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Review article

Performance evaluation of the prospects and challenges of effective power generation and distribution in Nigeria

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A B S T R A C T

Effective Electric Power Generation and Distribution result in the overall increase in efficiency in an economy. Nigeria generates 4500 MW for a population of 200 million people; hence, more than 50% of the population has no electricity access, and those with access experience power outages. Inasmuch as Nigeria is blessed with a vast amount of renewable energy sources, the country heavily relies on Natural Gas for power Generation. With regards to Power Generation, it is seen that the Power Generated is not evacuated efficiently. The purpose of this study is to access the growth of the Nigerian Power Sector from 1898 till date. This is achieved by evaluating the Power Sector Reforms enacted by different government to analyze their effectiveness. Furthermore, the study reviews strategically research that have discussed the strengths and weakness of the Nigerian Power Sector to be able to suggest hidden opportunities and reveal threats to the attainment of sustainable energy for all in 2030. Some of the Challenges discovered were energy user challenges, financial challenges, and energy losses. Some solutions and opportunities are the use of distributed generation, smart meters and the implemented of a smart grid system. In the long run, the authors propose that viable renewable energy sources in each State of the federation be tapped for Power Generation this would enable each State to the self-reliant and contributors to the Nigerian Power Generation Pool. It is believed that this actions would promote economic, social and technological benefits for the every stakeholder.

1. Introduction

Electric power supply is an essential need by residential, industrial and commercial consumers. The journey to sustainable electric power supply in Nigeria has been a long, somewhat strategic, yet uneventful process; as most of the electric power supply targets have been left unsatisfied. The generating system capacity of Nigeria remains erratic and unreliable and cannot meet the increasing load demand. The power sector has gone through a lot of restructuring, but the efforts do not seem to affect the power supply to users.

Even though the first electric utility company in Nigeria, Nigerian Electricity Supply Company (NESC), was established in 1929, electricity generation started in 1896 [1,2]. Between that time and the year 2000, the state-owned company called National Electric Power Authority (NEPA) was in charge of generating, transmitting, and distributing electricity across Nigeria [3]. The company had two (2) hydro and four (4) thermal power plants and operated as a vertically integrated utility company.

In 2005, the Electric Power Sector Reform (EPSR) and the Nigerian Electricity Regulatory Commission (NERC) were established

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[4]. Also, the Power Holding Company of Nigeria (PHCN) was created from the then-existing NEPA, and 18 more companies were created; this included six (6) generation, eleven (11) distribution, and one (1) transmission company [5].

The Nigerian Bulk Electricity Trading (NBET) company was incorporated on July 29, 2010 [6]. NBET purchases electricity from the Generating companies and sells it to the Distribution Companies. The privatization and unbundling of the Nigerian Power sector occurred in November 2013; this included the privatization of all generation, and distribution companies while the transmission company remained in the control of the Federal Government. The 11th distribution company was privatized in November 2014. This act also created the Nigerian Electricity Regulatory Commission (NERC) as an independent sector regulator [7].

Nigeria's overdependence on non-renewable energy sources for electric power generation may be doing more harm than good for the country's electricity generation plans. Fig. 1 shows a chart detailing the consumption patterns of different energy sources in Nigeria. It shows that fuelwood constitutes the greatest percentage of energy use in Nigeria. Fuelwood is typically used in rural communities with little or no access to electric power supply. Apart from Fuelwood, Nigeria's electric power supply is obtained from Petroleum products, Natural Gas and Hydropower [8]. Table 1 shows the details of the current electrical power generators in Nigeria, it shows the installed capacity and the amount of generation available for each generator from 2017 to 2020.

Various administrations have made countless efforts to transform the power sector, which has been highlighted as a necessity for Nigeria's transformation. Even with the frantic restoration agendas undertaken after the total generating capacity dropped to less than 1900MW in the year 2000 (leading to the reform) and the reform act itself, the country has still not provided an uninterrupted power supply to its citizens [9].

Reasons for the reform include capital scarcity (as the government lacked funds for the power sector expansion making the private sector the next best option), economic inefficiencies due to losses, overstaffing, debt, non-payments, which made investors lose interest. In addition, tax subsidies to make up for these power sector financial shortfalls were becoming a burden. Persistent energy poverty ensued as the unreliable and inefficient power sector refuted growth and development. Privatization and reform were expected to be the best option to transfer these debts and deficits that the power sector had accumulated from unpaid tariffs and political favors to private firms [11].

Nigeria is rich in oil reserves accounting for up to 18 billion barrels. It has a promising economic future if it can make adequate changes to its power sector to encourage investors. Nigeria is at its breaking point in terms of power. Look at an example of Poland with just about 37 million people and producing up to 46,000 MW compared to Nigeria's less than 4500 MW for more than 200 million people. The sector degenerated to this point due to neglect during the military era, aging plants, and facilities left unmaintained for years [12].

Nigeria's economic growth measured by GDP cannot improve significantly if the rate of electricity generation continues at the current rate. Over the years, Nigeria has suffered from capital flight has many multinational industries and business take up residence in other neighboring countries to protect their investments. The efficiency of electric power sector in Nigeria has been mitigated by unlawful connections, frequent outages, unsettled tariff by consumers, estimated billing by the power utility [9].

The Nigerian power sector has undergone various reforms, which can be seen as unsuccessful. More research is needed to understand what problems hinder effective power generation and distribution in Nigeria and what could be done to minimize these hindrances such that the turnaround efforts in the sector would yield effective results. .

Nigeria is the most populous nation in Africa (more than 200 million) but has a generating capacity that is far below required (between 3500 MW and 5000 MW) [8]. Although having the largest economy in sub-Saharan Africa, Nigeria has one of the lowest values in terms of energy access. In terms of access to electricity, reference [13] stated that Nigeria has an overall electrification rate of 50–60%. Also, between 77 and 90% of rural communities do not have access to electricity [14]. Nigeria's installed capacity is 13,000 MW with 4500 MW generated consisting of natural gas 82.4% and 17.6% hydro. The current electricity supply system in Nigeria benefits urban communities while rural areas have little or no access, thus limiting economic growth [15].

Post power sector reform, Nigeria adopted privatization for power generation and distribution sectors. This ought to boost the generating capacity and engender competition for better performance but has worsened it to become far less than half of the available capacity [16]. The vast resources for energy production are being underutilized, which accounts for the sector's inefficiency. The

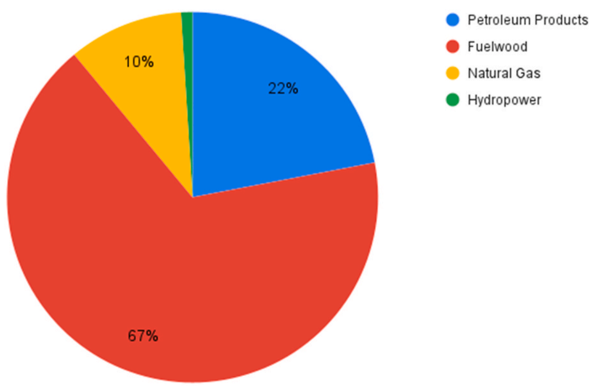

Fig. 1. Percent energy consumption in Nigeria (2013). Adapted from [10].

Table 1
Generating capacities of the current Nigerian electric power generators.

