Nigeria. In 1962, the Nigerian Federal Government initiated the construction of the Kainji Hydro Power Station in Kainji, Niger State. This decision was prompted by the increasing demand for electricity, which was outpacing the available supply due to industrial growth and rapid urbanization. Recognizing the potential cost-effectiveness of hydro power technology, the government sought to harness it as a means of providing a substantial and affordable electricity supply. At the commencement of operations in 1968, the initial capacity installed was 320MW. However, by 1970, the station underwent an expansion that involved only two 100MW-capacity generating

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units added, bringing the total capacity to 760MW. In 1985, Jebba Hydro Electric Power Station with generating capacity of 90MW- 578.4MW of electricity was established, exploiting the potentials of the river Niger, while the Shiroro Hydro Electric Power followed, situated strategically at an elevated position within the Shiroro Gorge along the Kaduna River, generating 600MW of electricity at full utilization [2]. Apart from hydro power generation in Nigeria, thermal power supply became another source of electricity generation in Nigeria. One of the power stations included is the Afam Thermal Station, situated on the outskirts of Port Harcourt in Rivers State, built in 1963 making use of available natural gas in the region. Today, the installed capacity has risen to 699MW. With a generating capacity of 1320MW, the Lagos Thermal Power Station at Egbin, the downtown area of Lagos, was developed in response to the rise in energy demand from users in the residential, commercial, and industrial sectors. Others are Sapele Power Station, located in Ugheli, Delta State built in the early 70s. The supply of inexpensive natural gas for burning has helped to meet the growing demand for electricity within and around Warri, which is home to large enterprises like the Nigerian National Petroleum Corporation and the Aladja Steel Complex. Sapele thermal power station in 1985 is capable of producing 720MW - 1020MW at full firing. The National Electric Power Authority (NEPA), founded by Decree No. 24 on April 1st, 1972, is responsible for maintaining Nigeria's efficient, well-coordinated, and cost-effective system of energy delivery. The initial phase involved four primary power stations, namely: Afam Thermal Power Stations, Ijora, Kainji Hydro Power Station and Delta, catering to over two million customers across the country. This development played a crucial role in driving the technological and industrial advancements of the nation.

**Table 1.** Comparison of electricity supply structure from inception of NEPA between 1972 and 1997

	<b>Supply system</b>	<b>1972</b>	<b>1997</b>
CAPACITY	Total installed generating capacity	5326MW	5,958MW
	Nation's Peak Demand	390MW	2,446MW
NETWORK DISTANCE	Length of 132KV Lines	1,012KM	6,000KM
	Length of 330KV Lines	1,262KM	5,000KM
	415 Volts Network	15,000KM	55,143KM

As a matter of national urgency, an energy emergency was declared in the late nineties, in order to move power production from the then current level of under 4,000 megawatts to over 30,000 megawatts of power by 2011 and 50,000 megawatts by 2015. Although despite the proposed increase, demand has not equated supply. Generating hydro power plants depend heavily on the inflow of water into the dams/lakes yet hydro power stations at Kainji, Jebba and Shiroro are experiencing sharp drops in the volume of water needed for generating power, due to sharp drop of rains during the dry seasons. Also failing equipment, due largely to old age, near relics of obsolescence, are other challenging factors. The point must be made as a matter of clarity that although the combined total (initial) installed capacity of hydro (Kainji, Jebba and Shiroro) and thermal power stations (Egbin, Afam, Sapele, Delta and Ijora) is 5,876MW. Full capacity utilization, is further impaired by the fact that most of the plants which constituted the initial capacity, have either been retired many years ago, or are in bad state of disrepair. This in effect reduces available capacity from time to time. Funding to carry out major overhauls of the aged plants which have broken down is the primary cause of the current difficulties in meeting the National Power demand. Furthermore, over flogging of hydro plants to meet the national power demand sometimes results in premature depletion of the hydro reservoirs. Therefore, a daily water utilization budget has to be implemented to ensure year-round hydro generation. It becomes imperative, therefore, that for the immediate short-term solution to meet the power demand of the country, urgent steps will have to be taken to restore to service more thermal generating plants in Delta, Afam, Sapele, and Egbin power stations in the long term, it is necessary to look for alternative energy supply which is renewable in nature. This is part of the objective of this paper. In effect, the global world is warming back to embrace renewable energies and associated technologies and Nigeria with all enthusiasm has joined the League of Nations in the embrace International Energy Agency [3]. However, the embrace did not only follow age-long anxiety over the eventual phasing out of combustion age but rather, included are the global warming or climate change, ozone layer depletion and other environmental hazards resulting from harmful carbon dioxide emissions of what experts called "Fossil power generation". However, in a spirited effort to stem the tide and secure its energy future, Nigerian government has launched Nigerian Renewable Energy Master Plan (REMP) towards a visionary step in developing renewable energy in Nigeria by the Council for Renewable Energy in Nigeria (CREN) [4]. The concern for climate change, the decline of global oil market, the increasing support from world governments coupled with energy security issues have triggered the need for renewable energy and energy efficient investment. The vast renewable resources available in Nigeria, including hydro, solar, biomass, and wind came into focus as panacea to boost her future energy requirements. In this context, the government is determined to ensure the accessibility of renewable energy in community areas which is a step in the right direction.

