A Critical Examination of Nigeria's Electricity Generation and Supply between 2001 and 2020

Justicia Chimuanya Otobo

A thesis submitted in partial fulfilment of the requirements of London South Bank University for the degree of Doctor of Philosophy

September 2023

ORCID Number: 0000-0002-6044-6181

Abstract

This study focuses on Nigeria's journey towards achieving the United Nations' 7th Sustainable Energy Goal by 2030, which aims to provide cheap, sustainable, and reliable energy access worldwide. It reviews Nigeria's electricity policies from 2001 to 2020 and employs a deterministic modelling tool to identify the least-cost electrification options for the entire country.

Nigeria, being in its early economic stages, is advised to promote renewable energy to diversify its energy mix and build renewable power plants. This shift towards renewables is seen as advantageous. The modelling tool introduced allows policymakers, even those without technical expertise, to assess the potential impacts of their decisions before implementation.

The study's projections indicate that a combination of renewable and non-renewable energy sources is the optimal path for Nigeria's future energy network. However, challenges such as oil price fluctuations, supply chain issues, and a high cost of living may slow the adoption of renewable energy.

Two scenarios are examined: the Forecast scenario based on the current national grid performance and the Policy scenario aligning with the Nigerian Government's 2030 electrification plan. Both scenarios suggest that increasing transmission lines and power generation while integrating renewables can significantly reduce operational costs.

Currently, only about 60% of Nigeria's population has access to electricity, and it is often unreliable. To support economic growth and population needs, the study emphasises the necessity of incorporating more renewable energy sources in Nigeria's energy expansion plans. Climate change and global warming underscore the importance of a resilient and stable energy sector.

Furthermore, the study identifies policies that have contributed to electricity generation and supply, especially in rural and off-grid areas. These policies encourage investment, support diverse energy sources, and involve various stakeholders in the electricity value chain. By implementing the right regulations to attract renewable energy investors, Nigeria can address its power sector issues and expand electricity access to unconnected regions.

In conclusion, Nigeria's path to sustainable and reliable energy involves a balanced mix of renewable and non-renewable sources, improved policies, and investments in untapped natural resources like solar, wind, biomass, and tidal energy. This approach can create a cleaner, more sustainable energy future for the country.

Acknowledgements

Firstly, I would like to start by giving God the glory for allowing me to do this research and introducing me to so many wonderful people along the way. I would like to express my gratitude to my husband, Dr Izibeya Otobo, for his unwavering encouragement and help throughout this study.

Thank you to my supervisors, Dr Rusdy Hartungi, Dr Abouzar Estebsari, and Dr Yusuf Ibraheem, for all your help and guidance throughout this project. They were always there to offer advice, share their excitement, and cheer me on in my development. I am grateful for the help and guidance they gave me while I was a student at LSBU (London South Bank University).

In addition, I would like to express my appreciation to Professor Issa Char, Prof Yamuna Kaluarachchi, Prof Harriet Nwigwe, Prof E.N.C Okafor, Prof Ebohon and Dr Amer Ali. who were incredible sources of encouragement and inspiration to me throughout my PhD studies and beyond.

The moral and financial support I have received from my family has been invaluable. I owe a debt of gratitude to them for serving as a source of inspiration and drive. At the same time, I would like to express my gratitude to my friends and everyone else who has helped me with their support, prayers, and words of encouragement as I have been studying.

In conclusion, I would like to express my appreciation to the Department of Built Environment and Architecture and the Research management team at London South Bank University.

List of publications

Otobo J.C., Hartungi R., Ibraheem Y., and Estebsari A.E., "Decision Support Tool for Electric Power Generation Development: A Feasibility Analysis for a Nigerian Case," MDPI Electronics, June 2023.

Otobo J.C., Hartungi R., Ibraheem Y., and Estebsari A.E., " A Critical Review of Nigerian Electricity Policies between 2001 and 2020," 23rd EEEIC International Conference on Environment and Electrical Engineering, Madrid, Spain, June 2023.

OTOBO, J.C., 2022. Sustainability and Resilience in the Nigerian Power sector, Industrial Engineering and Operations Management (IEOM), July 26-28, 2022.

OTOBO, J.C., 2021. Building Sustainability and Resilience in the Nigerian Power sector – A case study of the Rural Electrification Agency (REA), 2021, London South Bank University.

Table of Contents

List of Figures

List of Tables

Abbreviations

AEDC	Abuja Electricity Distribution Company
AI	Artificial Intelligence
ANN	Artificial Neural Network
AMCON	Asset Management Corporation of Nigeria
ARMA	Autoregressive Moving Average
ARIMA	Autoregressive Integrated Moving Average
DISCOs	Electricity Distribution Companies
DPR	Department of Petroleum Resources
ECN	Electricity Corporation of Nigeria
EE	Energy Efficiency
EEDC	Enugu Electricity Distribution Company
EPIC	Electric Power Implementation Committee
EPSRA	Electric Power Sector Reform Act 2005
FGN	Federal Government of Nigeria
FMP	Federal Ministry of Power
GENCOs	Electricity Generation Companies
GEP	Generation Expansion Planning
GDP	Gross Domestic Product
GIZ	The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
IBEDC	Ibadan Electricity Distribution Company
IEA	International Energy Agency
IPP	Independent Power Producers
LGA	Local Government Area
LSBU	London South Bank University
MYTO	Multi-Year Tariff Order
MV	Medium Voltage
NASENI	National Agency for Science and Engineering Infrastructure

NBPI	Nigerian Biofuel Policy and Incentives
NBET	Nigerian Bulk Electricity Trading Plc
NCC	Nigerian Coal Corporation
NDPHC	Niger Delta Power Holding Company
NEEDS	National Economic Empowerment and Development Strategy
NEMSA	Nigerian Electricity Management Service Agency
NIPP	National Integrated Power Project
NEPP	National Electric Power Policy
NEP	Nuclear Electric Power
NEPA	National Electric Power Authority
NERC	Nigerian Electricity Regulatory Commission
NESC	Nigerian Electricity Supply Company
NESI	Nigeria Electricity Supply Industry
NNPC	Nigeria National Petroleum Corporation
NREEEP	National Renewable Energy and Energy Efficiency Policy
OECD	Organisation for Economic Co-operation and Development
ONEM	Operator of the Nigerian Electricity Market
OPEC	Organisation of Petroleum Exporting Countries
OPF	Optimal Power Flow
PHCN	Power Holding Company of Nigeria
PPA	Power Purchase Agreements
PV	Photovoltaic
RE	Renewable Energy
REA	Rural Electrification Agency
REMP	Renewable Energy Master Plan
RESIP	Rural Electrification Strategy and Implementation
TCN	Transmission Company of Nigeria
TEP	Transmission Expansion Planning