NCC. No	Name of Station	Company	Primary Energy Resource	Commercial Operation Date	No. of Units	Gross Unit Capacity (MW)	Gross Plant Capacity (MW)	Grid Connection Substation	2017	2018	2019	2020
1	Kainji -G 5-6	Power Holding Company of Nigeria	Hydro	1968	2	120	240	Kainji	0	240	240	240
1	Kainji -G 11-12	Power Holding Company of Nigeria	Hydro	1976	2	100	200	Kainji	100	200	200	200
1	Kainji - G 7-10	Power Holding Company of Nigeria	Hydro	1978	4	80	320	Kainji			80	160
5	Sapele	Sapele Power PLC	Steam	1978	6	88	528	Sapele	140	250	400	400
7	Afam IV - GT 13-18	Afam Power PLC	Gas	1982	6	75	450	Afam	0	0	150	150
2	Jebba	Power Holding Company of Nigeria	Hydro	1983	6	101.15	606.9	Jebba	506	607	607	607
4	Egbin	Egbin Power Plc	Steam	1985	6	220	1320	Egbin	880	1320	120	120
3	Shiroro	Shiroro Hydro Electric	Hydro	1990	4	150	600	Shiroro	450	600	600	600
6	Delta IV - GT 15-20	Transcorp Power LTD	Gas	1990	6	99	594	Delta	526	630	630	630
6	Delta II - GT 3-8	Transcorp Power LTD	Gas	2002	6	24	144	Delta	79	123	123	123
7	Afam V - GT 19-20	Afam Power PLC	Gas	2002	2	138	276	Afam	0	0	0	276
22	Ebute Barge (Cyrex) AES	AES/CYREX Energy LTD	Gas	2002	9	31	279	Egbin	0	0	0	0
6	Delta III - GT 9-14	Transcorp Power LTD	Gas	2005	6	24	144	Delta	84	128	128	128
18	Okpai IPP	Nigerian Agip Oil Company	Gas	2005	2	165	330	Agip to Onitsha	300	300	300	300
18	Okpai IPP	Nigerian Agip Oil Company	Steam	2005	1	140	140	Agip to Onitsha	140	140	140	140
23	Omoku IPP	First Independent Power	Gas	2006	6	25	150	Independent to Ofitsha	150	150	150	150
8	Geregu FGN 1	Gerugu Generation Company LTD	Gas	2007	3	138	414	Geregu	414	414	414	414
9	Omotosho I	Omotosho Electric Energy Company	Gas	2007	8	42	336	Omotosho	304	304	304	304
10	Olorunsogo I	Pacific Energy	Gas	2007	8	42	336	Papalanto	335	335	335	335
19	Afam VI - GT 11-13	Shell ROT	Gas	2009	3	166	498	Afam	450	450	450	450
20	Ibom 1	Ibom Power	Gas	2009	1	42	42	Ikot Abasi	0	0	0	0
19	Afam VI - ST 1	Shell ROT	Steam	2010	1	230	230	Afam	200	200	200	200
20	Ibom 1	Ibom Power	Gas	2010	1	114	114	Ikot Abasi	114	114	114	114
24	Trans-Amadi IPP	First Independent Power	Gas	2010	4	25	100	Omoku	25	100	100	100
12	Sapele Ogorode 1 NIPP	NIPP	Gas	2011	4	113	452	Sapele	113	454	454	454
14	Olorunsogo II NIPP	NIPP	Gas	2011	4	120	480	Papalanto	240	240	240	240
14	Olorunsogo II NIPP	NIPP	Steam	2012	2	120	240	Papalanto	120	120	120	120
15	Omotosho II NIPP	NIPP	Gas	2012	4	120	480	Omotosho	240	240	240	240
25	Rivers IPP	First Independent Power	Gas	2012	1	191	191	Omoku	191	191	191	191
11	Geregu NIPP 1	NIPP	Gas	2013	3	148	444	Ajaokuta	220	220	220	220
13	Alaoji - NIPP	NIPP	Gas	2013	4	120	480	Alaoji	480	480	480	480
17	Ihovbor (Eyanen) NIPP	NIPP	Gas	2013	4	113	452	Benin North	339	339	339	339
16	Calabar/ Odukpani NIPP	NIPP	Gas	2015	5	113	565	Calabar	38	338	338	338
20	Ibom 1	Ibom Power	Gas	2016	1	40	40	Ikot Abasi	0	0	0	0
27	Gbarain - GT 2 NIPP	NIPP	Gas	2016	1	113	113	Yenegoa	113	113	113	113
28	Paras Energy	Paras Energy and Natural RES. DEV. LTD.	Gas	2016	9	9	81	Ikorodu-Shagamu	79	79	79	79

overdependence on natural gas and hydro limits the possibilities of the sector becoming reliable.

The reform was seen to be attractive as other countries adopted this same reform and had better results. There ought to then be a change in the country's power generation and distribution capacity, but several problems are still faced in the effective generation and distribution of power. This study seeks to review the reform process, highlight key challenges the sector faces in the generation and distribution of power and propose suggestions for effective power supply in the country. The research seeks to provide answers to the following research questions (RQ):

RQ 1. - What was the status of the Nigerian Power Generation and Distribution System before and after the Electric Power Sector Reform of 2005?

RQ 2. - What are some solutions to the perceived weaknesses and challenges of the current Power Generation and Distribution landscape that could threaten and hinder the growth of the Power Industry in Nigeria?

RQ 3. - What are the strengths and opportunities of the current Power Generation and Distribution landscape in Nigeria that could promote possible economic, social and technological benefits?

2. Methodology

The aim of this study is to use an integrative review process to access and analyze the discourse in literature on the strengths, weakness, opportunities and threats (SWOT) that exists on the Nigerian Power Generation and Distribution landscape [17]. The purpose of integrative reviews is to help the development of new perspectives and frameworks from the critique, evaluation and recombination of literature on a topic of interest [18,19]. In this research, a four staged approach would be explored as suggested by Ref. [18], (i) designing the review, (ii) conducting the review, (iii) conducting the analysis, and (iv) writing up the review.

To situate the progress in this research area, a detailed search of one of the widely used databases Scopus was carried out, Scopus was used to identify and curate research development in the field. Scopus was developed by Elsevier in 2004, although its coverage period starts in 1996 [20]. Scopus is the database of the choice of literature analyzes due to many advantages listed in Refs. [21–24]. A search in the Scopus database was performed using the article title, abstract, and keyword fields. The search parameter was developed thus:

(TITLE-ABS-KEY (strength) OR TITLE-ABS-KEY (weakness) OR TITLE-ABS-KEY (opportunit*) OR TITLE-ABS-KEY (threat) OR TITLE-ABS-KEY (challenges) OR TITLE-ABS-KEY (prospects) OR TITLE-ABS-KEY (solutions) OR TITLE-ABS-KEY (issues) AND TITLE-ABS-KEY ("Power generation") OR TITLE-ABS-KEY ("Power distribution") AND TITLE-ABS-KEY (nigeria)).

The publications reviewed in the article were exported on May 30, 2022. The publications reviewed are limited to Journal and conference papers. The inclusion criteria adopted in this research centered around research that fulfilled the following (i) the studies must discuss either the challenges, issues or problems with the Nigerian Power Generation and Distribution sector, (ii) the studies must also discuss the prospects, solutions and opportunities present in the Nigerian Power Generation and Distribution sector, (iii) only studies published in English were considered. Also, the authors search google scholar for research articles not indexed in Scopus. The snowball technique was employed to retrieve information from the citations of the primary studies.

The remaining sections (3–5) discusses which of the research questions identified in Section 1. A detailed analysis and discussion of each of the research themes in presented in each section. Section 6 concludes the topics and provides insight to strategies that could facilitate the attainment of sustainable energy for all in Nigeria in 2030.

3. RQ 1 – status of the Nigerian Power Generation and Distribution System before and after the power sector reform of 2005

The power sector of Nigeria has gone through a number of restoration agendas, termed as reforms. This section seeks to review the sector before the reform, its current state, and its reform.

3.1. Before the Nigerian Power Sector reform (1898–2005)

In 1898 electrical power was introduced to Nigeria, with the installation of the first power-producing plant by the British government. The plant consisted of 2 generator sets [16], and the body set up to run the plant was named the Public Works Department (PWD). The Electricity Corporation of Nigeria, tasked with producing, transmitting, distributing, and purchasing energy, was formed in 1950 [25].