Energy efficiency criterion as viewed in this study, will boost important economic and social benefits, as well as reduction of greenhouse gas emissions. Therefore, the optimal utilization and promotion of renewable energy sources, adoption of energy-efficient practices, and implementation of energy conservation measures across different sectors of the economy represent a positive stride forward. Some authors believe that full utilization and advancement of renewable sources of energy, energy efficiency practices, and the implementation of energy-saving measures in a variety of economic sectors will be a catalyst for addressing Nigeria's energy challenges. In the midst of their positions, to meet the country's growing demand for energy services, a robust mix of energy sources (both fossil and renewable) coupled with appropriate end-use efficiency will almost undoubtedly be required. In this context, Nnaji et al. [5] proposed allocating approximately 20% of industrial project investments towards alternative energy sources. It was in line with this that this paper intends to identify causes of energy crises in Nigeria, the potentials of alternative energy technologies for Nigeria with a view to recommending renewable energy and energy efficiency as necessary factors to achieve sustainable development in Nigeria. The specific objectives pursued in this study were to: (i) Identify the causes of energy crises in Nigeria. (ii) Identify the factors that are responsible for energy supply constraints in Nigeria. (iii) Examine the key variables that must be taken into account when transitioning towards a renewable energy future for Nigeria.

The value of this research lies in the fact that renewable energy provision and energy efficiency culture if made available in all the cities and in the rural areas will enhance developmental activities in the country. The findings of this research will sensitize new policy formulation and create the necessary awareness to all stakeholders of sustainable energy utilization in Nigeria.

### 1.1. Context of Study

Nigeria is located between the latitudes of 4° and 14° north of the Equator, and longitudes of 2° 2' and 14° 30' east of the Greenwich Meridian. It shares its northern borders with Niger and Chad, while the southern boundary is formed by the Atlantic Ocean. To the east, it is bordered by Cameroon, and by Benin to the west. With a population exceeding 200 million individuals [6], Nigeria stands as the most populous nation in West Africa and a national territory of 923,770 km<sup>2</sup>. The country is divided into 36 states, with "Abuja" serving as the Federal Capital. It has approximately 200 ethnicities and 500 indigenous languages. Nigeria's economy is rapidly growing in Sub-Saharan Africa and is primarily dependent on the petroleum industry.



**Fig. 1.** existing TCN transmission line system

Nigeria is one of the nations on the globe with an abundance of fossil resources, primarily crude oil, coal, and natural gas. Aside from these fossil fuels, it has a sufficient supply of renewable sources of energy [7]. Nigeria, together with Libya, holds the majority of Africa's crude oil reserves, making it the foremost oil producer on the continent.

