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Nuclear energy option as a viable means for generating 30% of cleaner and reliable electricity in Nigeria

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Abstract: The Nigerian National Energy Policy for 2015-2030 was recently ratified by the National Assembly. The Policy emphasizes the role of renewable energy as a viable option for meeting energy needs in an environmentally friendly manner. The environmental concerns associated with greenhouse gas (GHG) emissions from the use of fossil fuels for electricity generation have been one of the reasons why the Nigerian government has adopted other means to limit the use of fossil fuels. The Nigerian government has now committed, under a political mandate, that by 2030, the country should generate 30% of its electricity from clean energy sources such as wind, solar, hydro, and nuclear. Also, the current electricity supplies from the available energy sources in the country are inadequate. The generation sub-sector currently consists of 23 operational grid-connected generating plants with a total installed capacity of 10,396 MW; this capacity has been to increase to 14,000 MW in 2023 (but only 6,056 MW available). Thermal-based generation has an installed capacity of 8,457.6 MW (4,996 MW available), while hydropower has 1,938.4 MW. But most of the time, it can only send out about 4,000 MW, which is not enough for a nation with over 200 million people compared to South Africa, Egypt, and Algeria with higher generation capacity and less population. This study shows that the fulfillment of such a requirement is possible only if nuclear power plants are built in the country to generate electricity. Nuclear energy is clean and of low carbon. It is reliable and stable, and the waste, which is a major concern around the world, can be managed to international standards. Nuclear energy, by reliably providing electricity 24 hours a day, is an important part of the energy mix needed to meet electricity demand. And since there are no carbon emissions, it will remain an important source of clean energy in the future. The future energy portfolio of the Country should involve all available clean energy options, medium, and peak load renewables but well supported by nuclear base load.

Keywords: Nigerian National Energy Policy, Electricity Generation, Renewable Energy, Environmental Concern, Greenhouse Gas, Nuclear Energy.

1. Introduction

One of the great concerns of the global energy business is that a major oil exporter like Nigeria suffers from chronic power shortages, and indeed, the world's tenth-largest oil exporter and Africa's largest economy has a grid capacity of around 6,000 MW [1]. Despite five domestic refineries, Nigeria imports 75% of the petroleum products consumed domestically, and suffering from years of mismanagement, lack of investment and general neglect, Nigeria's domestic energy industry has consistently failed to meet consumer needs. Huge investment is needed to meet Nigeria's Sustainable Development Goals (SDGs), commitments and its political goal of becoming one of the world's top 20 economies by 2030, as set out in Vision 2030 as adopted. According to Power Africa [2], Nigeria has large reserves of oil, gas, hydro, and solar energy and has the potential to generate 12,522 MW of electricity from existing power plants. On most days, Nigeria can only distribute about 4,000 MW, which is not enough for a country of over 200 million people [3].

Nigeria is famous for oil and gas as they are the largest African exporter; however, electricity generation is grossly inadequate, with only 56 - 59% of the population having access to electricity. Nigeria has one of the lowest per capita energy consumption rates in a selection of African nations, with 145 kWh, compared to Ghana (351 kWh), Côte d'Ivoire 275 kWh, Angola 312 kWh, Kenya 164 kWh, South Africa 4198 kWh, etc. In terms of transmission infrastructure, Nigeria is likewise behind South Africa, Botswana, and Kenya. Higher transmission voltages in these three nations result in reduced system losses. Ghana a neighbouring smaller country has 4,710 MW of reliable electricity generation with 85.9% access to its population against Nigeria with 57% access in 2021. Only 56% of the city's population uses electricity, while a staggering 64% of the rural Nigerian population has no access to electricity [4]. Egypt's installed electricity generation capacity in 2021 was approximately 60,073 MW, making it one of the highest in Africa with 100 percent access for a population of about 80 million people. Also in 2021, South Africa's installed electricity generation capacity was approximately 58,095 MW with 89.30% access for a population of approximately 60 million people. These two countries, with economies similar to Nigeria, produce and distribute about 15 times more MW than Nigeria, which has almost three times the population. The government has set itself the ambitious goal of achieving universal access by 2030, and in order to achieve this goal, huge investments in the energy sector must be made; they are currently looking at renewable energy and nuclear power to achieve this goal [5]. The need for renewable energy and nuclear energy in the country's energy mix is clear to cope with economic development and provide a solid foundation for Africa's first economy [6]. The government's intention for these energy sources has already been stated as Nigeria wants to generate 30% of its energy from renewable sources by 2030. The same applies to nuclear energy as it is considered a reliable and sustainable alternative to fossil fuels.