In 1929, a hydropower plant was built in Plateau state, thus permitting the Nigeria Electricity Supply Company (NESCO) to commence operation. The first 132 kV line connecting the Ijora power station to the Ibadan power station was erected in 1962. The Nigeria Dams Authority (NDA) was also established, by the act of parliament, with the construction of the Kainji hydropower plant [26].

NESCO had the authority to produce power in some locations in the country. NDA had the duty to install and maintain dams and other works on the River Niger, and any other location, which produced energy using hydropower, improving and promoting fish brines and irrigation. The NDA produced hydro-based electricity and sold it to the Electricity Corporation of Nigeria (ECN) for distribution and sales at standard voltages [27].

Initially, electricity was provided to only government structures and housing such as European quarters (later Government

Reserved Areas, GRAs) but was later broadened to all houses. With the increasing population of Nigeria, the electricity supply became a necessary commodity as its demand arose. Thus, through Decree No. April 24, 1972, the Federal Military Government integrated ECN and NDA to establish the National Electric Power Authority, NEPA [28]. It is interesting to note that at this time of formation, the maximum demand was 390MW, and the proposed energy supply was 1030MW [29].

The ECN, which was mainly set up to handle distribution and sales, was incorporated with NDA, which dealt with power generation and transmission. The objective for this union was to grant the authority for electricity generation, transmission, and supply to one body, thus allowing adequate use of the human, financial and other resources accessible to the electric industry all through the country [30].

In 1973, NEPA became functional and merged power generation, transmission, and distribution [31]. It began with just the four power stations of Ijora, Delta, and Afam thermal stations and Kainji hydropower station. This has a combined total installed capacity of 532.6 MW, which supplies about 2 million people. This expanded to 5,958MW in the year 2000 with the construction of more power stations, i.e., Jebba and Shiroro hydropower stations, Egbin, Sapele, and Delta thermal power stations between the late 70s and early 80s. An increase in tariffs led to the partial commercialization of NEPA to draw investors to the sector [25].

It can be seen from Table 1 that there is variation between the installed and available capacity many of the power plants. This shows that even from the onset, the initial time of installation of these plants, the available capacity could not meet up with the installed capacity.

The period that came after was defined as the period of critical electricity dilemma due to the inability of NEPA to meet the increasing population and thus increasing demand for energy supply. During this period, the additional plants that were constructed in response to the increase in demand were unable to meet up. The existing infrastructures were not properly maintained, so the total installed capacity was never met, which caused a strain on the facilities. These numerous challenges stimulated the power sector reform [32,33].

3.2. The Nigerian power sector reform of 2005

From the inception of the fourth republic in 1999–2000, the distressing energy-generating status of the country led the Federal Government of Nigeria (FGN) to carry out the vigorous restoration of energy infrastructures between 1999 and 2004 which was regarded as Infrastructure Rehabilitation phase of the reform. A dominant aspect of this phase is the National Integrated Power Project (NIPP), launched in 2004 to boost electric power generation capacity by establishing natural gas power stations in the country [34].

Before 1999, the power sector had not seen significant investment in infrastructure expansion for more than two decades because, at the time, no new plants were built, and those that were built were not properly maintained, resulting in a dreadful state of affairs in the electricity sector. In 2001, generation dropped from roughly 5,600MW installed capacity to an average of approximately 1,750MW, despite a load demand of 6,000MW. In addition, less than half of the installed generating units were operational [27].

This drove the Obasanjo-led government to develop a new power policy that was supported by the national council on privatization and authorized by the federal executive council in 2001. This prompted the formation of the Electric Power Sector Reform (EPSR) Act, which was later legislated on March 11, 2005 [35]. The ESPR had the following goals: to achieve complete deregulation of the power industry within two years, thus disintegrating NEPAs monopoly, providing adequate electricity production and distribution to customers, and making the sector more attractive to investors, thus aiding national development [36]. Some highlighted motives driving the reform are: (i) to eliminate the hindrances of NEPA and transform the exclusive energy provider into an adequately coordinated sector, (ii) provide opportunity for the creation of small and medium enterprises by stimulating private sector involvement, (iii) reduce the number of lives lost due to fires caused by candle lights and generating sets, (iv) induce shifts from cities to rural areas by providing sufficient electric power in the rural areas for processing farm goods, and (v) facilitate job creation for Nigerian youths [37].

The power sector reform encompassed revamping and privatization. The declaration of the Bill into law paved the way to commence the legal separation of NEPA into successor companies, the creation of an independent regulatory agency and the Initiation of a Consumer Assistance Fund to guarantee systematic and objective utilization of subsidies to the less privileged [38].

Thus, NEPA was revoked, and the Power Holding Company of Nigeria (PHCN) was set up. The Electric Power Sector Reform (EPSR) Act enabled Independent Power Producers (IPPs), allowing private companies to be involved in power generation, transmission, and distribution. The government restructured PHCN into 11 electricity distribution companies (DISCOs), one transmission company (TCN), and six generating companies (GENCOs). The act also established an independent regulator for the sector, and the body was named the Nigerian Electricity Regulatory Commission (NERC) [39]. The Nigeria Electricity Regulatory Commission (NERC) is charged with the responsibility of (i) Standardizing tariffs and improve the quality of service (ii) Supervising the processes of the industry to improve productiveness (iii) Proper administration by the regulating authorities (iv) Authorization of Generation, Distribution, Transmission, and Sales companies that emanate from the restructuring of NEPA (v) Acting as a legal body to incorporate special conditions in licenses (vi) Acting with the general public's interest in mind when creating policies on fuel supply, energy sustenance, environmental law, supervision and allocation of scarce resources, improvement of energy supply, and advancement in renewable energy, and reporting data and news and (vii) Rendering a lawful ground necessitates enabling legislation for setting up, modifying, implementing, and coordinating technical and market regulation [40,41].

In 2007 President Yar'Adua augmented the reform in conformity to the goals of the EPSRA 2005 to boost energy generation, transmission, and distribution by first announcing depression in the sector. Thus, directing resources to boost the critically low energy generation to a higher level, thereby improving national development [37]. This process was curtailed, and the privatization process was put on hold [38]. After the two-year break in the reform process from 2007 to 2009, the new administration of President Jonathan resumed the reform process and, in August 2010, initiated the Power Sector Roadmap [34]. This was in response to public desire for a genuine and prompt increase in supply. The FG then established the Presidential Action Committee on Power (PACP), which was led by the President and included the majority of the market's decision-makers. At the same time, a Presidential Task Force on Power (PTFP) was established to carry out the PACP's day-to-day tasks. The Task Force was made up of technocrats and experts from the industry.

The Presidential Action Committee on Power (PACP) was formed to eliminate "red-tape", bring about coherence to policy, and penetrate bureaucracy in judgment and policy execution by major shareholders in power. The Presidential Task Force on Power (PTFP) was then formulated for the daily designing, modification, and advancement of the Reform agenda for the Nigerian Power sector, which was the Electric Power Sector Reform Act (EPSRA) constituted in 2005 [42].

The PTFP created a Roadmap (published in August 2010) to accelerate the power sector reform program, enhance service delivery in the short term, and set medium to long-term supply targets for the country. Accelerating the power sector reform program entailed: (i) taking steps to remove barriers to private sector investment, which is a major reform objective and will be done by adopting an adequate pricing framework and establishing a bulk trader, NELMCO, and other key bodies that support the sector's commercial sustainability and (ii) developing techniques and time frames for sales of the asset for PHCN Successor Companies. Enhancing service delivery in the short term involved: identifying supply shortages, creating short, medium, and long-term goals for bridging the gaps and identifying projects that can help close the gap.