TPES	Total Primary Energy Supply
SDG	Sustainable Development Goals.
SEA4All	Sustainable Energy for all
SERC	Sokoto Energy Research Centre
UN	United Nations
UNDP	United Nations Development Programme

1. Introduction

1.1 Background

It is common knowledge that the availability of energy is a significant factor in the economic growth of a nation. Electricity is the form of energy that can be utilised in the widest variety of settings, including commercial, residential, and industrial buildings (Ugwoke et al., 2020). Because of this, the investigation will concentrate primarily on electricity as a source of power. Electricity is a vital resource that plays a crucial part in the process of driving innovation, industrialisation, technological progress, and economic expansion around the world (Squalli, 2007; Kumari and Sharma, 2018; Wu et al., 2019; Lee, 2005; Best and Burke, 2018; Akinlo, 2009). In addition, an increase in electricity consumption is a leading indicator of an increase in a nation's economic activities; consequently, enhancing the development of the electricity sector will improve productivity and contribute to the growth of a prosperous economy (Iyke, 2015).

Electricity is utilised to a significant degree in the production of goods and services across all areas of the economy. Although a nation's standard of living as well as its level of economic progress are largely determined by the amount of energy it consumes, the production and distribution of electricity have the most considerable influence on overall levels of productivity as well as economic expansion (Monyei et al., 2018). Unfortunately, many developing countries, including Nigeria, are still unable to provide adequate and sustainable electricity to their population, which is required to improve their standard of living and drive economic growth. This is a problem because adequate and sustainable electricity is required to accomplish these goals (Ohiare, 2015; Agbo et al., 2021; World Bank, 2020).

According to the World Bank, Nigeria is the continent's leading exporter of crude oil and possesses the most natural gas reserves of any country on the African continent. Because of this, crude oil is the primary factor behind the expansion of the economy, and since 1980, it has been responsible for more than 90 percent of the total exports from the country (Iwayemi and Fowowe, 2011). However, despite the country's vast oil and gas reserves as well as its substantial income from exports, Nigeria is experiencing a significant shortage of electricity generation and supply. This is because the country has been unable to build enough capacity to keep up with the country's expanding population and its accompanying demands. This incapacity is manifested in power plants that are in a state of disrepair, equipment that is obsolete, and a distribution system that is inadequate and broken (Lin, Ankrah 2019).

One of the primary reasons for inadequate electricity supply in Nigeria is the country's rapidly growing population, which experienced exponential growth between the years 1990 and 2017, when it increased from 95 million to 195 million, representing a growth rate of 49% over the course of 27 (World Bank, 2022; Emodi, N. V. et al., 2022; Chanchangi et al., 2022)

However, out of the total population of the country, only forty percent are connected to the national electricity grid. Even so, the supply is extremely unreliable, with blackouts frequently lasting for weeks or even months at a time (Dada and Moser, 2019). Furthermore, the high rate of urbanisation has resulted in an increase in energy consumption because of the increased demand for goods and services; consequently, the necessity of energy planning becomes crucial in the process of developing an environment that has access to energy that is dependable and sustainable (Trotter et al., 2017).

It would be prudent for Nigeria, which is still in the early stages of industrialization and economic advancement, to adopt the development of renewable energy sources in order to boost economic growth, reduce energy poverty, and ensure a sustainable environment (Lin, Ankrah 2019). Changes in the composition of the government in Nigeria have resulted in several adjustments being made to the country's energy policies. This study will investigate the current energy and electricity generation policies in Nigeria to determine whether they support the country's goal of achieving sustainable national electrification.

1.2 Problem Statement

Only about 60% of the population in Nigeria has access to electrical power, even though the country has the largest economy in Africa. This makes Nigeria one of the countries with the largest energy gaps in the world. Because of the consistently rising population, there is an immediate and critical need to boost its electricity supply in order to satisfy the rising demand. In addition, there is a significant disparity between the installed capacity of the power stations and the amount of electricity that is generated. Access to electricity is expected to rise to 90% by the year 2030, according to a goal set by the government (Adeoti, O., Adewumi, A. O., Oyedele, L. O., & Akinade, O. O, 2019; Edomah, 2021; Chanchangi et al., 2022; Emodi, N. V. et al., 2022).

In order to generate revenue that is capable of supporting investments in infrastructure, the government of Nigeria has taken steps to reform the energy sector. These steps include deregulating and restructuring the oil and gas sectors, as well as privatising the power sector. The privatisation of power generation and distribution was carried out by the government in two stages so that investments could be increased in the process of reorganising the power sector. This process, which aims to reinvest the proceeds into the expansion of hydropower plants across the country, is still underway. It is difficult to determine exactly.

The National Electric Power Policy, also known as the NEP, is intended to serve as a guide for the expansion of the energy industry. It establishes the policies of the FGN regarding the production, supply of all energy resources, and the consumption of energy in various industries. The primary objective of the policy is to achieve energy security through the utilisation of a diverse array of energy sources in order to bring about sustainable development and to protect the surrounding natural environment.

There is clear evidence that work is being done to translate the policies into actions. The findings, however, indicate that additional steps need to be taken, and that the policies in place should be periodically evaluated and updated in order to remain relevant considering developments on a global, national, and local scale.

1.3 Research Rationale

There has been an ongoing crisis in the energy sector in Nigeria, which has led to the country's inability to generate and supply sufficient electric power in a sustainable manner to its ever-growing population of over 200 million people (Emodi, N. V. and Boo, 2015). Even though it is the country with the largest economy in Africa, only about 60 percent of Nigeria's population has access to electricity (IEA, 2020).

It is estimated that between the years 1999 and 2017, the Federal Government of Nigeria (FGN) committed a massive investment of 2.74 trillion Naira, which is equivalent to $16 billion USD. This investment was made in order to restore the country's electricity sector. (Akuru, Onukwube et al. 2017).