Solar thermal energy has been used for decades in agriculture for food preparation and preservation. In 2016, the

Nigerian President opened the country's first solar power plant in Ibadan. As of December 2017, the Nigerian federal government has invested $20 million in solar projects across the country. The climate, resources, and economic and social conditions of Nigeria have made solar energy a suitable alternative source of energy. The northern part of Nigeria has the highest potential for solar energy. In addition to sufficient power output, solar energy will help the country reduce carbon emissions from fossil fuel energy production. Furthermore, solar energy can provide a reliable and stable source of energy both in cities and elsewhere and can also mitigate oil-related resource conflict [7]. In December 2020, the federal government of Nigeria entered into a partnership with local solar company Energy, which had raised over $9 million in foreign investment to increase solar electrification in Nigeria. Nigeria's energy policy highlights the importance of solar energy in the country's energy mix. Based on this, Nigeria intends to increase the supply of renewable electricity from 13% of total electricity generation in 2015 to 23% in 2025 and 36% by 2030. The policy incorporates provisions on renewable energy and energy efficiency activities into government policy statements and plans and thus recognizes the importance of creating an enabling framework for private investment in renewable energy and energy efficiency. The Nigerian government's Solar Power Naija initiative, which aims to roll out 5 million new solar-powered connections by the end of 2023, highlights how difficult it is to quickly scale renewable energy solutions. The program intends to increase access to electricity for 25 million people, providing electricity to just 28% of Nigerians who currently do not have access. Solar energy is an abundant renewable resource that can be used to generate electricity. While there are many benefits to using this resource for energy, there are also disadvantages. Solar energy is expensive for both individuals and large corporations. The systems are also weather dependent and inefficient in some locations. As a result, they are not as reliable as other alternatives for meeting energy needs consistently and reliably [6]. Solar power systems also require a huge amount of space to operate for large-scale use and emit some of the most potent greenhouse gases. While renewable electricity generation technologies such as solar have great potential, we still have a long way to go before they can be effectively and efficiently deployed on a large scale [7].

Despite the complexity and cost, nuclear power has distinct advantages for the Nigerian government over other sources of energy. First, nuclear power will provide basic electricity generation at relatively stable prices, avoiding the inherent price fluctuations of petroleum products [6]. Secondly, a reduction in domestic demand for oil will lead to an increase in foreign exchange earnings from the oil industry. Third, the reliance of much of its generating capacity on natural gas from the Niger Delta has put Nigeria's energy stability at the mercy of militants in the region and the recurring problems with natural gas supplies may also be related to the government's failure to price natural gas at cost-reflective levels, which encourages gas flaring and waste. Nuclear power will reduce the country's dependence on the unstable Niger Delta to meet its energy needs [3, 6]. Nuclear power would contribute to national energy self-sufficiency by reducing Nigeria's total dependence on fossil fuels and water resources from neighbouring states [3, 6-7]. In Africa for example, South Africa has two operating nuclear reactors with a total net capacity of 1.9 GW and is the only African country that currently generates electricity from nuclear power. But a number of other African countries are currently pursing nuclear power. The list includes Algeria, Egypt, Ghana, Kenya, Libya, Morocco, Namibia, Niger, Nigeria, Senegal, Sudan, Tanzania, Tunisia, Uganda, Zambia and lately, Rwanda.

Based on the information available, it is clear that Nigeria is in the second phase of the IAEA's three-phase Nuclear Power Program Evaluation System. Nigeria has made a political decision to develop nuclear power and is currently undertaking preparatory work for the complete feasibility studies and to lay the groundwork for a possible bid for and construction of a nuclear power plant. It has adopted policies to build human and regulatory capacity but is not yet ready to accept calls for construction. There is still significant work to be done before Nigeria reaches the second milestone and moves into the construction phase with regards to the NAEC Strategic Plan.

Energy production and use account for about three-quarters of global CO_2 emissions, of which power plants and thermal power plants account for about 40%. Moreover, global electricity demand is ready to rise in the coming decades [6]. Thus, the transition from fossil fuels to low-carbon electricity generation is the key to reducing a significant share of emissions and mitigating climate change through increased use of nuclear, hydro, wind, and solar energy.

2. Current Electricity Generation in Nigeria

Nigeria, as one of the largest economies on the continent, has a significant installed capacity of over 13.5 GW. Compared to the country's peak demand of 8.25 GW, generation should be able to adequately meet national demand. However, in 2019, the available capacity was only 3.7 GW. National electrification accounts for 60% of the population, leaving millions of households without access (See Figure 1). The residential subsector consumes almost 60% of the total electricity generated, followed by commercial and utility services, which account for another quarter [4]. Tariffs are low compared to many countries in the region, ranging from €4.5/kWh to €6/kWh. Tariff increases scheduled for the second quarter of 2020 were pushed to the first quarter of 2021 due in part to the COVID-19 pandemic, and implemented in 2023. Peak electricity demand is expected to rise to 15 GW by 2025 as more of the population seek to have access to electricity as the economy grows. The government has set a target of 90% electrification by 2030, which will be met by an ambitious target of 45 GW of installed capacity in the same year [8].

The country is part of the Economic Community of West African States and part of the West African Power Pool (WAPP), a specialized agency of the Economic Community of West African States (ECOWAS), which includes the 14 countries of the regional economic community. WAPP was initiated to promote and develop electricity generation and transmission infrastructure, as well as coordinate the exchange of electricity among ECOWAS member states. Currently, Nigeria supplies electricity to the Republic of Benin, Togo and Niger.