Consequently, Nigeria ranks second, following Algeria, in terms of natural gas production [8]. The Nigerian economy relies heavily on energy exports and possesses abundant energy resources, the sixth largest crude oil reserves globally. Nigeria is believed to possess approximately 36.2 billion barrels of oil reserves. She is emerging as a significant gas province with proven reserves of nearly 5,000 billion cubic meters. The primary areas where oil and gas reserves are found in Nigeria are the Niger Delta, Gulf of Guinea, and Bight of Bonny. Most of the exploration operations are focused on deep and ultra-deep offshore regions, while there are also plans for activities in the Chad basin located in the northeastern part of the country. Nigeria is thought to have 2.7 billion tonnes of coal and lignite deposits, while its tar sand reserves are equivalent to over 31 billion barrels of oil. The overall capacity of the identified hydroelectricity plants is about 14,250 MW. The nation has a wealth of biomass resources that can be used for a variety of energy needs, including the production of electricity [9]. Notably, a sizable portion roughly 70% of rural Nigerians largely rely on fuelwood as their main energy source. Even though Nigeria has a lot of energy resources, power stability and outages are major issues affecting the lives of people in rural areas who lack street lighting system and municipal water supplies [10]. However, due to global warming issues, the use of fossil fuels is decreasing steadily. Nigeria is shifting to other alternative sources of energy to meet the country's energy demand as a result of the environmental risks posed by the use of fossil fuels [5,11]. Having an easy to install and maintenance system, solar energy is one of the most practical renewable energy sources. Nigerian Council for Renewable Energy estimates that power interruptions cost the nation 126 billion naira (\$984.38 million) annually [12]. Furthermore, according to the Central Bank's 1985 estimate, Nigeria consumed 180,000 barrels of oil per day, or 8,771,863 tonnes of oil equivalent [13].

## 2. Literature review

### 2.1. Renewable Energy Technologies

Renewable energy plays a crucial role in fulfilling the future energy requirements of both urban and rural communities [14]. Compared to other energy sources, renewable energy resources and technologies have minimal environmental impact, making them effective in mitigating the environmental pollution caused by greenhouse gas emissions from fossil fuels which are also depleted via mining and usage. Additionally, renewable energy promotes system decentralization and local solutions, offering cleaner alternatives that are independent of the national power grid. This approach not only benefits small remote populations but also generates economic advantages.

### 2.2. Solar Energy

Several indigenous authors in Nigeria have explored the feasibility of utilizing renewable energy resources in the region. Onyebuchi [15] conducted a study on Nigeria's technical solar energy potential and calculated that, based on an assumption of a 5% device conversion efficiency, it would produce about  $15.0 \times 10^{14}$  kJ of useable energy annually. This translates to an equivalent of yearly 258.62 million barrels of petroleum, which aligns with the country's current yearly generation of fossil fuels. Also, the study found that this solar energy potential could generate approximately  $4.2 \times 10^5$  GW/h of electricity annually, which is around 26 times greater than the nation's current yearly power output of 16,000 GW/h. Furthermore, the work of [16] demonstrates that Nigeria gets an abundance of sunlight which can be productively utilized, with an average daily solar radiation of approximately 5.25 kW h/m<sup>2</sup>/day throughout the year. The solar energy availability in Nigeria varies across different regions, ranging from 3.5 kW h/m<sup>2</sup>/day along the coast to 7 kW h/m<sup>2</sup>/day at the northern frontier. On average, the country experiences approximately 6.5hrs of sunshine per day. This results to an annual mean solar energy amount of 1,934.5 kW h/m<sup>2</sup>/year. Consequently, an estimated total of 6,372,613 PJ/year (equivalent to nearly 1,770 TW h/year) of solar energy is irradiated onto the total surface area of Nigeria over the course of one year. This amount of solar energy is roughly 120,000 times greater than the combined annual electricity generation of Nigeria's Power Holding Company (PHCN). The total ultimate energy demand for Nigeria in 2030, as estimated by the Energy Commission of Nigeria (ECN), is around 23 times greater than the amount of solar energy that is currently available, even if conversion efficiency is conservatively assumed to be 10% [17]. Solar energy is best suited for areas in Nigeria where there are no power lines. Solar electricity application for streetlamps and hydrokinetic applications has been discussed in terms of design, installation, and financial feasibility. According to the International Conference on Modelling, Simulation, and Control [18], LED lights are more energy efficient than other lighting devices such as CFLs, fluorescent lamps, and incandescent lamps. According to Rai [19] solar industry, through solar photovoltaic can generate electricity, heat and hot water. He stated that the heat from solar energy can be applied on water heating systems for domestic, industrial, commercial applications. Also as reported by [20] the mean daily solar radiation potency of Nigeria is approximately 3.5-7 kwh/m<sup>2</sup>.