The country's estimated medium to long-term supply targets were an estimated 14,212MW generation capacity and 9057MW distribution capacity by December 2013. It is evident that asides from the establishment of bodies to control the sector, that is, to still leave some government control in the supposed privatized sector, the other goals and proposed estimates of the reform failed to be met. Section 3 will highlight challenges the reform has faced that limited the resuscitation of the power sector.

3.3. *Current status of the Nigerian Power Generation and distribution sector*

A breakdown of the current state of the sector was given by Ref. [43], in terms of;

a) Electricity generation: the nation, notwithstanding the alleged investments in the sector, still experiences restrictions to a constant power supply with frequent outages. The power supply still has not met up with demand as only about 65% of the 30 installed power-producing plants are functional [27].
b) Capacity usage: pre-reform, the total installed capacity was about 6200MW with a majority of power utilization rate from hydro plants than thermal plants due to insufficient gas supply. Also [44,45], showed that as of 1999 (pre-reform), the installed capacity was at 5888MW with a net generation of 1761.6 MW, while in 2009 (post-reform), installed capacity was 6210MW and net generation was 1829MW. This signifies that the sector is performing far below standard even after the reform.
c) Energy diversity: shown in the variety of fuel sources used for power generation, ranges from hydro, coal, and natural gas. The reform stimulated the building of various plants, and this is also suitable for the differences in the nation's geography [46]. However, the sector still relies on just hydro and steam plants
d) Electricity demand: This is sectored into residential, industrial, and commercial. The industrial sector accounts for about 20.1%. A decrease in demand occurred due to the irregular power supply, which caused small companies to stop operation and the larger companies to depend more on private means of energy production. The residential sector accounts for about 55%, and an increase in demand was experienced due to the rise in population.

As of 2018, the Federal Government has mostly dismantled its hold on the six GENCOs, with Afam, Egbin, and Ughelli power stations having a 100% privatization status. Sapele power station was 51% [30], while 60% of its ownership in the eleven (11) DISCOs now belong to the private operators. The Transmission Company is still a sole body under government [47].

The government financed additional power stations in Omotosho (335MW), Geregu (414MW), Papalanto (335MW), Alaoji (346MW), and Delta III (150MW) with assistance from the Chinese business partners. Also, to support and offer monetary and skill-based aid to several operators in the rural areas, the Rural Electrification Agency of Nigeria (REA) was set up [48]. Some of the milestones achieved by the Electric Power Sector Act are [49]:

i. NEPA was altered to PHCN Plc. as a holding company for the resources, liabilities, workers, entitlements, and duties of NEPA [33].
ii. On May 5, 2005, the PHCN incorporation procedure was completed, and the first transfer of these assets and liabilities from NEPA to PHCN was on July 1, 2005.
iii. The independent industry regulator, NERC, was commissioned in October 2005.
iv. The 6 GenCos, 1 TransCo, and 11 DisCos were launched in November 2005.
v. The market and industry rules to direct the activities of the electric sector were authorized by NERC in 2008.
vi. The committee to easily nullify the operations of PHCN was set up on April 12, 2011, and called the Liquidation Committee.
vii. Market codes for grid, distribution, performance, metering, and other services have been published.
viii. Nigeria Bulk Electricity Trading (NBET) Co Plc and Nigerian Electricity Liability Management Company (NELMCO) have been established to carry on the bulk trading and liability management activities in the transition period.
ix. In 2006, the government set up and endorsed the Rural Electrification policy, but its activities were discontinued in 2009.
x. It is working with PTFP to define how the sector will operate when it is privatized.
xi. On July 1, 2006, the successor companies acquired PHCN's assets, liabilities, and staff, allowing them more operational independence.

In 2019, President Muhammadu Buhari set up the Electrification Roadmap of the power sector, which entailed a merger between Nigeria and Germany to build up the capacity of the sector.

The Electrification roadmap for the Nigerian power sector was prepared with a special focus on priority projects in the power sector. The Bureau of Public Enterprises (BPE) represented Nigeria's goals, and Siemens represented Germany's goals in this project. There are three stages to this project;

i. The first stage will focus on implementing projects that would considerably boost Nigeria's energy supply in a short amount of time. The objectives are to add 2 GW to the grid, significantly reduce Aggregate Technical, commercial, and collection Losses (ATC&C losses), and improve system dependability and stability.
ii. The system's operational capacity will be increased to roughly 11 GW in the second stage.
iii. The system's capacity will be raised to 25 GW in the third phase, including improvements and additions in the generation, transmission, and distribution throughout the medium to long-term planning period.

Following the signing of this agreement, the stage that follows would be to begin comprehensive commercial talks with the distribution companies and the Transmission Company of Nigeria (TCN) to determine the level of financial participation and the mechanism for making cash available to follow the roadmap.

Not much can be said about the achievement of the goals of this roadmap currently. However, the term of the current administration still has some years to go to improve the power sector, but there is little confidence by the public in the reality of these proposed estimates being accomplished.

3.4. Analysis of the current Nigerian Power Generation and distribution data

Currently, the generation sector of Nigeria consists of the privatized generation companies (Table 2), the Independents power producers (IPPs), and the National Integrated Power Project (NIPP). This makes up total of 23 grid-connected generation plants (operational) which is made up of a total installed capacity of 10,396 MW (available capacity = 6056 MW) with thermal and hydropower plants having an installed capacity of 8457.6 MW (available capacity = 4996 MW) and 1938.4 MW (available capacity = 1060 MW) respectively.

In addition to these power generation plants, the Federal Government incorporated the Niger Delta Power Holding Company (NDPHC) in 2004 to manage the National Integrated Power Projects (NIPPs) as seen in Table 3. By ensuring infrastructure construction in generation, transmission and distribution, and the natural gas supply sub-sectors.

The NDPHC is expected to add ten (10) new generation plants to the grid. The ten plants are currently at different levels of completion. 4774 MW would be added to the grid via the NIPP power stations. Some of these NIPP plants have been privatized, while others await interested investors.

Nigeria targets 40,000 MW generating capacity by the year 2020. An approximate $10 billion per annum would need to be spent over the next ten (10) years. The Nigerian generation and load buses are provided in Tables 4 and 5.

The Federal Government of Nigeria manages the Transmission Company of Nigeria (TCN). It was incorporated in November 2005 and Issued a transmission license on July 1, 2006 [53]. Its activities include electricity transmission, system operation, and electricity trading. Power generated by the generation companies is evacuated to the transmission infrastructure to the distribution companies.

The theoretical wheeling capacity of high voltage substations in Nigeria is about 7500 MW, spanning about 20,000 KM of transmission lines. In the true sense, the transmission infrastructure can evacuate 5300 MW of electricity. The current generation capacity is 3878 MW, while the installed capacity is about 12,522 MW. Nigeria's power system infrastructure is a radial system void of redundancies, making the entire system unstable and unreliable. An approximate loss of 7.4% occurs on the transmission lines; this is relatively high when compared to the developing economies average of 2–6%.

In Nigeria, the power system structure is made up of standard high voltage transmission line voltages of 330 KV, 132 KV and 33 KV. The transmission landscape is shown in Fig. 2.

There are eleven (11) distribution companies (DISCO) in Nigeria. The Companies are Kaduna DISCO, Kano DISCO, Yola DISCO, Jos DISCO, Abuja DISCO, Ibadan DISCO, Ikeja DISCO, Eko DISCO, Benin DISCO, Port Harcourt DISCO and Enugu DISCO as seen in Fig. 3.

The low voltage or distribution line voltage are 33 KV, 11 KV and 415V. The distribution line supply power directly to the consumer's premises through the service mains at 220 V (Single Phase) or 415 V (Three Phase).