Nigeria's average power generation increased by 8.6 per cent year-on-year to 3,970.33 megawatts (MW) in July 2023 from 3,655.64 MW recorded in the corresponding period of 2022, which is still low compared to its needs. Nigeria is currently one of the underpowered countries in the world, with actual consumption of 80% below expectations based on current population and income levels. Self-generation is extremely common in Nigeria; Small diesel and gasoline generators have a capacity of about 14 GW, and almost half of all electricity consumed is self-generated, meaning there is a huge gap in demand. Given this, we can assume that the demand gap in Nigeria is significant, although exactly how much is debatable. According to Statista, Nigeria topped the list of countries with the longest average annual downtime in Africa in 2018, with 4,600 hours. This is 3,200 hours more than the next country on the list, Niger. In the 2019 World Bank Enterprise Survey, unreliable electricity supply is the top constraint for nearly 40% of companies in sub-Saharan Africa. In 2018, a typical Nigerian firm experienced more than 32 power outages.

The Energy Commission of Nigeria (ECN) leads strategic planning and national policy coordination. It has strong representation from the ministries of energy, commerce, science and technology, foreign affairs, and finance, among others. This puts it in a strategic position to ensure cooperation between ministries with a direct mandate and other powers that can indirectly influence the management of the energy industry. Over the past 45 years, Nigeria's electricity generation has varied from gas, oil, and hydropower to coal-fired power plants [7]. Currently, hydropower systems and gas installations predominate in the structure of the energy balance. Gas-fired power plants has locations in the southern region of the country, while hydroelectric power plants are located in Jenna, Kanji, and Shiroro [3]. The electricity generation sector is run by privatized generating companies (Gen-Cos), independent power producers (IPP), and generating stations under the National Integrated Power Project (NIPP) [3]. Currently, the total installed generating capacity is 12,800 MW (see Table 1) [6].

Table 1. Installed capacity, peak, and average hourly generation 2010-2020 (Nigerian transmission data).

Year	Installed capacity (MW)	Peak generation (MW)	Average Hourly Output (MWh/h)
2010	8460.40	3804.30	2856.16
2011	8910.40	3804.30	2856.16
2012	9995.40	4518.00	3366.69
2013	10915.40	4458.20	3382.19
2014	11165.40	4389.70	3439.04
2015	12132.40	4883.90	3597.60
2016	12317.40	5074.00	3248.06
2017	12324.40	5222.30	3595.43
2018	12910.40	5190.90	3843.72
2019	12974.40	5375.00	3818.38
2020	12974.40	5520.40	4043.37

Source: Orumo et al. [6]

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The dams at Kainji, Shiroro (in the state of Niger), and Jebba (in the state of Kwara) are the primary sources of hydroelectric power. About four-fifths of the nation's electricity is produced by thermal plants powered by coal and natural gas, which are located near Afam, Sapele, Lagos, and the Oji River. The cretaceous Anambra Basin is the source of coal production, which reaches Okigwe in the south and Dekina in the northern portion of the Benue state basin. Over 70% of the country's population lives in rural and peri-urban areas and depends on biomass and petroleum fuel wood for over 90% of their home energy needs. A disproportionate dependence on natural gas causes generating to be concentrated in the south. Inter-regional transmission therefore becomes essential to supplying demand. Important routes for the transmission of power are those in the north, including Kwara, Kogi, and Niger, which border areas where gas is produced. Niger State is the greatest electricity exporter, mostly to states in the North-West, due to its huge hydro generation and closeness to the gas-rich South-West. Although they lessen the region's dependency on imports, the availability of hydroelectric power in Taraba and coal plants in Bauchi and Gombe is still crucial for supplying domestic demand. Although a cost-optimal electricity system may be achieved by strategically concentrating power infrastructure, investment, and jobs, this is unlikely to be practical given Nigeria's political environment, which requires the equal distribution of economic resources across geopolitical zones. There are 1481 active wells and 159 oil fields in Nigeria, as reported by the Department of Petroleum Resources. The coastal Niger Delta Basin, often known as the "South-South" zone, has 78 of the 159 oil fields in the Niger Delta and is the most producing area in the country. Nigeria ranked ninth in the world with natural gas reserves of around 300 cubic feet, the largest of which was held by Imo State out of all the Nigerian states.

In addition, problems with the gas supply, lack of water, problems with the National grid, and breakdowns are blamed for the limitation of production. According to country energy records, “Nigeria’s energy consumption in 2018 mainly consists of gas-fired electricity (85%) and hydropower (15%).” This shows how much Nigeria is dependent on fossil fuels, which are very polluting and prone to pipeline sabotage. More recently, however, the Electricity Authority has generated electricity through a combination of both thermal (gas) and hydro systems. All electrical, distribution, and substations are interconnected in a special way by a transmission network, commonly known as the national network (grid). Figure 3 shows the share of electricity production by various sources in Nigeria as it is dominated by gas currently [4].