### 2.3. Wind Energy

According to Rai [19], winds are caused from two main factors; i) Heating and cooling of the atmosphere, which generates convection currents. ii) The Earth's rotation in relation to the atmosphere and its orbit around the sun. Wind energy, which is derived indirectly from the conversion of solar energy, can be harnessed by using windmills. These windmills utilize the power of the wind to drive a rotor, generating electricity in the process. Furthermore, several local studies in Nigeria have investigated the feasibility of utilizing wind energy resources and explored the potential for their integration into the country's energy system. Adekoya and Adewale [20] analysed air velocity data from 30 stations across Nigeria to determine the average annual wind speeds and power flux densities. The results showed that wind speeds ranged from 1.5 to 4.1 m/s, while power flux densities varied between 5.7 and 22.5 W/m<sup>2</sup>. Fagbenle and Karayiannis [21] conducted an analysis of wind data spanning a period of ten years, from 1979 to 1988. Their study considered various factors such as surface and upper winds, as well as maximum gusts. Similarly, Ngala et al. [22] utilized a statistical approach, incorporating the Weibull distribution and ten years of wind data (1995-2004), to assess the wind energy potential specifically in Maiduguri, Borno State. An econometric analysis of wind energy conversion systems for the production and distribution of electricity in city was also performed. Each of the aforementioned studies highlights the significant potential of harnessing wind energy for power generation in Nigeria. Specifically, there is a notable advantage in cultivating wind resources in the core northern states, hilly regions of the central and eastern states, and offshore areas. These regions experience abundant and consistent wind throughout the year, making them ideal for the establishment of wind farms and the efficient harvesting of wind energy.

### 2.4. Hydro Energy

According to Akinbami [23], Nigeria has an estimated hydropower producing potential of 8,824 MW, with a capability to produce more than 36,000 GWh of electricity per year. 824 MW of the total are produced using hydroelectricity technology, and the remaining 8000 MW are produced using large-scale hydropower technology. Currently, 4% and 24% of the country's minor and significant hydroelectric power prospects, respectively, have indeed been exploited.

### 2.5. Bio-based Energy

Bioenergy is a type of renewable energy sourced from organic materials, such as biomass, which are derived from recently living organisms. It serves as a versatile energy source capable of producing transportation fuels, heat, electricity, and various products [24]. *Biomass* is an attractive renewable energy and may be exploited using more environmentally friendly technologies. According to Akinbami et al. [25], identified various feedstock substrates suitable for a financially viable biogas initiative in Nigeria. These substrates include water hyacinth and lettuce, agro residues and dung, solid waste and sewage, industrial and household waste. As stated by the authors, Nigeria generates approximately 227,500 tons of fresh animal waste per day. With each kilogram of fresh animal waste yielding approximately 0.03 cubic meters of gas, Nigeria has the potential to generate approximately 6.8 million cubic meters of biogas daily. Consequently, on average, it is believed that the nation generates 20 kilograms of municipal solid waste per person annually.

### 2.6. Energy Efficiency

Ayres et al [26] conducted a study examining the interplay between sustainable energy, efficiency, and economic growth. Their findings highlight the significance of energy as a crucial factor in primary production (5). In Nigeria, a significant amount of energy is squandered due to excessive consumption in households, private offices, government establishments, and industrial settings, surpassing the actual energy requirements resulting in energy waste. Energy efficiency refers to the enhancement of methods and products aimed at minimizing the energy required to deliver various services. This can be achieved by accomplishing more tasks with less energy or accomplishing the same tasks while consuming a reduced amount of energy [27].

### 2.7. Alternative Energy Potentials

Investment in clean energy refers to allocating resources towards establishing an energy supply and distribution system that provides the required energy while simultaneously limiting negative social and environmental repercussions [28]. Investing in sustainable energy infrastructure is considered the most impactful approach to enhance the engagement of Nigerian stakeholders in the Clean Development Mechanism process and, consequently, the global carbon market. Sustainable energy entails the provision of energy services that can be provided to all people in ways that are sufficient to satisfy basic needs, affordable, and environmentally friendly [29-31].

## 3. Materials and methods

The methodology involved a qualitative analysis of existing literature on the study objectives. This study involved personal experience of the authors, secondary data from journals and media reports, the internet, and existing works of other authors on the subject. In this study, the challenges and crises arising from Nigeria's dependence on fossil fuel, its supply constraints and variables for consideration in transitioning to a future powered by renewable energy were investigated. A comprehensive literature review covering some data and other publications was adopted in order to achieve the set objectives. Consequently, the information obtained were subjected to thematic context analysis and used for discussion. Results are presented in form of text.