Even though Nigeria has access to a sizable amount of energy resources, the purpose of this study is to determine why the country's population is not served by a reliable source of electricity.

1.4 Aim of the Research

This research aims to critically examine the Nigerian electricity sector to determine the impacts of policies in electricity generation, and supply between 2001 and 2020, and to develop a predictive model to help future policy makers.

1.5 Research Objectives

The aims of this research will be achieved through the following objectives:

1. To conduct a critical review of the electricity generation and supply in Nigeria from 2001 to 2020.
2. To examine the impact of policies on the generation and supply.
3. To evaluate forecasting techniques and expansion planning methods and identify the best option for this study.
4. To develop a model to explain and predict the electricity generation and supply capacity.

1.6 Research Questions

The core questions this research will investigate are:

1 How have the policies impacted electricity generation, and supply?
2 What are the features and attributes of the current policies?
3 How appropriate is Nigeria's electricity policy to effect increased electricity generation to bridge the generation gap?

4 What is the current state of the capacity to formulate and implement the policies?
5 What strategic initiatives can be adopted to formulate and implement effective electricity policies in Nigeria?

1.7 Methodology

The first part of this research involved a detailed and critical literature review of the existing Nigerian Government policies on energy and electric power generation and supply to determine if they are robust enough to support sustainable national electrification. Ongoing and current issues on electricity generation and supply were identified and critically examined.

Due to the complex nature of this study, a mixed-method methodology was chosen to conduct it. This methodology consisted of conducting a literature review, research surveys such as questionnaires, and semi-structured face-to-face interviews. Both quantitative and qualitative methods were used to analyse the data collected during the process of validating the findings from the various sources. (Weinberg, 2002).

The next phase of the research involved some quantitative analysis. Key informants for the qualitative part of the study were identified and recruited using purposive sampling. The qualitative data generated was analysed using the Grounded Theory, Social Network Analysis, and the quantitative data was analysed using SPSS.

Using the information from the survey and the policies, a model was built in MATLAB to simulate changes of the Nigerian transmission network based the IEEE 30 bus system. The distribution network was adjusted based on forecast data and from policy data for 2030, and then the network's power flow was calculated using the Newton-Raphson method. This model was used to assess the feasibility of the system and to identify the scenario with the least operating coat. Table 1-1 summarises the research methodology used for this study.

Table 1-1 Research Methodology

Philosophical stance	Research approach	Research design	Research strategy	Time horizon	Techniques and procedures
Pragmatism Provides structured yet multiple options to explore the research problem and contribute practical solution(s)	**Abduction** To explore the phenomenon, identify themes and explain patterns, to generate a new or modify an existing theory which is subsequently tested, often through additional data collection	**Mixed method** The use of qualitative and quantitative methods to enable reliable and relevant data collection to address the research problem	**Survey** Supports exploratory nature of the research aim and will allow the collection of standardised data **Case Study** Looks at real life cases and studies people, processes, and organisation within their natural environment to arrive at a definite conclusion	**Cross Sectional** This research is time constrained	**Data collection** Literature review Questionnaire Interviews **Data analysis** The qualitative data will be analysed with NVivo, and the quantitative data will be analysed with SPSS and Model built in MATLAB

1.8 Research Challenges

Some of the problems encountered during this research was the availability of data on the usage of electric power in Nigeria, and the estimation of the actual energy demand of the country, due to the absence of a central electronic data unit in the Nigerian power sector as it is a developing country. However, this situation improves with large organisations such as the Central Bank of Nigeria, UN, World Bank, IEA, etc.

1.9 Ethical Issues

The main ethical issues considered while carrying out this research was related to obtaining the respondents' informed consent while maintaining their anonymity and confidentiality because of the sensitive data that may be required during data collection.

1.10 Original contribution to knowledge

One of the study's original contributions is the creation of a specialised decision-support tool that can evaluate an electricity network's viability without requiring the user to have extensive technical knowledge or to purchase expensive software. In addition, the tool’s application is not limited to Nigerian scenarios; it can be used to analyse electricity networks anywhere in the world.

The thesis primarily focuses on UNSDG 7, which emphasises the promotion of affordable and clean energy, particularly through the increased utilization of renewable and cost-effective energy sources. This approach aims to deliver energy services that are both accessible and dependable. Nevertheless, the policy analysis presented in the thesis also makes valuable contributions to several other UN Sustainable Development Goals - UNSDGs (United Nations, 2022):

- UNSDG 3 – Support for Research and Development (R&D) of Renewable Energy Sources (RES), thereby enhancing the quality of life within local communities.
- UNSDG 8 – Promotion of sustainable economic growth and the creation of suitable employment opportunities for young individuals who are not engaged in employment, education, or training.
- UNSDG 9 – Establishment of resilient infrastructure and facilitation of innovation to foster societal progress.
- UNSDG 11 – The extension of electricity to rural areas will lead to an expansion in the count of urban centres and human settlements.
- UNSDG 13 – Integration of Renewable Energy Sources (RES) into the grid, resulting in a reduction of greenhouse gas emissions.

Finally, a survey was administered to experts with in-depth knowledge of the Nigerian electricity industry so that the individual contributions of the chosen policies to electricity generation and supply between 2001 and 2020 were evaluated in Chapter 4, resulting in the bespoke findings presented in chapter 5 of this report.

1.11 Validation of research findings

Findings from this study show that the Nigerian government needs to create a long-term strategy for the electricity sector that considers renewable energy, energy efficiency, and the correction of institutional weaknesses. It is recommended that for the government to meet the rising demand for electricity, it will have to prioritise investments in the transmission and distribution infrastructure as demonstrated successfully by countries like India which achieved 100% electrification in 2019 via an ambitious rural electrification program.

A combination of government policies, public-private partnerships, and the adoption of innovative technologies helped India achieve 100% electrification, which supports the effectiveness of results and recommendations from this study.

1.12 Structure of the Thesis

Chapter 1 - This research's historical context is discussed in Chapter 1 of this report, along with the research aim, research objectives, and research questions. Figure 1.1 shows the Research Theoretical Framework for this study.