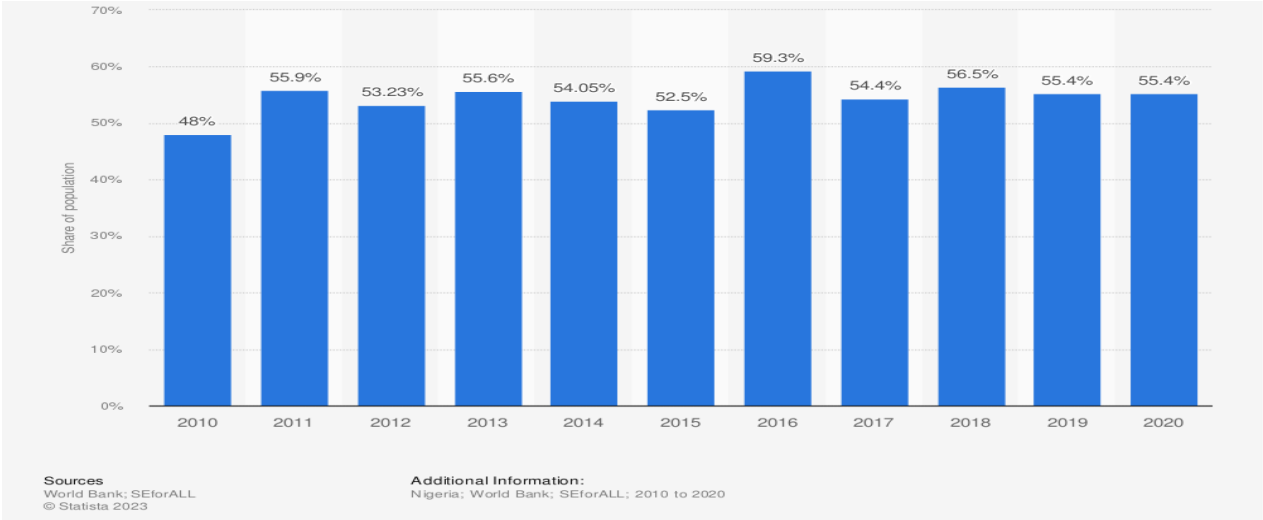

Figure 1. Share of population with access to electricity in Nigeria during 2010-2020.
Source: Orumo et al. [6]

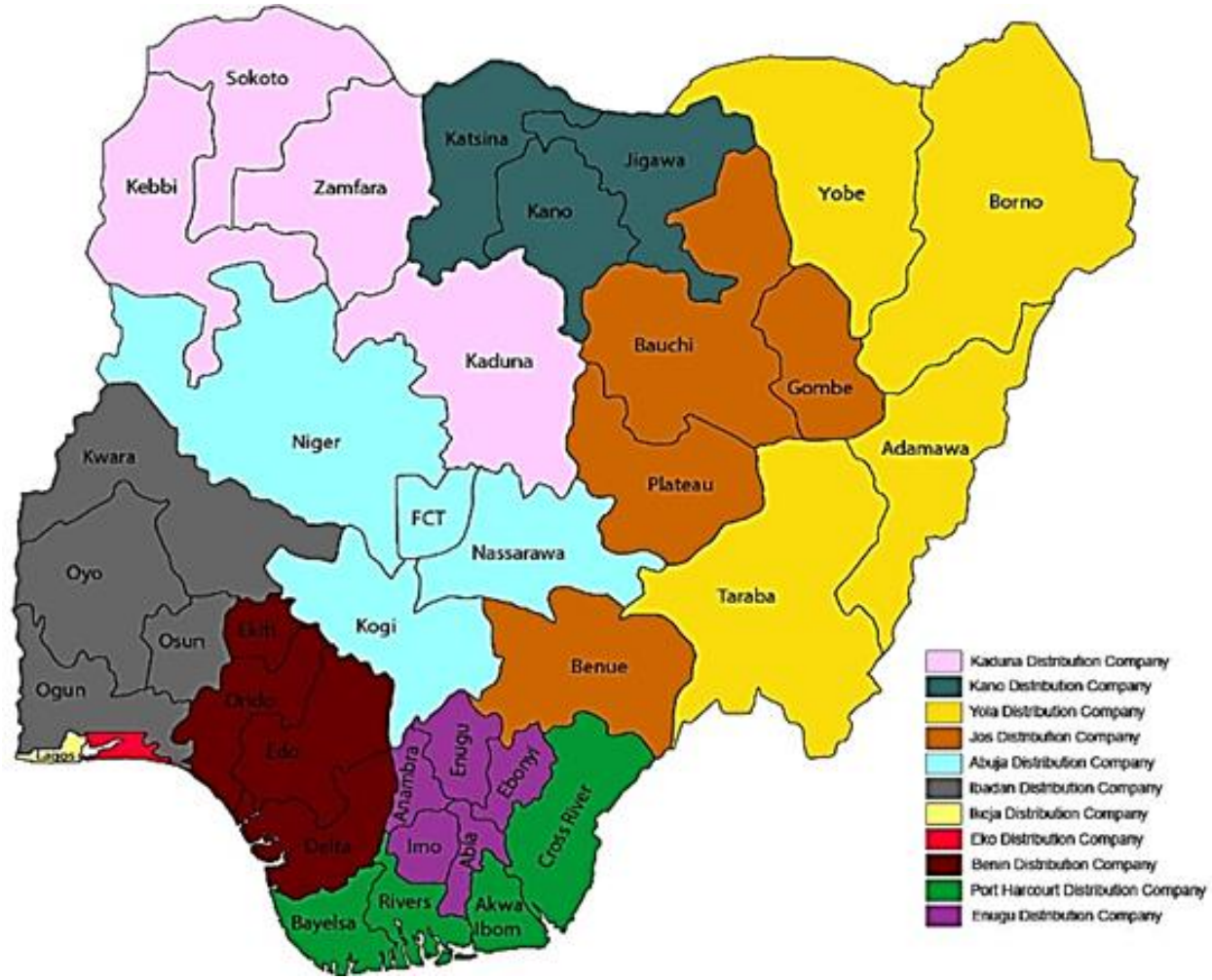

Figure 2. Coverage areas of distribution companies in Nigeria.
Source: http://nerc.gov.ng