Table 2
Privatized generation companies in Nigeria.

s/n	Generating Company	Installed Capacity MW)	Type of Generation	Privatization Status
1	Afam Power Plc	776	Gas	100% Sold
2	Sapele Power Plc	414	Gas	51% Sold
3	Egbin Power Plc	1020	Gas	100% Sold
4	Ughelli Power Plc	900	Gas	100% Sold
5	Kainji Power Plant	760	Hydro	Long Term Concession
6	Jebba Power Plant	578	Hydro	Long Term Concession
7	Shiroro Power Plc	600	Hydro	Long Term Concession

Source [50]:

Table 3
National Integrated Power Projects (NIPP) plants in Nigeria.

s/n	State	Location	Installed Capacity (MW)
8	Abia State	Alaoji	1074
9	Edo State	Benin (Ihovbor)	451
10	Cross River State	Calabar	563
11	Imo State	Egbema	338
12	Bayelsa State	Gbarain	225
13	Kogi State	Geregu	434
14	Ogun State	Olorunsogo	1056
15	Ondo State	Omotosho	451
16	Rivers State	Omoku	225
17	To Confirm	Sapele (Ogorode)	452

Source [50]:

Table 4
Nigeria's generation buses [51,52].

Bus Number	Bus Name	Bus Number	Bus Name	Bus Number	Bus Name
1	Egbin GS	6	Kainji GS	11	Afam GS
2	Olorunsogo GS	7	Geregu GS	12	AES
3	Omotosho GS	8	Sapele GS	13	Omoku
4	Shiroro GS	9	Delta GS	14	Egbema
5	Jebba GS	10	Okpai GS	15	Calabar

Table 5
Nigeria's load buses [51,52].

Bus Number	Bus Name	Bus Number	Bus Name	Bus Number	Bus Name
16	Jebba	22	Jos	28	Onitsha
17	Benin	23	Gombe	29	Alaoji
18	Birnin Kebbi	24	Yola	30	New Haven
19	Ikeja West	25	Katampe	31	Sakete
20	Kano	26	Ajaokuta	32	Ayede
21	Kaduna	27	Akangba	33	Osogbo
34	Ganmo	40	Lokoja	46	Damaturu
35	Aja	41	Aliade	47	Maiduguri
36	Aladja	42	New Haven South	48	Owerri
37	Ikot-Ekpene	43	Makurdi	49	Erunkan
38	Port Harcourt	44	Eyaen	50	Gwagwalada
39	Papalanto	45	Alagbon	51	Ikot-Abasi
Bus Number	**Bus Name**				
52	Jalingo				

Table 6 details the Energy generated and energy sent out from the Nigerian Power Generation companies from 2017 to 2020. Table 7 compares the MYTO allocation for each distribution station to the actual consumption by each DISCO.

The data for 2017 reveals that the energy generated in most of the GENCOs is not representative of the installed capacity for the GENCOs. In addition, some plants. Such as Dadin Kowa, Azura-Edo, Alaoji NIPP, ASCO, and AES had not commenced operation.

At the end of 2018, the energy situation remains the same: the energy transmitted is less than what is generated. However, the Azura-Edo power station saw a boost in energy generation.

The energy situation worsened in 2019, with the energy generated being more than what is transmitted and more plants barely generating any amount of energy. The energy situation in 2020 improved a bit compared to 2018, but there was no change in the losses incurred in sending out energy.

In general, it can be seen that a common factor has existed through the years. This is because the energy generated is not transmitted efficiently. In addition, some plants have not been able to produce energy through the years.

The objective of the survey analysis carried out is to deduce the common challenges faced in both generation and distribution of power in Nigeria as reported in literature. These common challenges will be referred to as "key" challenges are Customer/energy user challenges, financial challenges (investments and billings), and Energy losses.

Majority of the literature reviewed identified specific challenges which seem to be repeating. This enables a ranking of the challenges in order of occurrence. This will be done to focus on obtaining solutions to certain repeating challenges that will be later be termed as "key" challenges in power generation and distribution in this research work.

In Table 8, the most important challenges facing the Nigerian Power Generation Sector as evidenced by literature is Poor

Fig. 2. Electric Power Transmission landscape in Nigerian (Source: [53]).

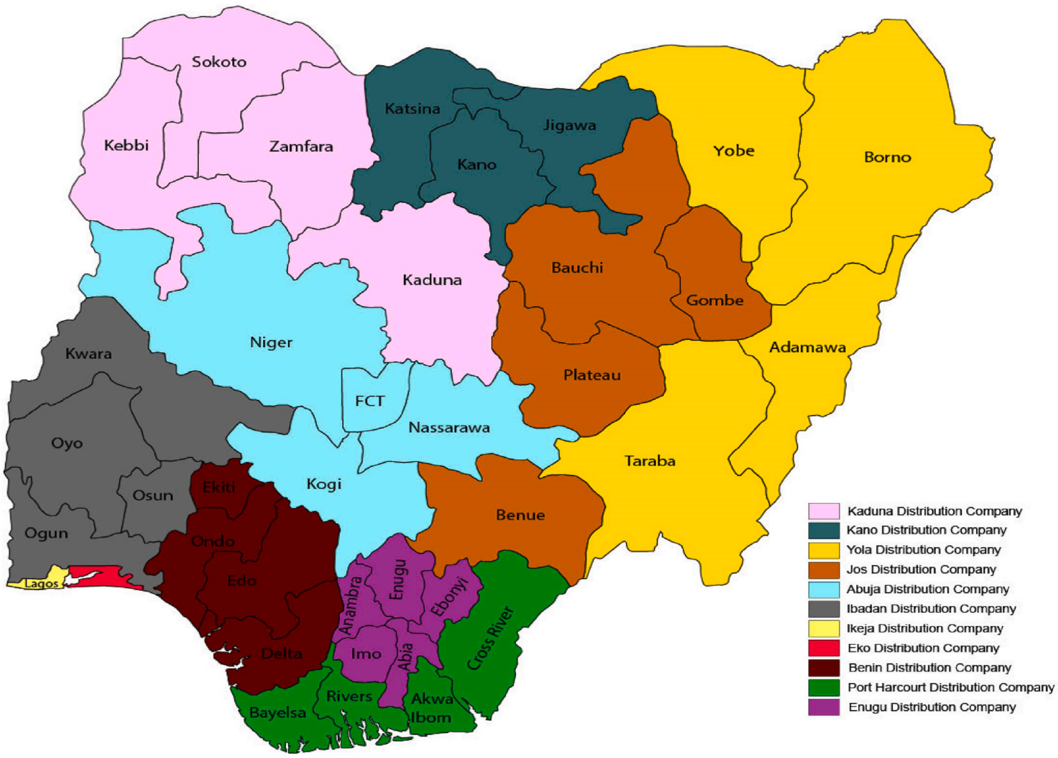

Fig. 3. Electric power distribution landscape in Nigeria (source: [54]).

Table 6
Energy generated and sent out per year (2017–2020).