Chapter 2 - The literature review and an update on the current state of the Nigerian electricity sector are presented in Chapter 2. It analyses the energy sources that are available in the country, the state of the power sector, and the current electricity policies that are in place in Nigeria. Additionally, it discusses the energy and electricity policies that were chosen for this study. The results of the literature review are incorporated into the construction of a conceptual framework, which served to direct the research methodology.

Chapter 3 - The third chapter provides an overview of the electricity generation, transmission, and distribution industries in Nigeria as well as discusses the generation expansion projects and transmission expansion projects that are currently being undertaken in the country. In addition to this, it examines a variety of forecasting methods that were investigated throughout the course of this study and justifies the technique that was chosen considering objective 3 of this study.

Chapter 4 - In chapter 4, the research approach that was taken for this study is examined. This section discusses the various approaches that were considered and explains why the methodology presented here was chosen. Lastly, it gives an overview of how the conceptual framework and selected policies from the literature review in chapter 2 and the forecasting technique in chapter 3 were used to design the survey and interview questions. This information can be found in the concluding section of this chapter.

Chapter 5 - In the fifth chapter of the report, the findings from the surveys, questionnaires, and interviews are presented. It also gives some background information on how these findings were used to develop their deterministic model, which was developed in this research to assist future policymakers in evaluating the viability of various scenarios. As a result, this helps support research objective number four.

Chapter 6 - The findings of the study, as well as its recommendations and conclusions, are outlined in Chapter 6. It explains how policymakers can use the tool developed to design policies that help increase electricity generation and supply to bridge Nigeria's demand and supply gap, thereby reducing or eliminating energy poverty in other developing countries. The tool was developed to help increase electricity generation and supply in order to bridge Nigeria's demand and supply gap.

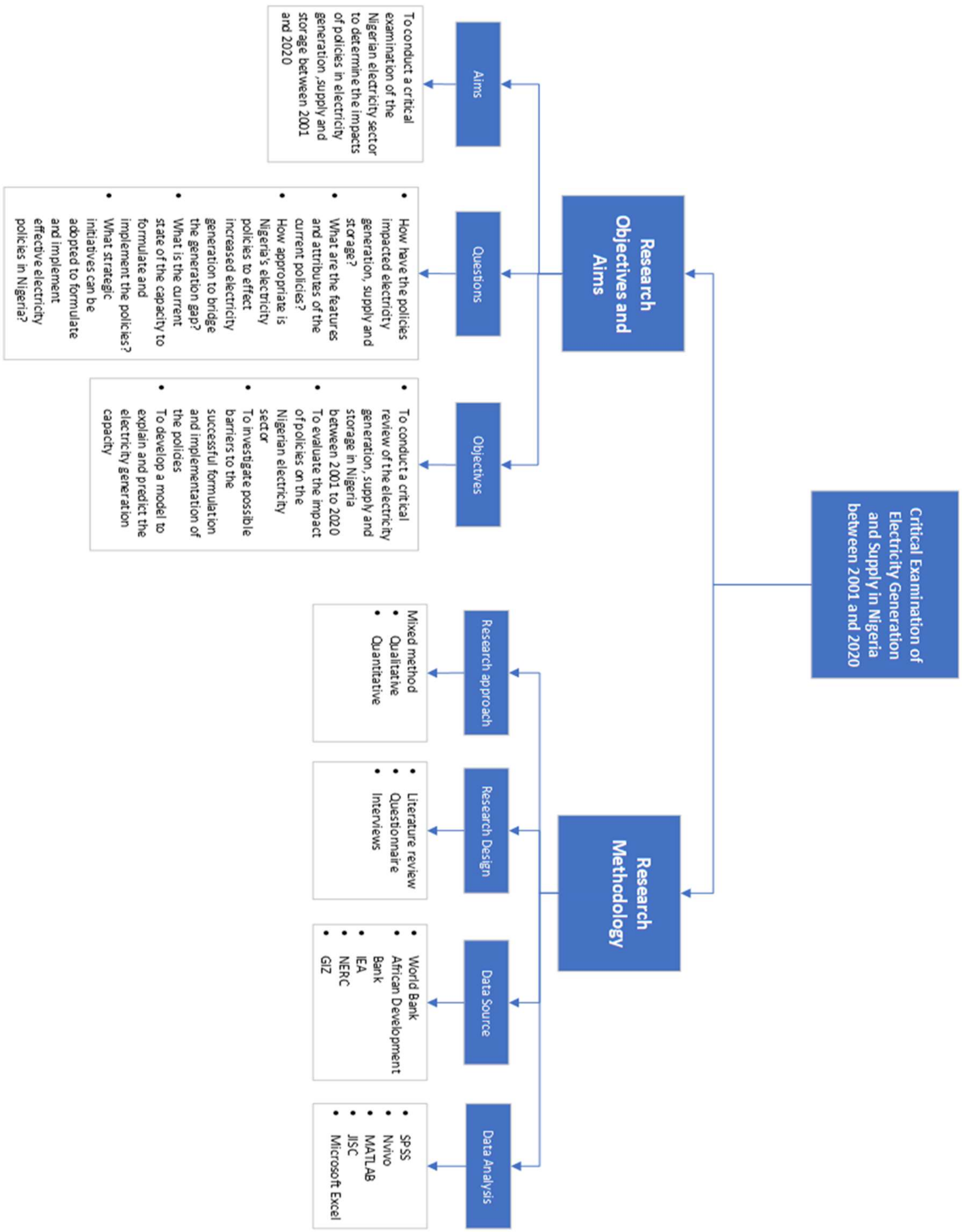


Figure 1.1 Research Theoretical Framework

2. Literature Review

It is projected that 60 percent of the population, or 75 million people, had access to electricity in 2017, with only about 10 percent of those people living in rural areas. In total, over 200 million people are living in the country (World Bank 2020). The current energy crisis in Nigeria has made the country expensive and unattractive for foreign investors. As a result, businesses have chosen to relocate to neighbouring African countries rather than risk an increase in their cost of production (Akuru et al., 2017). As a result of this circumstance, commercial establishments and residential homes had no choice but to run noisy electric power generators fuelled by fossil fuels to power their homes and businesses, as this was the only option available to them. It has been estimated that Nigeria spends a total of 796.4 billion naira (or 4.65 billion USD) each year on fuel for its power generators, according to recent reports. This does not consider the approximately 350 billion naira (2.04 billion USD) that businesses spend annually to fuel their own generating (Akuru et al., 2017).