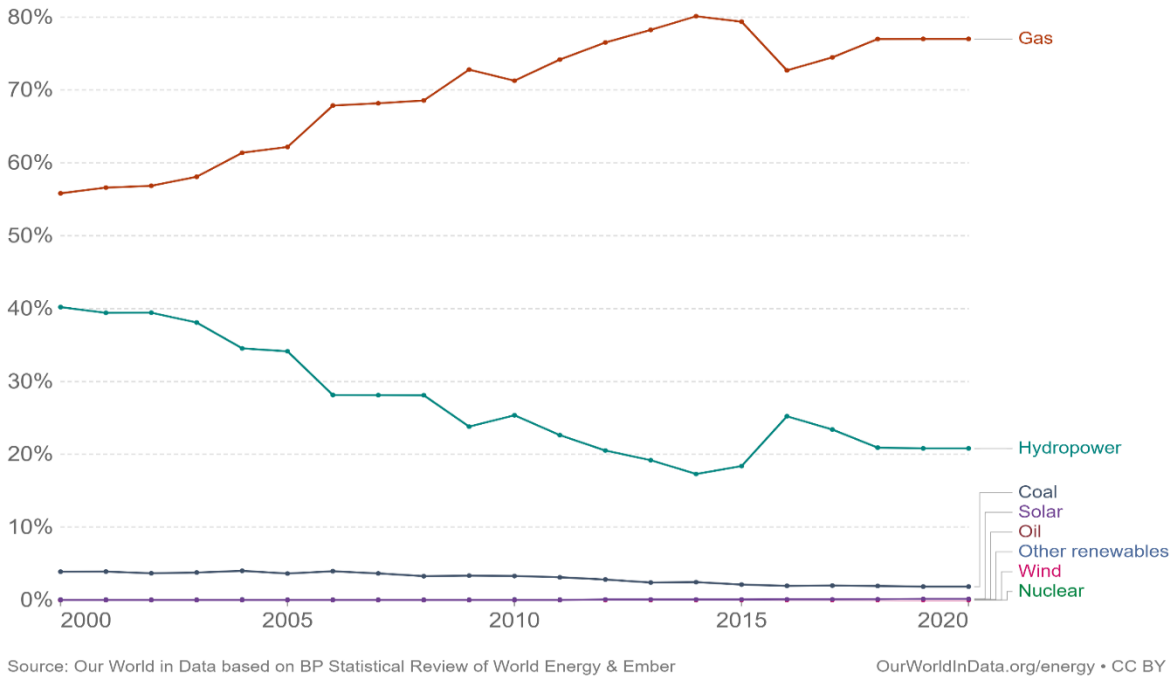

Figure 3. Share of electricity production by source in Nigeria.
Source: Ritchie et al. [4].

3. Current Status of Nuclear Energy and Recent Developments

Nuclear technology uses the energy released when atoms of certain elements are split. It was first developed in the 1940s, and during World War II research was initially focused on making bombs. In the 1950s, attention shifted to the peaceful uses of nuclear fission, controlling it to generate electricity. Currently, civilian nuclear power boasts over 18,000 reactor years of experience, with nuclear power plants in operation in 32 countries around the world [9-10]. In fact, through regional transmission networks, many other countries are partly dependent on nuclear energy; Italy and Denmark, for example, get almost 10% of their electricity from imported nuclear energy. When the commercial nuclear industry was born in the 1960s, there were clear boundaries between the industries of East and West. Today, separate American and Soviet spheres no longer exist, and the nuclear industry is characterized by international trade. A reactor being built today in Asia may have components supplied from South Korea, Canada, Japan, France, Germany, Russia, and other countries. Similarly, uranium from Australia or Namibia could end up in a reactor in the UAE after being converted in France, enriched in the Netherlands, reconverted in the UK, and fabricated in South Korea. Nuclear technology also helps control the spread of disease, helps doctors diagnose and treat patients, and supports our most ambitious space exploration missions [3]. These diverse uses have placed nuclear technology at the center of the world's efforts to achieve sustainable development [9-10].

About 10% of the world's electricity is generated by about 440 nuclear power reactors. About 55 more reactors are under construction, equivalent to 15% of the existing capacity [10]. In 2020, nuclear power plants supplied 2,553 TWh of electricity, compared to 2,657 TWh in 2019. Until 2020, electricity generation from nuclear energy has been increasing for seven consecutive years. Thirteen countries produced at least a quarter of their electricity in 2020 from nuclear power. France gets about three-quarters of its electricity from nuclear power, Slovakia and Ukraine get more than half from nuclear power, and Hungary, Belgium, Slovenia, Bulgaria, Finland, and the Czech Republic get one-third or more. South Korea typically gets more than 30% of its electricity from nuclear power, while in the US, UK, Spain, Romania, and Russia, about one-fifth of its electricity comes from nuclear power [10-11]. Japan has grown accustomed to relying on nuclear power for more than a quarter of its electricity and is expected to return to around that level. Russia has 37 operating nuclear reactors with a total useful capacity of 27.7 GW. In 2020, nuclear power produced 20.6% of the country's electricity. A 2016 government decree provides for the construction of 11 nuclear power reactors by 2030, in addition to those already under construction [10-11]. The strength of the Russian nuclear industry is reflected in its dominant position in the export markets for new reactors. The country's national nuclear industry is currently involved in new reactor projects in Belarus, China, Hungary, India, Iran, and Turkey, and to varying degrees as an investor in Algeria, Bangladesh, Bolivia, Indonesia, Jordan, Kazakhstan, Nigeria, South Africa, Tajikistan and Uzbekistan among others [10-11].