Generation Station	2017		2018		2019		2020	
ST	EG	ESO	EG	ESO	EG	ESO	EG	ESO
Kainji	355.71	350.04	391.32	380.7	403.75	383.09	362.55	353.28
Jebba	287.5	278.52	384.51	373.69	397.92	387.06	356.66	346
Shiroro	187.98	170.5	273.22	252	394.51	373.3	331.11	329.89
Dadin Kowa	0	0	0	0	0	0	17.34	15.14
Egbin ST 2-5	474.29	449.62	306.73	288.9	537.76	508.88	651.87	622.3
Egbin ST 6	136.49	125.96	133.03	126	0	0	0	0
Sapele	0	0	32.71	30.82	7.87	6.06	50.76	47.43
Delta	441.27	432.84	372.29	365.56	283.1	262.32	278.56	264.71
Afam IV - V	48.13	40.96	22.14	22.02	20.09	19	60.99	50.49
Geregu Gas	271.05	259.89	347.25	335.93	278.64	267.5	316.31	300.24
Omotosho Gas	153.2	143.77	132.59	121.54	82.18	71.32	104.33	93.94
Olorunsogo Gas	147.56	135.76	142.37	131.22	142.25	121.18	123.9	110.57
Geregu NIPP	121.29	119.69	164.78	154.11	107.26	100.7	112.86	100.36
Sapele NIPP	168.53	157.6	73.13	62.51	2.08	2	76.05	66.25
Azura-Edo	2.64	2.12	339.78	328.68	288.98	267.96	413.69	402.32
Alaoji NIPP	0	0	13.79	12.74	12.88	10.83	0	0
Olorunsogo NIPP	143.63	131.63	30.1	20.93	13.62	11.43	1.37	1.01
Omotosho NIPP	120.59	109.08	96.89	86.57	61.77	51.22	101.4	91.2
Odukpani NIPP	203.6	200.14	97.88	80.37	278.05	266.73	338.79	327.13
Ihovbor NIPP	82.78	72.03	87.61	72.47	4.01	3.93	0	0
Okpai	244	237.54	170.45	160.35	122.78	118	152.68	147.54
Afam VI	276.04	261.99	93.57	82.1	77.93	76.64	336.93	322.21
Ibom Power	85.52	75.14	87.08	79.01	23.59	20.46	58.87	48.93
ASCO	0	0	5.85	0	0	0	0	0
A.E.S	0	0	3.91	0	0	0	0	0
Omoku	44.84	43.74	61.8	51.45	73.21	66.09	42.84	33.68
Trans Amadi	17.04	13.6	51.55	40.35	0	0	74.86	70.28
Rivers IPP	47.71	42.76	95.08	84.7	61.64	54.67	72.41	60.86
Paras Energy	59.92	57.83	65.37	54.86	38.81	35.52	53.13	50.82
Gbarain	23.9	22.4	71.64	61.11	38.07	32.71	0	0

EG – Energy Generated.
ESO – Energy Sent Out.
All Energy values are in MegaWatt (MW).

Table 7
MYTO Allocation (MA) and Actual Consumption (AC) per DISCO per year (2017–2020).

	2017		2018		2019		2020	
DISCO	MA	AC	MA	AC	MA	ESO	EG	ESO
ABUJA	667.60	410.26	481.90	424.86	431.17	426.52	483.58	464.60
BENIN	521.96	293.13	359.56	288.79	335.37	249.49	365.65	355.89
EKO	732.79	400.97	526.67	394.15	497.84	394.99	547.05	447.59
ENUGU	522.44	299.98	359.65	267.31	360.99	275.06	390.66	365.29
IBADAN	753.13	422.67	519.81	392.21	503.82	451.07	549.16	506.22
IKEJA	868.10	441.94	593.99	496.98	633.19	549.36	711.58	567.14
JOS	320.50	171.58	219.67	163.43	205.35	151.01	229.08	164.27
KADUNA	462.81	240.71	319.96	262.67	296.80	192.37	324.43	255.01
KANO	444.87	249.96	319.66	256.43	295.85	196.92	324.43	250.33
PH	392.26	278.17	287.80	205.98	241.88	209.84	272.90	235.61
YOLA	202.67	122.51	144.21	131.75	131.13	120.78	148.58	138.06

MA – MYTO Allocation.
AC – Actual Consumption.
All Energy values are in MegaWatt (MW).

maintenance of generation infrastructure, inadequate investments by the public and private investments, insufficient power supply and energy user issues. Similarly, the most important challenges facing the Nigerian Power Distribution Sector are aging facilities, customer issues, financial issues, distribution losses.

Customer and end user challenges consists of issues with billing and collection, which stems from the fact that for stable energy supply, the energy tariff will have to be set at a reasonable amount that would result into profit generation for the DISCOs. These energy charges are mostly estimated such that the users pay an unreasonable tariff even after experiencing power outages for months. This result in customers bypassing the energy meters. They may go as far as committing energy theft, such that either a third party suffers the burden of the energy bills or the DISCOs. Metering was attempted as a solution to this problem, but an insignificant increase for customers was realized. Also, customers who have paid for meters are yet to receive them and are still receiving estimated bills [39,

Table 8
Challenges of power generation and distribution in Nigeria.

Identified Challenges	[55]	[31]	[56]	[57]	[58]	[59]	[60]	[61]	[62]	[63]	[39]	[64]	[65]	[66]	[67]	[68]	[69]	[70]	[71]
Unskilled Technical staff/Poor Customer Service	P			P		P										P	P		
Poor maintenance	P	P			P	P		P		P		P							
Lack of investment/funding	P	P	P		P	P	P	P		P	P	P	P		P		P	P	P
Poor energy mix	P																		
Insufficient Power Supply		P						P		P									
Defunct Operational tools and equipment		P							P	P	P			P		P	P	P	
Limited and Outdated control and communication devices		P								P					P				
Poor exploration activities to access energy sources		P																	
Staff Dissatisfaction		P																P	
Inefficient Operation of Plant generation, transmission and distribution			P	P		P	P	P	P							P			P
Lack of responsibility/Corruption			P						P	P		P	P						P
Erratic and Incompetent government and reforms				P			P												
Consumer Issues				P	P			P	P	P									
Irregular Billing System										P									
Distribution Losses										P			P	P					
Issues with billing											P	P	P		P	P			
Illegal Connections													P					P	

72].

In addition, energy users misuse power and fail to conserve power thus causing inefficiency in generation and supply as energy is being unnecessarily wasted. Customers fail to conserve energy as seen in leaving electric equipment on when not in use. This also has adverse effects on the environment, as described in Ref. [73] that a slight increase in electricity consumed produces an even greater increase in carbon emissions. As majority of the energy source in Nigeria is fossil-fuel based, the amount of carbon emissions due to energy wastage will be considerably large.

Lack of funding is also a major challenge in the electricity sector. This may be due to energy customer's unwillingness to pay thus limiting DISCOs ability to purchase electricity from the GENCOs. It may also result from the unattractiveness of the sector to investors, where this unattractiveness is due to the corruption and illegal practices in the sector. As funding is provided but there is no evidence of it. This poses a huge problem, as no industry can run without funding and the power industry is not exempt from this. Funds are needed to carry out maintenance, as most power infrastructure is worn out and requires proper maintenance at the generation and distribution levels. Funding is also required to set up new stations and plants. Renewable energy solutions are preferred but are expensive in their startup cost, and adequate financing of every power project is necessary to avoid these projects being abandoned.

Also, this also relates to issues with the DISCOs not appropriately making use of the funding they receive, and they fail to supply energy to the users and bring bills to the users with an expectation of payment. These energy users are frustrated and will bypass payment, thus limiting the funding that can be received. If there can be a constant effective power supply, customers will be willing to pay, thus aiding the sector's funding.

This has to do with inefficient generation and distribution. Losses occur at different stages in the power system. Power is generated at the plants; the power sent out is slightly less than what was generated. NBET acquires a portion of this power, mainly due to a lack of funds, thus reducing the amount of energy to be transmitted. This power goes through losses in transmission, either technical losses or vandalism. The power received at the distribution level is thus reduced further by the financial limitations of the DISCOs. Also, at this distribution level, several losses occur, thus making the final power received by the customers to be a minor fraction of the initial power generated. This brings about what is termed as the "telescopic nature of the energy market". This implies that from the generation of energy to the customer level, the various losses reduce the energy received by the customer. It appears to have gone through a telescope when looking from the customer end.

4. RQ 3 - Strengths and opportunities of the current Nigerian Power Generation and distribution sector

An effective power generation and distribution is necessary for the economic development of any nation. Inasmuch as there are challenges in achieving this; this study has identified some strengths and opportunities of the current Power Generation and Distribution system that could translate to sustainable energy for all in 2030. The proposed solutions will be based on research and analysis as well as researcher opinions. The focus will be on minimizing the effects of the key challenges present in the generation and distribution.