Previous research has demonstrated that the interdependence between the availability of energy, its supply, its demand, and its consumption is essential for the growth of a nation's population and for the integration of rural and urban areas (Ajayi, Ajayi 2013). Moreover, energy is one of the most key factors in economic development and a necessary condition for continued economic expansion and growth. As a result, the decision-makers in Nigeria should ensure that barriers that make investments in the power sector unfavourable are removed or reduced. They should also provide incentives to encourage investments in the industry (Ajayi and Ajayi, 2013; Gatugel Usman et al., 2015).

Nigeria's government has reformed the energy sector by privatising and restructuring the power sector to boost investments for increased power generation and distribution. These steps were taken as part of the government's effort to reform the energy sector. In addition, the government has developed programmes to encourage energy-saving technologies and renewable power sources (NERC, 2019).

Despite the efforts that the government of Nigeria has made over the past few decades to reform the energy sector, the country does not currently have sufficient electric energy to both feed the economy and provide sufficient electricity to residential homes, industrial businesses, and businesses in general (Emodi, N. V. et al., 2022)

In this study, we will investigate the policies that are currently in place regarding energy and electricity generation and supply to determine whether these policies are robust and whether they support sustainable, accessible, and affordable national electrification.

2.1 Overview of Energy in the World

Many researchers have found that a nation's or region's energy consumption can indicate the level of economic development in that nation or region (Khan et al., 2019). It has been determined that Nigeria's power sector represents a significant barrier to the country's

overall economic expansion (GIZ, 2015). Since the beginning of the first industrial revolution in Europe and the United States, the application of energy has been the primary force behind advancements in agriculture, manufacturing, transportation, communication, and technology, all of which have contributed to an increase in economic output (Brower 1994).
Incandescent lighting was one of the first applications of electricity, which began around 1880. In the latter part of the 1890s, the system for the generation, transmission, and distribution of electricity had already developed into the form that is still in use today. This system was commercially viable by that time. The late 18th century and the early 20th century saw an increase in the prevalence of internal combustion engines and electric motors as sources of energy. By the year 1929, electrical motors accounted for more than 80 percent of the total installed mechanical power in factories and other commercial establishments. In addition, households made use of electricity to facilitate the completion of daily responsibilities, as well as for the provision of lighting, climate control, and heating (Smil, 2004).
As a result of an increase in population, there has been a concomitant rise in the requirement that energy is made available and consumed. The global population increased from 1.6 billion in 1900 to 6.1 billion in 2000, which led to an increase in the annual supply of commercial energy from 14 GJ in 1900 to 60 GJ in 2000 (Brower 1994). The expansion and development of economies are contingent on the availability of energy. On the other hand, the relationship between energy consumption and economic growth and development is a complicated topic that will be discussed in greater detail later in this investigation.

The total amount of energy that is available to a country or region at any given time is referred to as the Total Primary Energy Supply (TPES) (IEA, 2019b). This considers energy that is both exported and imported and is derived from the use of natural resources as a source of energy. This is important to keep in mind because energy sources are used to generate electricity. In 2017, the top five countries by TPES accounted for 48% of the world's GDP (Gross Domestic Product) and 44% of the world population, as seen in Table 2-1. On the other hand, these five countries consumed 52% of the world's Energy (IEA 2019). This points to a connection between the production of energy, the consumption of energy, and the expansion of the economy as measured by GDP, as seen in Figure 2.1.

Table 2-1 TPES - top 10 countries in 2017

Country	TPES (Mtoe)	Share in world TPES 2017	Share in world TPES 1971
People's Rep. of China	3 063	22%	7%
United States	2 155	16%	29%
India	882	6%	3%
Russian Federation	732	5%	N/A
Japan	432	3%	5%
Germany	311	2%	6%
Brazil	290	2%	1%
Canada	289	2%	0.3%
Korea	282	2%	3%
Islamic Republic of Iran	262	2%	3%
Rest of the world	5 274	38%	44%
World	**13 972**	**100%**	**100%**

Source:(IEA, 2019c)

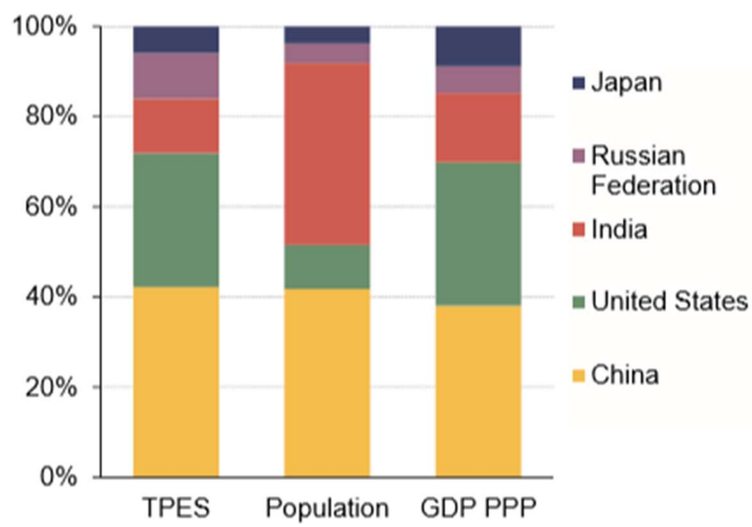


Figure 2.1 Top 5 energy consumers in 2017
Source:(IEA, 2019c)

The International Energy Agency (IEA) reports that between 1971 and 2017, the global total primary energy supply (TPES) rose from 5,519 Mtoe to 13,972 Mtoe, representing an increase of over 250%. Additionally, a shift in the composition of the energy sources went into the calculation of the TPES, with the oil and gas industries exhibiting the most notable shifts.

Even though oil remained the most critical fuel in 2017, its total primary energy supply proportion decreased from 44% to 32%. The proportion of natural gas increased from 16 percent to 22 percent of the total. Between 1971 and 2017, the electricity generated by nuclear power rose from 0.5% to 4.9%, while the electricity generated by coal rose from 26% to 27%, as shown in Figure 2.2. There were fluctuations in the percentages of both types of power generation in the years in between, especially between 1999 and 2011, and these fluctuations were primarily driven by the consumption of coal in China (IEA, 2019c).