The performance of nuclear reactors has greatly improved over time. Over the past 40 years, the proportion of reactors achieving high power factors has increased significantly. For example, 66% of reactors achieved a power factor above 80% in 2020 compared to less than 30% in the 1970s, while only 9% of reactors had a power factor below 50% in 2020 compared to just over 20% in the 1970s. In addition to commercial nuclear power plants, there are about 220 research reactors operating in more than 50 countries, and more are being built and used for research and education, medical and industrial isotope production. More than 160 ships, mostly submarines, are powered by approximately 200 nuclear reactors [10-11]. Russia also operates a fleet of large nuclear-powered icebreakers and is building more [12]. It also connected a 32 MW twin-reactor floating nuclear power plant to the grid in the remote Arctic region of Pevek [12]. In 2021, nuclear power delivered safe, reliable, low-emission electricity generation in the face of evolving global crises, according to annual data released by the IAEA Power Reactor Information System, ranking second in annual production in the past decade as the world emerged from the COVID -19 pandemic. Further in 2021, nuclear power reactors generated 2,653.1 TWh of low-emission, dispatchable electricity, slightly more than in 2020, representing about 10% of the world's total electricity generation. The Middle East and South Asia showed the largest growth, generating 20% more electricity from nuclear power plants than in 2020. For the second year in a row, China produced more electricity than France, making China the second largest producer of nuclear power after the United States. Also, nuclear power generation in Eastern Europe was the highest in a decade, 6% more than in 2020 and about 15% more than in 2010. Overall, nuclear power generation has shown steady and commendable growth in recent years, up more than 13% since 2012 [10-11].

In Nigeria, the Federal Government of Nigeria has set a target of generating 4,800 MW of nuclear power between 2027 and 2030 [1]. To achieve this goal, Nigeria has already begun the process of acquiring nuclear technology, as they have signed an intergovernmental agreement (IGA) with Rosatom (Russia) to build and operate nuclear power plants, as well as the Multipurpose Research Reactor Complex (MRRC), which will house a nuclear research reactor [6-7]. The MRRC can stimulate new technology industry platforms, agricultural exports, regional investment climate, and job creation. Rosatom is expected to build four nuclear power plants with a total capacity of 4,800 MW, which will cost about $20 billion. Nigeria as seen is cooperating with the IAEA to assess its nuclear readiness, as the IAEA conducted two missions in 2015 to verify Nigeria's readiness and compliance with its framework [6-7]. In addition, another mission took place in July 2017, leaving the team to be optimistic. Potential sites selected by the government for the nuclear power plant are Itu in Akwa Ibom State and Geregu in Kogi State [6-7] with other nuclear facilities in five locations across the country (See Figure 4). The agreement with Rosatom will be based on a Build-Own-Operate-Transfer (BOOT) model although is still being reviewed, with Rosatom expected to hold majority of the equity.

In addition, various State Governments like Imo, Kogi and Ekiti States have entered into agreements with international partners for nuclear energy developments in their states. The government of Imo State has signed an agreement with the US Company Barnett Holding Co to evaluate potential sites in Owerri the state capital for 5-20 MW modular reactors. The Chinese Government is partnering Kogi State and Ekiti State in Nigeria for nuclear energy technological development. China (by delegations from China National Nuclear Cooperation CNNC in August 2022) had expressed its willingness to explore viable areas of partnership, with an interest in nuclear energy in Nigeria and Kogi State in particular, to establish one of its two Proposed Nuclear Power Plants (NPP) in the state. Their main interest is to promote investment as well as the use of nuclear technology for the benefit of Nigeria and in particular Kogi State, believing that nuclear energy will further attract investment to the state, improves its infrastructure, improve its tax revenue, create jobs and attract significant social economic changes. The Chinese Government had also pledged to establish a department of Nuclear energy at the Confluence University of Science and Technology, Osara in Kogi State and other institutions as part of plans to nurture local breed in the nuclear field, adding that the Kogi government should similarly encourage and facilitate some of its young

Engineering talents for exchange programmes in China. The Chinese Government had also assured the Ekiti State Government of their willingness to work with the State to develop a Knowledge Zone Project on the use of nuclear science and technology in the development of critical sectors of the state. The Ekiti State's partnership with the China National Nuclear Corporation (CNNC) is seen as a technology collaboration that will promote an understanding of how to use nuclear energy peacefully for the benefit of the people of Ekiti State.