#### **4. Results**

Electricity plays a vital role in Nigeria, serving as both a fundamental driver of economic prosperity and a critical enabler for various industries and sectors [32]. Nigeria possesses abundant conventional energy resources, including oil, natural gas, lignite, and coal, which contribute to its energy wealth. Okafor and Joe-Uzuegbu [33], assert that she is fortunate to have access to clean energy resources like solar power, hydroelectricity, and wind energy. According to ECN, [34], the patterns of energy consumption in Nigeria's economy can indeed be categorized into industrial, transportation, commercial, agro, and household sectors. As reported by ECN [17], the residential sector accounts for roughly 65% of the overall energy consumption in Nigeria, mainly due to the limited progress in other sectors. Based on the report, the activities that consume the most energy in Nigerian households are electrical appliances, lighting, and cooking. As per the findings, the majority of household energy consumption, accounting for 91%, is attributed to cooking activities. Lighting accounts for approximately 6% of energy usage, while the remaining 3% is attributed to the operation of basic electronic devices such as televisions and other household appliances. In the same vein, Famuyide [1], reported that the primary energy sources utilized for domestic and commercial purposes in Nigeria include fuel wood, charcoal, kerosene, cooking gas, and electricity. Energy demand is on the increase locally and globally because the level of prosperity in a particular nation can be directly linked to the per capita energy consumption. Hence as Rai [19] put it, the energy crisis is caused by two factors: first, a massive rise in global population; and second, a rise in the human living standards. Consequently, global economic growth is putting new pressure on conventional fuels, which cannot possibly be met entirely by traditional energy sources. In this regard, the International Energy Agency (IEA) forecasts a massive global upsurge in primary energy demand of more than 50% by 2030, to 16.3 billion tons of oil equivalent, more than five billion more than today [35]. Further, IEA predicts that in 2050, with an extra 2.4 billion added to the earth's population, projections will range from 21 billion tons or more. (U.S. Census Bureau, 2005). Supply Constraints is another aspect of energy crisis the world is facing due to the prospects of limited production capacity. While there is much to discuss concerning the future of non-renewable energy production, a few realities are becoming increasingly clear. First, production in many of the world's major oil fields is declining. Since 1999/2000, the North Sea, for example, has been experiencing a year production drop. The world's second-largest producer, Kuwait's Burgan field, is currently in decline, such is Mexico's largest, Cantarel. Some experts believe Saudi Arabia, which has the world's largest oil field, is also having difficulties keeping up with global oil demand [37]. In fact, in Nigeria, the Energy Agency has electricity generated using a combination of thermal and hydro systems. The national grid, which encompasses the transmission network, interconnects power distribution and substations. All the electricity generated in Nigeria is consolidated at the National Control Centre in Osogbo, from where it is distributed across the country. Because many of the existing power plants have components that require rehabilitation, retrofitting, and upgrading, they operate at far below their installed capacity [38]. Hydro turbines contribute to 34.89% of the total generation source, while gas turbines account for 35.27% and steam turbines contribute 29.84%. The overall electricity production reached 2,997.3 MW/h by the end of 2005 [39]. A number of issues have contributed to the power sector's inability to satisfy the country's power needs, and it has hampered economic growth and GDP recovery. The Nigerian Central Bank [40] highlighted nine problems with the Nigerian Power company namely; there is a lack of regular maintenance and preventive measures for facilities, leading to significant energy losses, consistent major breakdown occur due to the utilization of outdated and severely overloaded equipment, Insufficient collaboration between town planning authorities and the Power company of Nigeria leading to ineffective planning of the power system and excessive strain on Power equipment, deficient power generation arises from operational and technical issues resulting from machine failures reduced pressure of gas and inadequate level of water. Lack of organization financing, insufficient budgeting allocation, and inordinate waiting time in releasing funds to PHCN, as well as an inefficient billing and collection system, were all identified. Vandalism and pilferage of Power equipment and significant level of indebtedness to PHCN by government & non-governmental users. Furthermore, to these, the majority of Nigeria's existing power plants are underutilized or do not function at all. Innumerable explanations could be advanced as to why these plants are underutilized. Some of these include: (1) a lack of discipline among consumers and non-availability of qualified personnel for regular repairs; (2) inadequate availability of necessary spare parts for equipment and plant; (3) deficient capacity of local manufacturing; (4) a dearth