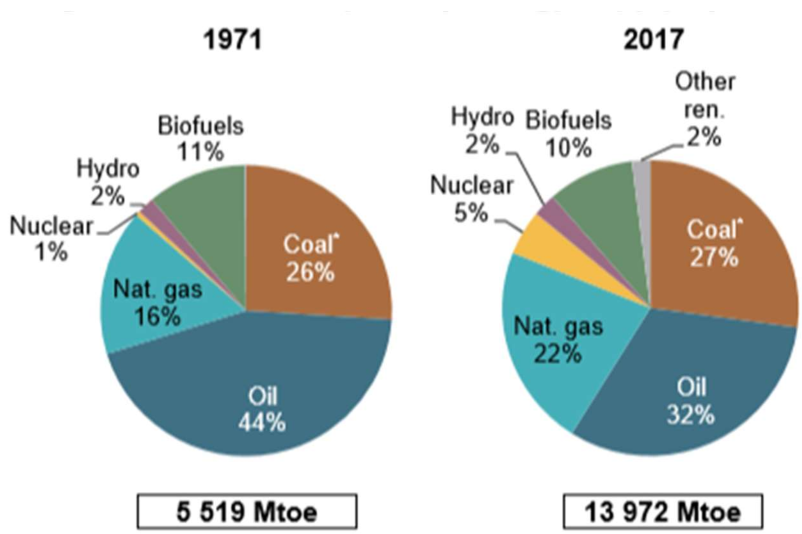


Figure 2.2 World total primary energy supply by fuel
Source:(IEA, 2019c)

In 2017, global energy production reached 14,035 Mtoe, representing a 2.2% year-over-year increase from 2016. This growth was primarily driven by increases in coal and natural gas production. In 2017, fossil fuels such as coal, natural gas, and oil were responsible for producing 81.3% of the total energy produced globally. The Mtoe is a unit of energy used to describe the equivalent amount of energy produced by the combustion of one metric tonne (1,000 kilogrammes) of oil, which is equivalent to 7.4 barrels (Martínez et al., 2019).

Electricity is the most flexible and adaptable form of energy because it can be used to power vehicles and industrial, commercial, institutional, and residential structures. Because of this, the investigation will concentrate primarily on the use of electricity as a source of power. In 2017, the generation of electricity from coal accounted for the largest share, 38.5%, of the total amount of electricity produced across the globe. The contribution of renewable sources to the overall mix was almost 25%, making them the second-highest contributor. Figure 2.3 shows that the percentage of contributions made by gas rose to 23%, while the percentage of contributions made by nuclear energy fell to approximately 10% (IEA, 2019c; World Bank, 2019b).

Before the oil crisis of 1973, oil had a significant role in the generation of electricity, accounting for a high proportion (25%) of the total. Since the financial crisis, the contribution of oil has dropped from being the second highest after coal to being the fifth highest in 2017, with less than 3% of the total. Even though oil's contribution to electricity generation has decreased globally, it is still responsible for more than 90 percent of the electricity produced in South Sudan, Lebanon, and Cyprus. In some Middle Eastern countries, such as Oman, Qatar, Bahrain, and Brunei Darussalam, natural gas and oil are the only sources of energy used to generate electricity, as seen in Figure 2.4 (IEA, 2019c; World Bank, 2019b).

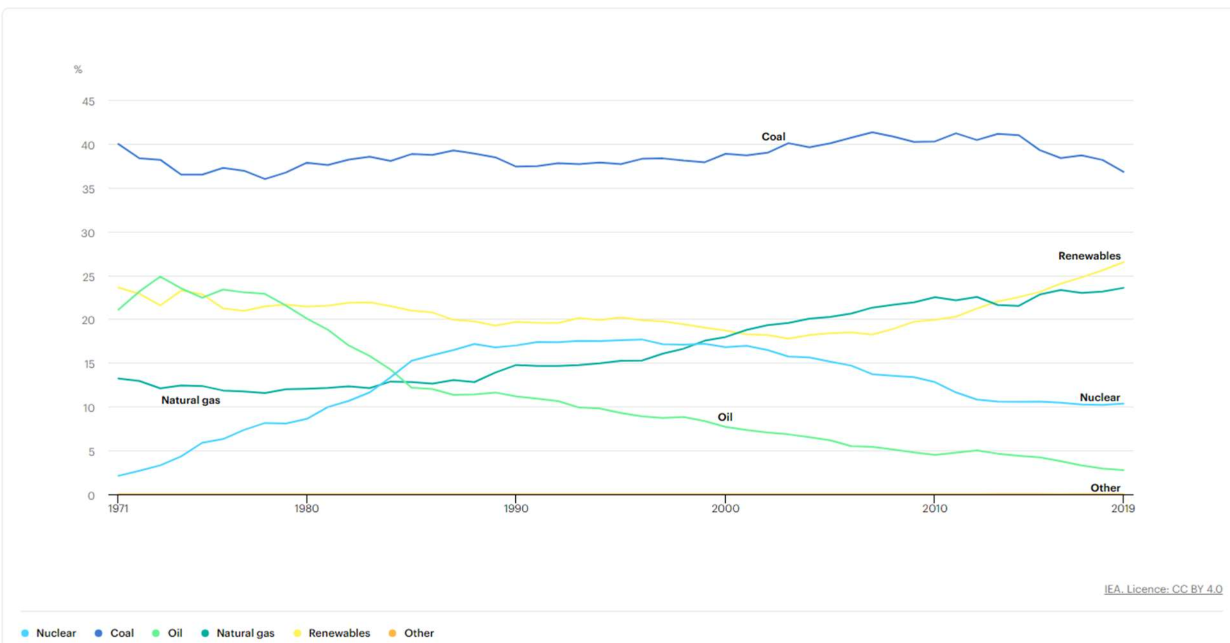


Figure 2.3 Global electricity generation mix between 1971 and 2019.
Source:(IEA, 2019c)

In 2017, Africa was responsible for producing 8% of the world's energy, which is comparable to the percentage it contributed in 1971 (7.8%). During this time, however, Africa's actual contribution increased by a factor of three (IEA, 2019c). Oil continues to be the primary contributor to energy production in Africa, accounting for 35% of total output. This is followed by biofuels and waste, which account for 32%, followed by natural gas, which accounts for 17% and 14%. According to Figure 2.5, in 1971, oil contributed

65% of Africa's total energy production, biofuel and waste comprised 26% of the continent's total, and natural gas made up only 0.9%.