4. Mitigation of Greenhouse Gases Using Nuclear Energy for Electricity Production

Nuclear energy is an environmentally friendly energy source with near zero emissions [9]. It generates energy through fission, which is the process of splitting uranium atoms to produce energy. The heat released from the fission is used to create steam that turns a turbine to generate electricity without the harmful by-products of fossil fuels. The United States avoided more than 471 million metric tons of carbon dioxide emissions in 2020, according to the Nuclear Energy Institute (NEI) [10]. This is the equivalent of taking 100 million cars off the road and more than all other clean energy sources combined. It also keeps the air clean by removing thousands of tons of harmful air pollutants every year that contribute to acid rain, smog, lung cancer, and cardiovascular disease [6, 9-10]. Despite producing massive amounts of carbon-free energy, nuclear power produces more electricity on less land than any other source of clean air. A typical 1,000-megawatt nuclear plant in the United States needs just over 1 square mile to operate. According to the NEI, wind farms require 360 times more space to produce the same amount of electricity, and solar PV plants require 75 times more space. To put this into perspective, there would be a need of over 3 million solar panels to produce the same amount of power as a typical commercial reactor, or over 430 wind turbines (without regard to power factor). Also, nuclear fuel is extremely dense [11]. This is about 1 million times more than other traditional energy sources, and therefore the amount of nuclear fuel used is not large [9, 11]. All of the spent nuclear fuel produced by the US nuclear industry over the past 60 years is still within a depth not more than 10 yards, and these wastes can also be recycled.

Greenhouse gas (GHG) emissions and their implications for climate change have sparked global interest in understanding the relative contribution of the electricity industry [9, 13]. Accordingly, the world emits approximately 27 gigatonnes of CO_2 equivalent from various sources, while electricity generation accounts for 10 gigatonnes or approximately 37% of global emissions. In addition, the demand for electricity is expected to grow by 43% over the next 20 years. This significant increase will require the construction of many new power plants and will provide an opportunity to build these new capacities in a way that limits greenhouse gas emissions. Nuclear power emits about 30 tons of CO_2e/GWh, which is 7% of the emission intensity of natural gas and only 3% of the emission intensity of coal-fired power plants (See Figure 5). In addition, the GHG emission intensity over the life cycle of nuclear power is consistent with renewable energy sources including biomass, hydropower, and wind (See Figure 5), but with the advantage of having higher power factors and availability, and thus can be used as a source of electricity for base load [9, 11-18].

Total life cycle GHG emissions from renewable energy and nuclear energy are much lower and generally less variable than from fossil fuels as shown in Figure 5.

As earlier stated, the Nigerian government had set a goal of generating 30% of its electricity by 2030 using clean energy sources such as wind, solar, hydro, and nuclear power [8, 15-18]. Considering that only nuclear power can actually be used entirely as a producer's base electricity [18], it is clear that the goal cannot be achieved unless renewable sources are used. In addition, the low power factors and availability of other renewables like wind energy as a viable option will require the installation of thousands of wind turbines and thus the introduction of clean energy strategies to feed electricity into the grid and find mechanisms with alternatives as soon as the wind stops blowing in some wind farms. Also, the costs to be invested in renewable energy, energy storage development, and research are significant and very high which will have an impact on the Nigerian economy, hence the consideration of nuclear energy mix as the best option. While it is necessary to have a strategy that includes renewable sources in the energy portfolio, it is also clear that without the construction of nuclear reactors in the country [18], the goal of 30% of its electricity using clean energy sources by 2030 may be unattainable.

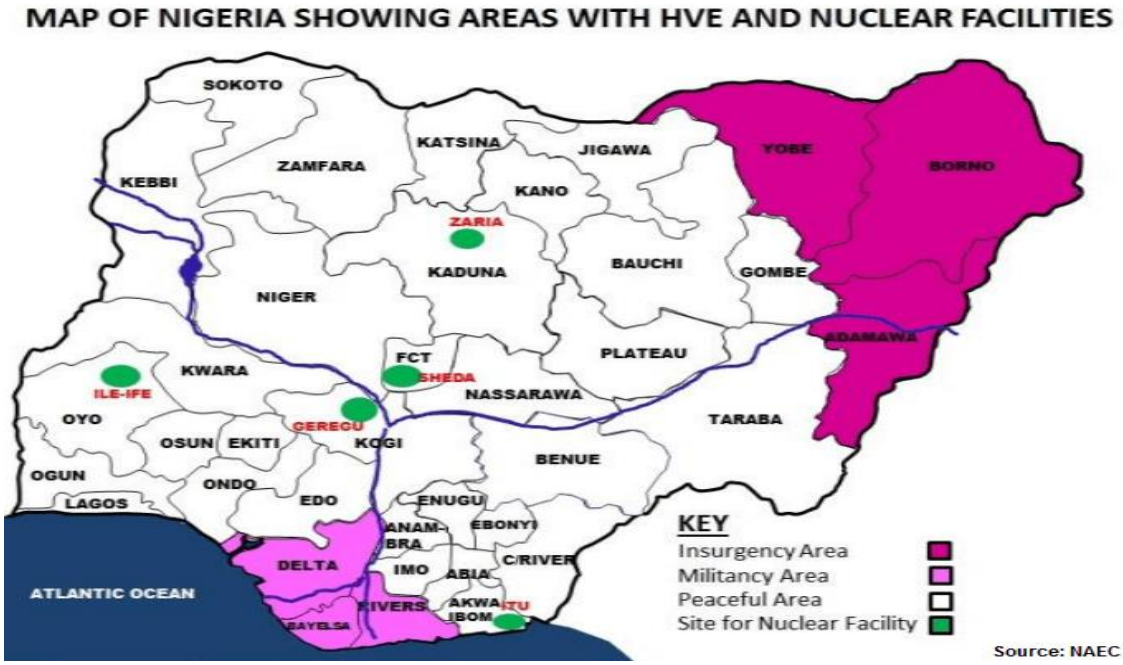

Figure 4. Location of nuclear facilities in Nigeria.
Source: https://nigatom.gov.ng/