of studies on distribution network optimization to tackle excessive losses stemming from unplanned system extension; and (5) the failure to convert gas flares into a viable electricity source as reported by Emeka [41]. In Nigeria, there are only 14 power plants (3 hydro and 11 thermal stations). Not more than 4,500 MW of Nigeria's estimated 8,039 MW installed capacity is ever produced. This is due to poor maintenance, fluctuations in sea levels that power the hydroelectric dams, and transmission losses. A network of infrastructure covering 23,753 kilometres of 33-kV lines, 19,226 kilometres of 11-kV lines, and 679 33/11-kV substations makes up the distribution sector. Additionally, it has 680 injection substations and 1790 distribution transformers [42]. Nigeria possesses five local oil refineries that collectively have a capacity to process 450,000 barrels of oil per day. However, the country relies heavily on imports to fulfil over 75% of its demand for refined petroleum products. In the last two decades, the state-owned refineries have rarely operated at more than 40% capacity utilization for extended periods of time. The Minister of Energy estimates that in 2008, subsidies for gasoline importation exclusively will amount to 700 to 800 billion naira [43,44]. Nigeria's substantial reliance on self-generated energy and other energy-related issues, such as frequent power outages, serve as examples of the country's second energy shortcoming. Despite Nigeria's abundant energy resources, this development has occurred. For the past three decades, the electricity market, dominated on the supply side by the state-owned PHCN, formerly known as NEPA, the national electricity provider, has failed to meet the global standards for electricity service reliability, accessibility, and availability [45].

## 5. Discussion

The goal of this study was to identify the nature of Nigeria's energy crises, the factors responsible for Nigeria's energy supply constraints, and the factors that must be considered in Nigeria's transition to a sustainable energy future. From the findings presented in the previous chapters, three major factors have been identified for further discussion which include; Limitations on energy production, a drop in power sector investment, and the lack of sufficient expansion to meet the increasing electricity demands. Other Energy crises in Nigeria are (i) inadequate power supply, (ii) inadequate supply of petroleum products, (iii) high electric bills, (iv) vandalization of oil installations, (v) under-utilization of natural gas and other energy resources such as coal, wind etc. Arobieke et al. [10], also included power instability and power outages. The problems are inherent in both the city and rural areas hence according to Famuyide, et al. [1], government had no option than to subsidize electricity and petroleum products put up several programs to stem the tide. On the other hand, the second objective focused on energy supply constraints. Major constraints identified in this study include; i) sole dependence on spare parts importation which attracts high exchange rates, ii) hydro power reduction in the dry season for hydro power stations. iii) poor conditions of most of the combined hydro and thermal plants due to poor maintenance. In view of the challenges enumerated above, it became necessary to shift to alternative power supply which is renewable and obviously sustainable in nature. Hence, the concern for climate change, coupled with energy security issues triggered Nigeria to bid for renewable energy and energy efficient investment as reported by ECN [11] and Nnaji et al, [5]. In fact, according to David [4], the government took a bold step in the launch of Nigerian Renewable Energy Master Plan (REMP) towards developing renewable energy in Nigeria by the Council for Renewable Energy in Nigeria (CREN). It was this reason that Nnaji et al. [5] suggested that 20% of all investments made in the industrial sector should go towards financing renewable energy alternatives. It was also in line with this that this study strives to bring the factors that need to be considered for alternative energy future for Nigeria into focus with a view to recommending renewable energy and energy efficiency as a welcome scenario to achieve sustainable development in Nigeria. This is part of the enumerated target objectives. The following factors must be considered when transitioning to a sustainable energy future: i) Alternative Energy Potentials, which necessitate clean energy investment in a system for supplying and utilising clean energy with negligible negative social and environmental consequences [28]. ii) Sustainable energy provision services that can serve people today and in the coming years, are adequate to meet basic needs, are affordable, and are not harmful to the environment were proposed [29-31]. iii) the use of solar energy system that are feasible with easy installation and maintenance. The researchers in this study argue that if renewable energy provision and energy efficiency culture are associated with important economic and social benefits of reduction of greenhouse gas emissions and reduction of the energy bills for the teaming consumers, it is necessary to sensitize new policy formulation and create the necessary awareness to all stakeholders connected with energy utilization in Nigeria. According to Hui [14], in fulfilling the energy requirements of the future for urban and rural regions, renewable energy will have a significant impact. Many indigenous researchers for example, Onyebuchi [15], has examined the accessibility and feasibility of renewable energy sources in Nigeria and calculated the technical capacity of solar energy in Nigeria, considering a 5% conversion efficiency of solar devices, which amounts to an estimated annual useful energy of  $15.0 \times 10^{14}$  kJ. Solar energy as viewed in this study is particularly well-suited for areas in Nigeria where access to power lines is limited. The implementation of solar energy solutions for street lighting and water pumping, utilizing energy-efficient LED lights, offers favourable design, installation, and economic feasibility. According to Rai [19], wind energy can be economically used for generation of electrical energy. The