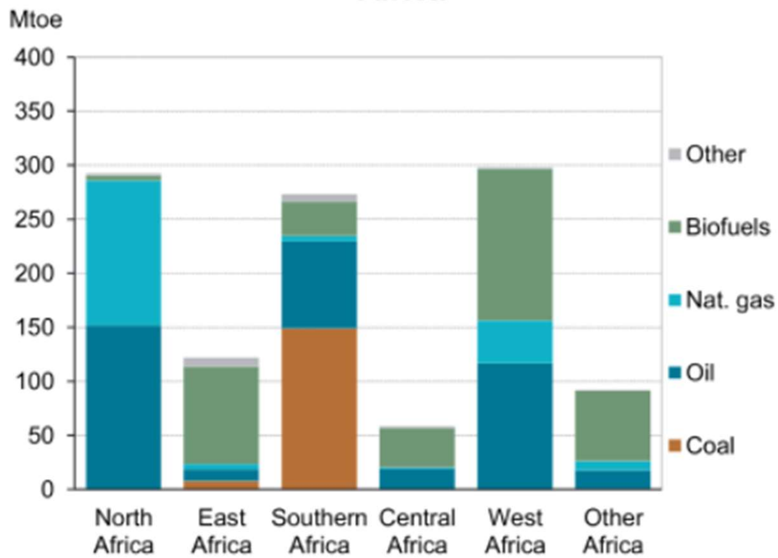


Figure 2.4 Africa's 2017 energy production by region
Source:(IEA, 2019c)

Both the production and consumption of biofuels on the African continent are at the top of the world's rankings. The total TPES contributed by biofuels in 2017 was 45% in Africa, while the average worldwide contribution was 9.5% from all regions (IEA, 2019c). This has been linked to the existence of large forests, a high population density in rural areas, agriculture, and a low GDP per capita, all of which have led to the production of solid biofuels for use in cooking (IEA, 2019c).

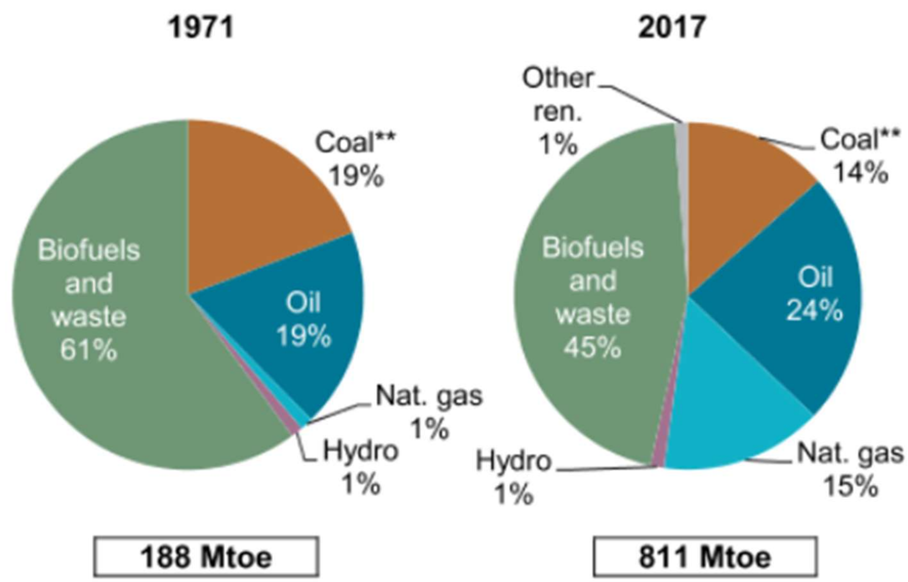


Figure 2.5 Africa's TPES by Fuel
Source:(IEA, 2019c)

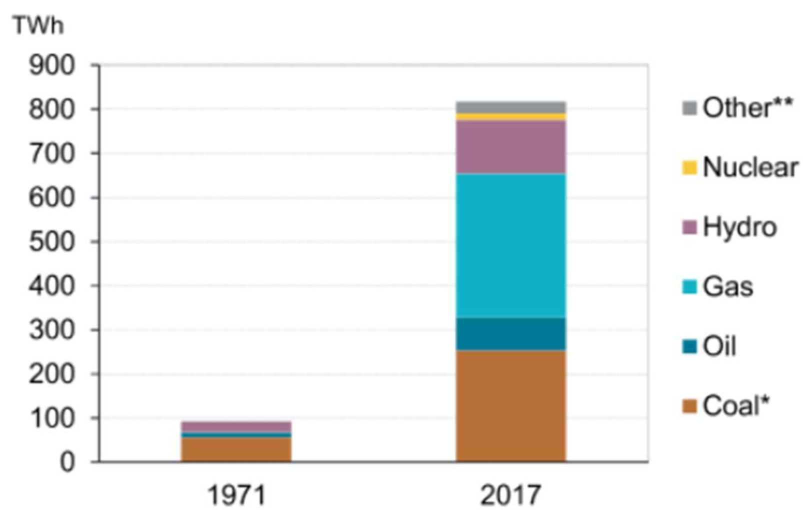


Figure 2.6 Africa's Electricity Generation by source
Source:(IEA, 2019c)

Both the production and consumption of biofuels on the African continent are at the top of the world's rankings. The total TPES contributed by biofuels in 2017 was 45% in Africa, while the average worldwide contribution was 9.5% from all regions (IEA, 2019c). This has been linked to the existence of large forests, a high population density in rural areas, agriculture, and a low GDP per capita, all of which have led to the production of solid biofuels for use in cooking (IEA, 2019c).