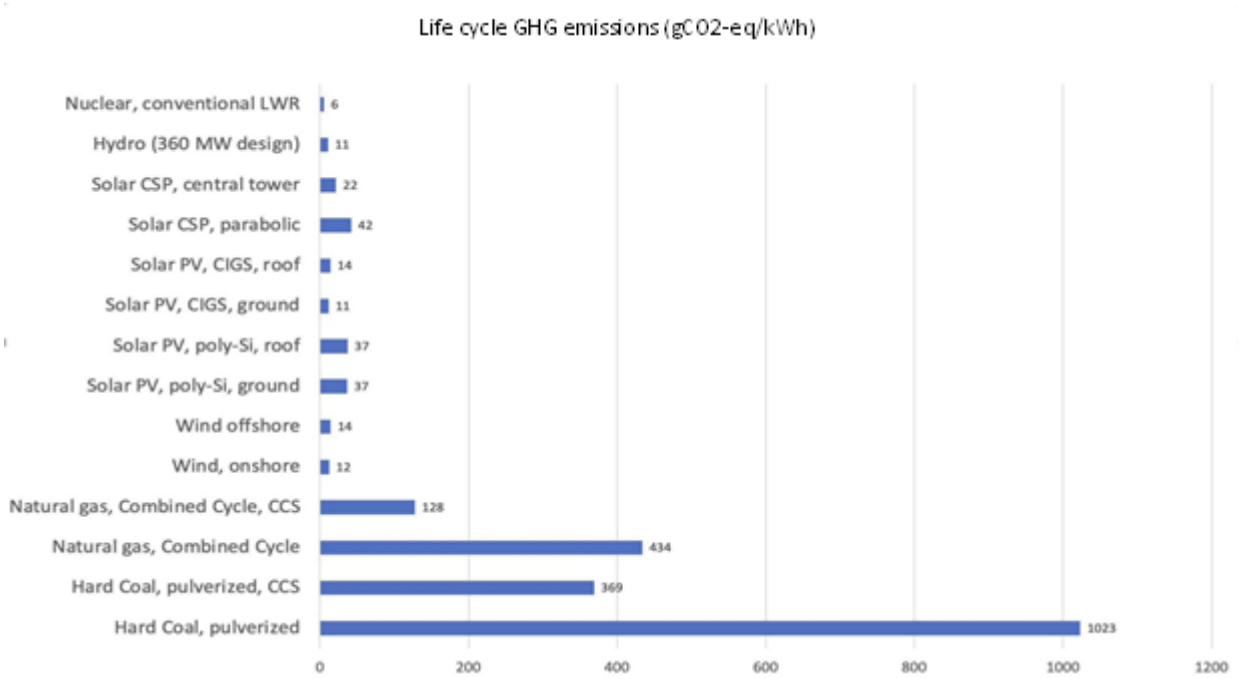

Figure 5. Life cycle greenhouse gas emissions intensity of various electricity generation methods.
Source: Ritchie et al. [4].

5. Conclusion

Nuclear power is a sustainable source of energy, which has been demonstrated even during the pandemics, which already provides one - third of all low-carbon electricity. With technological and scientific advances in the use of nuclear energy, it is seen that nuclear power can play a significant role in the clean energy transition, helping countries to meet both climate and developmental goals. The application of nuclear power for electricity generation would help Nigeria to meet the goal of 30% of clean energy sources by 2030.

Overall, with a strong push for a more diversified sector and a stronger grid in Nigeria, the future looks bright. One example of this commitment is the agreement between the Nigerian government and Siemens to implement a roadmap to address challenges in Nigeria's energy sector. According to the Bureau of Public Enterprise BPE in 2019, the deal is structured in three phases. The first phase will focus on implementing projects that will significantly improve electricity supply in Nigeria in a short period. The goals are to provide an additional 2 GW to the network, significantly reduce and control losses, and achieve improved network stability and reliability. The next phase will aim to bring the system's operating capacity to approximately 11 GW, while the third phase will involve increasing system capacity to 25 GW over the medium to long-term planning period, with associated upgrades and expansion of the generation, transmission and distribution.

Under the current conditions and without the inclusion of nuclear energy, it seems impossible to achieve what the Nigerian Government has legally declared in its energy policy for the socioeconomic development of the country. Strong economic viability needs nuclear energy as a baseload for all developmental indices. Nuclear power had delivered safe, reliable, low-emission electricity generation in the face of evolving global energy crises, according to annual data released by the IAEA Power Reactor Information System overall, nuclear power generation has shown steady growth in recent years, up more than 13% since 2012. A suitable electricity portfolio in Nigeria should consider nuclear power along with all other renewable forms of energy. The success of the net zero emission plan in Nigeria requires comprehensive planning of Nigeria's entire energy system, taking into account various sources of clean energy, particularly nuclear energy, which will help provide efficient, reliable, emission free, and cost-effective energy for socioeconomic development and poverty reduction.

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