The use of Natural Gas and Hydropower energy resources in Nigeria has been a feasible strategy and roadmap toward the target of achieving sustainable energy for all in 2030 [74]. However, it is important to increase the use of renewables like Solar [75–79], Wind, and Bioenergy [71,78,80–86] in the energy mix for increased power generation and supply. Studies like [87,88] have developed plans for an electrification roadmap for Nigeria for current and future power demand and generation till the year 2030. Reference [89] developed a Multi-Criteria Decision tool that would select an optimal solution to different power generation alternatives for Nigeria. These research findings conclude that the Nigerian energy mix would consist of a combination of Natural Gas and Renewables.

Reference [74] suggests that a combination of Natural gas (32,500MW), on-shore wind (7000 MW), and solar photovoltaic (12,000 MW) with an annual cost of $22B and investment cost of $48.7B would be a feasible solution to the Nigerian Power Problem. Reference [90] suggests that the best renewable configuration for the six geopolitical zones in Nigeria is the PV-Diesel-Battery configuration which provided the least Net Present Cost (NPC). Even though the Wind/Diesel system provided less NPC compared to a Diesel only system, it is not the best option because of relatively low wind speeds across the six locations studied. Nigeria is blessed with high solar irradiation and this contributes significantly to the lower NPC when compared to other solutions. With regards to Building Integrated Photovoltaics (BIPV), the authors [91] provided the economic analysis of integrating BIPV systems for studio, 3 bedroom and 4 bedroom apartments in Nigeria, it resulted into a total cost of $10,215.68, $21,654.25 and $41,507.23 respectively which consisted of module cost, inverter cost, balance of system equipment, installation labour, installer margin overhead, environmental duties, and taxes. The nominal levelized cost of electricity (LCOE) was calculated as 20 c/kWh, 6 c/kWh and 6 c/kWh respectively for each of the residences which is a significant improvement when compared to 37c/kWh that would have been paid by the residences if they had to depend on energy from fuel generators and public utility in Nigeria. Another parameter to consider is, what is the payback period for the proposed systems? The research [91] evaluated the payback period of the studio, 3 bedroom and 4-bedroom apartment to be 12.3, 12.3 and 18.2 years respectively. The life span of many Solar panels extends to 25 years. Seeing that the payback period is well beneath the life span of the solar module, the developed building-integrated solar power generating system is a feasible solution. Asides from residential building, other research [79] have also confirmed the viability of Solar powered solutions for commercial buildings.

For Biomass related solutions, the authors in Ref. [92] developed a novel hybrid system of a gas turbine cycle and a biomass/syngas in a CCHP to reduce environmental pollution and increase sustainability of the gas generation turbines being installed in Nigeria. The proposed configuration resulted into a Levelised Cost of Electricity (LCOE) of 0.13 $/kWh which either outperforms or is comparable to other cost models in literature. Nigeria has a very impressive biomass reserve. From agricultural wastes, manure, abattoir waste, municipal waste and human waste with a combined total of 181.8 million tonnes [86]. It is estimated that 270 TWh of electricity could be generated from biomass sources. In Ref. [88], the authors developed a biomass integrated multigeneration system for a rural community in Ekiti. The energy requirement for the community was estimated to be 944 kWh, the biomass system was designed to produce 969.8 kWh. On plastic wastes [81], suggests that a total of 29 GW of electricity can be generated from plastic waste in Nigeria annually. Scavenging for plastic wastes for electricity generation by the informal sector can serve a dual purpose of electricity and income generation [93]. Other authors like [85] have investigated the use of rise-husk technology has a fuel for power generation in Enugu state Nigeria. The LCOE evaluated for the developed risk-husk electric power generator was 3.6Naira/kWh, which is a significant improvement when compared to the National utility cost of 30.93 Naira/kWh. There are other States in the country with high viability for Bioenergy like Lagos, Abuja, Portharcourt. Major cities tend to produce a significant amount of municipal wastes [80–83].

The Nigerian government has to seek for both internal and external expertise on areas like demand side management [58], smart grids [68,69], metering technologies [68], cross-continental power pool project [94], fabrication and testing of electrical materials and systems [58]. Reference [58] mentioned a significant solution that has not been giving enough thought. In 2010, there was significant interest by foreign investors like Goldman Sachs, Sieman AG, Royce Rolls, JP Morgan, Suzlon Energy in investing in the Nigerian Power System ecosystem. However, due to the obvious lack of trust and the Government's inability to secure the World Bank partial Risk Guarantee and a Federal Ministry of Finance Risk Guarantee to mitigate against risk of a political nature, the proposed investments fell through. Nonetheless, it is possible that if the Nigerian political ecosystem can be more stable with progress driven leaders, we could attract the right investments for power system expansion.

Other solutions that could enhance the increase in energy access is the replacement of non-energy efficient lightbulbs with their energy efficient alternatives. A study showed that the replacement of incandescent light bulbs alone would save 69.9% of electrical energy from lighting [95]. To achieve this policies to preventing the importation of non-energy efficient lightbulbs should be implemented. Also, the manufacturing of energy efficient lightbulbs can be strengthened for job creation and in expensive access to energy efficient bulbs [96].

For the challenges with energy users and financing, a solution that will satisfy customers, thus increasing their willingness to pay and retain the attraction of the investors, is proposed. This solution is based on a pollution charge/permit. This is a combination of pollution charge and tradeable permits that are economic incentives to minimize pollution emission.

When the pollution producers are levied based on how much pollution is produced, it is known as pollution charge. Within pollution charges, there is also a consideration where credit is refunded to the customer based on certain preset criteria. In the case of tradeable permits, there is a permissible limit of the amount of pollution that can be generated, which is assigned to companies in the form of permits. Companies who manage their permits below the permissible limit may then resell or sublet their excess to other businesses or utilize them to compensate for surplus emissions in their other businesses [97].

According to The World Bank in Ref. [98], as of 2014, about 40 countries and more than 20 cities, states, and towns utilize these pollution charge schemes. These regions became responsible for combating approximately 22% of worldwide emissions. This proves the efficiency of the pollution charge schemes [99].

The proposed solution is based on the combination of these economic-incentives schemes. The framework is a smart meter that gives benefit to both the customers and investors. The regular meters allow customers to buy electricity units on a prepaid or postpaid arrangement. However, with the pollution charge/permit-based smart meters, energy customers are allotted a rated maximum power consumption (a limit) depending on the level of load (residential or industrial), and depending on the scheme, deposits on payments may be made. Where a consumer exceeds his or her limits, their tariff price will be automatically increased. However, any customer with a surplus will be allowed to resell or lease their excess or other special incentives such as tariff reduction and deposit refunds.

Another suggestion is a community or estate-based allocation. If the community collaborates to conserve electrical power, incentives such as more light days or a reduction in tariff rating can be provided. Other advantages of implementing a smart energy meter are:

i. Increased Customer satisfaction: Smart Energy Meters (SEMs) would ensure that the customers are able to pay for the energy credits they desire. Customers would have more trust in the system and be willing to pay for services rendered, this would in turn make the investment profitable.
ii. Securing Investor attraction: Smart Energy Meters provide reliability and system security that is appealing to Investors. The installation of SEMs would safeguard their investments and ensure that electricity generated is utilized efficiently.
iii. Energy and cost-saving: SEMs ensure that electricity generated is properly accounted for and paid for. When consumers are responsible for the energy they consume, the instinct to conserve as much as they can kicks in.
iv. Environmental benefits: Energy monitoring would lead to a reduction in Carbon emissions, as energy will be conserved, which will reduce the carbon emissions caused by the generation of energy.

This scheme is not limited to the incentives proposed, as various strategies could be set up to create a win-win solution for both customers and investors.