hydroelectric industry is the giant of the renewable energy sector with technology existing for over a century. Akinbami [23], opined that the country is estimated to have a hydroelectric power potential of approximately 8,824 MW, with an average yearly electricity generation capacity in excess of 36,000 GW. Bioenergy is geographically widespread across the Earth's surface compared to finite energy sources, and it can be harnessed using environmentally sustainable technologies. As shown by Akinbami et al. [25], water lettuce, water hyacinth, dung, cassava leaves, urban refuse, solid (including industrial) waste, agricultural residues, and sewage are among the feedstock substrates identified for a commercially viable biogas program in Nigeria. Ayres et al [26] investigated the relationships between sustainable energy and factors such as efficiency and economic growth. In the bid to consider alternative energy for sustainable energy future for Nigeria several authors have investigated some renewable energy potentials in the ensuing literature. Evidence includes the studies on the utilization of alternative energy sources has the potential to drive growth across all sectors of the economy [32]. Nigeria possesses a wealth of alternative energy sources, including timber, sun, wind, and water [33]. Energy consumption trend in the Nigeria's economy is categorized into different sectors, namely industrial, transportation, commercial, agricultural, and household. [34]. The residential sector generates about 65% of total energy consumption in the country, owing to the low level of development in all other sectors; [17]. In Nigeria cooking gas, wood, electricity, and charcoal are the most common energy resources utilized for both commercial and residential purposes [1]. Energy demand is rising both domestically and internationally as energy plays a crucial role in all sectors of an economy. The level of per capita energy consumption directly correlates with the standard of living in a country. Hence as Rai [19], put it, energy crisis can be attributed to two factors: firstly, the rapid growth of the global population, and secondly, the rise in living standards worldwide. In this regard, the International Energy Agency (IEA) forecasts a more than 50% increase in global primary energy demands by 2030, to 16.3 billion tons of oil equivalent, or more than five billion tons more than today [35]. Further, IEA predicts that by the year 2050, the global population is projected to increase by an additional 2.4 billion individuals, projections will range from 21 billion tons or more. This implies that it will be erroneous to predict a lower consumption of energy. Supply constraints contribute to the energy crisis in Nigeria and globally, primarily due to the decreasing production capacity of major oil fields worldwide. Notable declines in production have been observed in significant oil fields such as the North Sea, starting from 1999/2000, followed by Kuwait's Burgan field, which is the second-largest producer globally, Mexico's largest Cantarel field, and Saudi Arabia's world's largest oil field [37]. Existing plants in Nigeria are currently operating well below their maximum capacity due to the need for rehabilitation, retrofitting, and upgrading of their components [38]. According to CBN [39], hydro turbines account for 34.89% of generation capability, gas turbines account for 35.27%, and steam turbines account for 29.84%. Hydropower stations contribute a larger proportion to the overall power generation (measured in MWh) compared to thermal power plants. The CBN, estimated that total electricity consumption in 1970 was 145.3 MW/h; it rise in 1980 to roughly 536.9 MW/h, and overall electricity consumption rise to 1,873.1 MW/h in 2005 [39]. However, the cumulative electricity production, which in 1970 was 176.6 MW/h and rose to 815.1 MW/h by 1980, reached a total of 2,997.3 MW/h by the conclusion of 2005 [39]. The Central Bank of Nigeria [40] highlighted inherent problems with the Nigerian Power Sector as follows: a total absence of precautionary and schedule maintenance of facilities, frequent major breakdowns due to outdated and heavily overloaded devices, equipment failure, inadequate gas pressure, insufficient water supply, inadequate financial resources, inefficient billing and collection system, and a lack of accountability, high community and private consumer debt to PHCN, insufficient maintenance, non-availability of critical industrial plant spare components for maintenance, a non-existence for indigenous manufacturing capabilities, and an unwillingness to transform gas flares to a source of power [41]. The existing transmission network comprises 5,000 kilometers of 330-kV lines, 6,000 kilometers of 132-kV lines, and 23 substations operating at 330/132-kV. The combined capacity of these substations is either 6,000 or 4,600 MVA, assuming an 80% utilization factor. The collective capacity of the 91 substations operating at 132/33-kV stands at 7,800 or 5,800 MVA, taking into account a utilization factor of 75%. Within the distribution sector, there are 23,753 kilometers of 33-kV lines, 19,226 kilometers of 11-kV lines, and a total of 679 substations operating at 33/11-kV. According to reference [42], there are also 680 injection substations and 1,790 distribution transformers. Despite having a 450,000 barrels per day processing capacity, Nigeria buys in excess of 75% of what it requires in petroleum product needs. Over the past twenty years, the utilization of state-owned refineries has seldom surpassed 40% of their capacity. The other aspect of energy issues in Nigeria remains the regular power blackouts with a widespread dependence on self-generated power. This situation arises from the inability of the state-owned power generating corporation (NEPA) to meet even the basic global standards of energy provision [45]. NEPA currently operates nine power distribution zones in Abuja, Benin, Enugu, Ibadan, Jos, and Kaduna. At present, the Nigerian electricity grid is primarily reliant on PHCN (formerly NEPA), that is responsible for around 98 percent of the overall electrical energy production [40]. Nevertheless, as highlighted by Wajim et al. [46], hydropower has emerged as a more significant energy source compared to others, primarily because of its cost-effectiveness.