The installed generation capacity of Nigeria is nearly 13,000MW; however, less than 5000MW is being generated. The transmission capacity is approximately 7500MW, with less than 5000MW being transmitted [100]. Suppose we assume no losses in generation, with the entire installed capacity being generated. In that case, the transmission line will introduce problems as it will not evacuate this generated energy. This implies that, even if the proper maintenance and restoration activities are carried out on the generation infrastructure, and more plants are being set up to meet the demand of the increasing population, the power generated would not be able to be transmitted due to the limited transmission line capacity.

Assuming its capacity is expanded, this transmission grid will still introduce losses in transmission of energy over long distances and various forms of vandalism. In addition, this makes the effective monitoring and control of the lines to be difficult as they are located in remote and inaccessible areas. Hence, the solution proposed is to reduce the losses and limitations introduced by the transmission components of the sector by implementing distributed generation.

Distributed generation or micro-generation implies on-site generation, such that the power is generated at or near the load centers. It eliminates the complexity and limitations of the transmission grid and allows for private sector participation. It also allows for the incorporation of diverse energy sources into the power industry. This provides advantages in: Energy diversity with the integration of diverse renewable energy sources for power generation, thus reducing the sector's overdependence on oil for power generation. It also diversifies power generation location across the country, as the most generating stations were located in the southern area due to the utilization of natural gas as the energy source. Now, solar irradiation in the northern areas can be efficiently utilized. Also, Private sector participation will be assured because consumers would be involved in the generation and consumption of energy by setting up various distributed generation units nationwide. Lastly, losses due to long-distance transmission would be eliminated, which is limited in capacity and network congestion. The difference between power generated and power delivered to consumers would be within manageable limits.

The population of Nigeria is more than 200 million [8], and in order to follow the rule of thumb for any developed industrial nation that per million head of population, at least 1,000MW of electricity generation and consumption is required as stipulated in the 2010 roadmap for power sector reform [28]. Hence, more than 200,000 MW in energy generation and distribution is required to satisfy this rule. Also, if the kWh consumed per person for each country is considered, Nigeria has a figure of 115 kWh per capita for a population of more than 200 million. Brazil also has a population of more than 200 million but has a figure of 2405 kWh per capita. Even South Africa, with a smaller population of 50 million, has 3668 kWh consumed per person, India with a larger population of more than a billion has 857 kWh per capita. This boasts of the inefficiency of the power supply in Nigeria, especially when you consider the vast natural energy resources in the country.

As of July 2021, Nigeria is generating 5000MW, which implies a huge deficit if there is an adequate power supply throughout the country. The proposed distributed generation recommendation will utilize the largest rating DGs, and it is stated in Ref. [101] that large DGs are rated 50–300MW. It will also be based on the energy source that is most available within that particular region. Thus, it is proposed that the DISCOs continue to supply power to the country, but to minimize transmission losses and boost the effective supply of power, each Local Government Area (LGA) in each state will have its own 300MW micro-generation. This will enable the LGAs to generate power independently, without reliance on the GENCOs and DISCOs for constant power supply. The visual description of this prospect is presented in Fig. 4.

Hence a zonal distribution of the Distributed generation plants based on type can be deduced as depicted in Table 8. In addition, it can be noticed that the Distributed generation allocation allows for a constant power supply and allows effective utilization of the vast

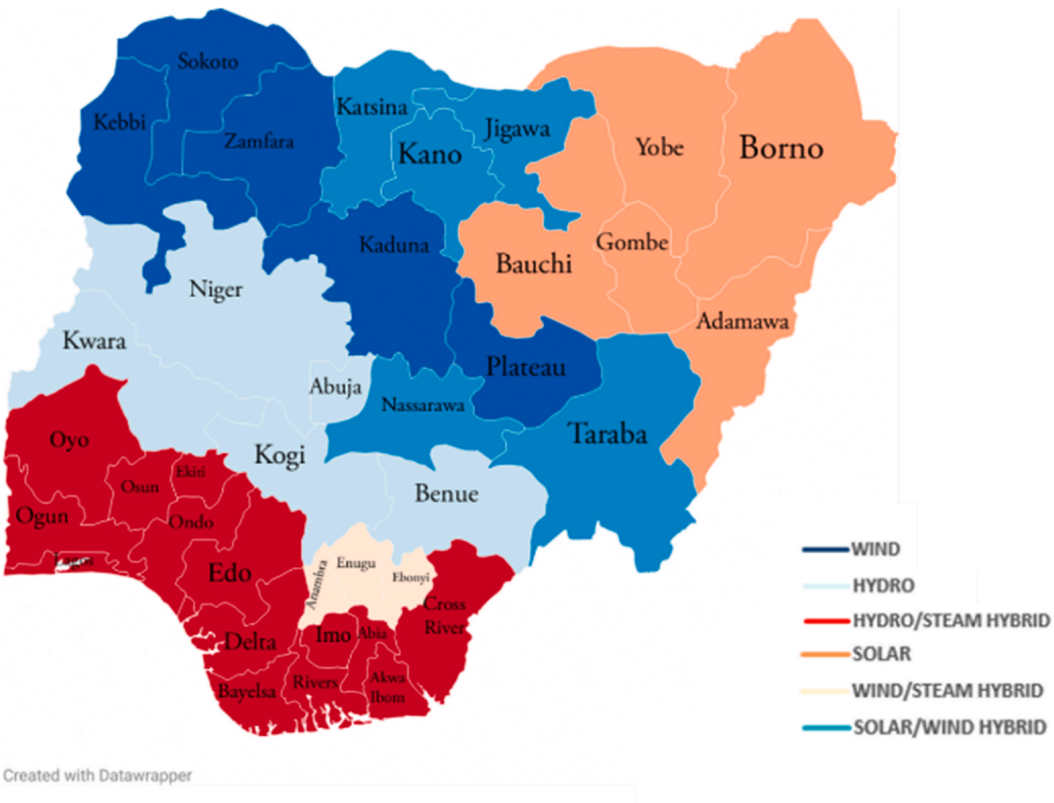

Fig. 4. Renewable energy coverage areas.

energy sources within the country.

Thus, effective power generation and distribution can be achieved by Distributed generation. If states with large populations such as Kano, Lagos, etc. and states with the most industries such as Ogun, Lagos, etc. should utilize multiple large DG stations, this will be just enough to satisfy the stipulated rule of the thumb and increase kWh per capita thus resulting in effective power generation and distribution in Nigeria.

Although this research work has achieved its objectives, there is still room for more research and improvements. For further works towards a postgraduate degree, the following project works are recommended; further research and actual implementation of the proposed smart metering system and feasibility study on the economic benefits of the proposed distributed generation allocation

5. Conclusion

In conclusion, this study has been able to identify the challenges in generating and distributing power in Nigeria effectively. It identifies issues with the energy user, financial issues, and energy losses as the key challenges faced. The lack of constant, inefficient power supply creates problems in the financing of the sector. The energy users are highly dissatisfied, and the investors are not attracted to the unstable sector. It also identified the Nigerian energy market as telescopic in nature and analyzed available load and generation data from the Osogbo control station to support the results obtained.

Then, the prospects of a smart metering system based on various pollution charge schemes such as tradeable limits and deposit-refunds were proposed in order to achieve a win-win situation between the investors and customers. This will then improve financing in the sector and customer satisfaction. It also describes the prospect of using distributed generation per Local Government Area to achieve an effective generation and supply of power, such that the energy users are independent. In the event of a power outage by the DISCOs, they can maintain a constant power supply. This will also improve the utilization of the vast energy resources in the nation as a zonal distribution was deduced based on the type of energy source used. The zones are Zone 1 with Solar DG type, Zone 2 with Wind DG type, Zone 3 with Solar/Wind Hybrid DG type, Zone 4 with Hydro DG type, Wind/Steam Hybrid DG type, and Hydro/ Steam Hybrid DG type.

Author contribution statement

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Declaration of interest's statement

The authors declare no conflict of interest.

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