## 6. Conclusion and Recommendation

The identified causes of Nigeria's energy crises typically involve electricity production limitations, declining investment in the power sector, and stagnant expansion to satisfy soaring electricity demand. Others are inadequate power supply, inadequate supply of petroleum products, high electric bills, vandalization of oil installations, under-utilization of renewable energy resource such as wind and biomass. Energy crisis was also linked to rapid increase in world population and increase in standard of living of humans. Supply constraints identified in the study include; limited production capacity, decline in production of majority of the world's largest oil reserves. Others supply constraints comprise; frequent major breakdowns due to outdated and heavily overloaded equipment, device failure, reduced gas pressure, and reduced hydro water levels. Poor financing, an ineffective payment and billing system at PHCN, high indebtedness by both government and private consumers, an absence of vital spare parts for repair work, a shortfall in local manufacturing capacity, as well as a failure to transform gas flares to a power source. According to the study, the following factors must be considered when transitioning to a sustainable energy future; alternative energy that require Clean energy investment with the least amount of detrimental social and environmental implications, sustainable energy provision services that are sufficient to meet basic needs without negatively impacting the environment, the use of solar energy system with easy installation and maintenance, inexhaustible supply and efficient culture which will reduce greenhouse gas emissions and energy bills for the teaming consumers.

The findings of this current study, highlights that renewable energy and energy efficiency are two components that should be combined in order to achieve sustainable development in Nigeria. The need to preserve the existing energy resources in Nigeria and promote sustainable development necessitates the adoption of energy-saving techniques and products. Solar energy has gained significant popularity in the country as a viable solution due to its renewable nature, minimal maintenance requirements, abundant availability and reductions in greenhouse gas emissions. The following recommendations are hereby proposed;

- Energy crises in Nigeria can be reduced by improvement of supply system, creating enabling investment environment in the power sector, diversification by establishment of suitable infrastructure and raise awareness to encourage the promotion and advancement of the nation's huge supply of renewable energy resources.
- The existing energy plants and facilities need well organized routine maintenance, upgrading and replacement of outdated ones. This will require adequate budget allocation.
- More investment prospects need to be encouraged into thermal power energy provision by conversion of gas flares into a viable electricity source taking benefit from the nation's plentiful natural gas.
- Funding should be improved through private sector investment while billing and collection system should adopt electronic metering system for transparency and accountability between suppliers and consumers.
- New policies on energy efficiency need to be developed and integrated into the current energy policies which is critical in steering general public towards a more appropriate end-user practice.
- A comprehensive evaluation should be undertaken to assess the overall renewable energy capacity of the country, encompassing local characteristics across different ecological zones. This evaluation should focus on incorporating improved passive design techniques and maximizing the utilization of solar photovoltaics.
- Agricultural residues should be used to generate power, making use of biogas obtained from livestock waste and animal husbandry should be made. Biofuels should also be used as a transportation fuel, likewise wind and solar energy be utilized for purposes such as pumping irrigation supply and power for agricultural activities.

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