The percentage of biofuels and waste has decreased from 61% in 1971 to 45% in 2017, as shown in Figure 2.6. This can be attributed to the rise in the use of natural gas in power generation in Africa and the increase in the continent's overall electrification rate (IEA 2019). In 1971, natural gas contributed less than one percent to the generation of electricity; in 2017, that number had increased to forty percent. In 1971, the proportion of coal to the overall energy mix in Africa was the highest it had ever been. In 2017, it was ranked second, behind only natural gas, in terms of the proportion of the continent's electricity it generated (IEA, 2019c; World Bank, 2019b). In 2017, hydro was the third largest producer of electricity on the continent, while in 1971, it was the second largest.
South Africa and the countries in North Africa generate 74% of the continent's electricity, even though their combined populations only account for 20% of Africa's total population. This demonstrates a significant imbalance in the continent's electricity production (IEA 2019).
Access rates in sub-Saharan Africa remain an issue, with nationwide electrification rates averaging 41.7%, compared to 50.6% for the whole of Africa, and with only 22.3% in rural sub-Saharan Africa and 22.6% in rural Africa (IEA 2019, IEA 2020, World Bank 2017).

2.2 Global Energy Challenges

It is estimated that there are still approximately 950 million people in the world who do not have access to electricity. This is the case even though many different sources of energy and advancements have been made in the production and utilisation of energy (IEA, 2019c; World Bank, 2019b). According to projections made by the World Bank, the number of people living on this planet reached 7.5 billion in the year 2017, and it is anticipated that this figure will increase to 8.5 billion in the year 2030 and 11.2 billion by the year 2100. Despite all the progress that has been made to this point, the world is still not on track to achieve its goal of achieving the objectives of Sustainable Energy for all (SEA4All) and ensuring global access to reliable, affordable, and modern services by the year 2030 (Warner and Jones, 2017).
For instance, as of 2018, the population of the world's sub-Saharan Africa region lacked access to electricity for 600 million people, while the population of developing Asia lacked access for 350 million people. Additionally, it is estimated that there are 2.7 billion people in the world who do not have access to clean cooking facilities; as a result, they make use of kerosene, biomass, or coal as their primary source of fuel for cooking (IEA, 2018)
Concerns have been raised about the availability of energy considering the anticipated decline in the production of non-renewable sources of energy and the fact that the world's population is growing at an alarming rate (Warner and Jones, 2017). However, as shown in Figure 2.3, non-renewable sources continue to make up most of the world's energy supply. This trend can also be seen in Africa, as shown in Figure 2.6. Oil accounts for 35.4% of the world's energy supply, while natural gas and coal each contribute 28.1%.
The world's environment is in jeopardy as a direct result of our unending reliance on the burning of fossil fuels. Since we do not possess an infinite reserve of fossil fuels, efforts have been made to diversify energy sources to include renewable sources such as solar

and wind in order to lessen our reliance on the dwindling reserves of fossil fuels, as well as to lessen the impact that we have on global warming and pollution (Brower, 1994).

Energy poverty, increasing oil prices, an ever-increasing demand for energy on a global scale, and an ever-increasing level of competition for limited energy resources have been identified as critical issues in the context of gaining access to energy around the world (Halff, A. Sovacool, B. K. Rozhon, J., 2015).

The developed and developing regions of the world each struggle with energy issues in their unique ways. People living in South Asia and sub-Saharan Africa are more likely to be without access to reliable sources of electricity. These individuals have a challenging time gaining access to technologies such as stoves for cooking, biogas units, heating and cooling systems, and electrical power for their homes, which prevents them from using things like televisions, refrigerators, microwave ovens, and mobile phones (Halff, A. Sovacool, B. K. Rozhon, J., 2015). The world's poorest people are, unfortunately, the ones who suffer the most from a lack of access to affordable energy (IEA, 2020). The International Energy Agency (IEA) defines energy poverty as a lack of access to electricity as well as a reliance on traditional biomass fuels for cooking. People in some areas of the world continue to prepare their food using traditional methods, such as cooking with cow dung, crop residues, charcoal, and wood (Halff, A. Sovacool, B. K. Rozhon, J., 2015).

Energy issues in more developed regions of the globe are typically linked to climate change, energy efficiency, surging global demand for energy, rising oil prices, and increasingly intense competition for limited energy resources, in addition to having access to electricity that is priced more affordably. All these factors are in addition to the fact that access to electricity that is priced more affordably is an issue. Other factors that contribute to these issues include rising global demand for energy, surging global demand for energy, rising oil prices, and rising global demand for energy.

Most countries that are severely impacted by energy poverty also have some of the lowest GDPs, incomes, natural energy reserves, and mineral reserves in the world. This is because energy poverty is one of the main drivers of global poverty (Warner and Jones, 2017). There is a widespread misunderstanding that countries endowed with an abundance of natural resources, such as oil and gas, can use those resources as a basis for the expansion of their economies and as a source of energy and electricity for their populations. This is an example of a blessing that can be seen as a curse (Auty, 2007).

People in developed regions of the world experience the effects of energy poverty, as evidenced by the energy crisis that began in the United Kingdom in 2021. According to the BBC, between 2021 and 2022, the price of gasoline in the EU increased by more than 70 percent. About forty percent of the natural gas that is imported into the EU comes from Russia; approximately five percent of this gas is supplied to the United Kingdom. Because of this, monthly energy costs in the UK are rising at never seen before, and experts predict that they will double within the next 12 months. The United Kingdom is more susceptible to the energy crisis that is affecting Europe. This is because as of February 2021, the gas storage in the United Kingdom was at 86%, which is a significantly lower storage level than many other European countries (Otobo, 2022; BBC News, 2022).

The fact that the economy is beginning to recover after the pandemic is one of the factors contributing to the rise in gas prices. As a result, there has been a significant increase in the demand for gas, which has significantly impacted the United Kingdom. The United Kingdom is one of Europe's most significant natural gas users. Gas generates approximately one-third of the United Kingdom's total electricity supply, and approximately 85 percent of homes in the country have central gas heating systems. The proportion of energy that comes from natural gas has been growing while coal has been removed from the mix. The United Kingdom experienced less wind in 2021, which led to a decrease in the amount of electricity that was generated from wind. Because of this, the United Kingdom was forced to rely more heavily on gas in order to generate electricity (BBC News, 2022).

Finally, the conflict between Russia and Ukraine is the most critical contributor to the rise in the price of energy around the world. The effects of COVID-19 are still being felt around the world, and Russia's invasion of Ukraine is a severe cause for concern for both the economy of the entire world and the availability of crude oil. This is demonstrated by the fact that most European countries depend on Russia's oil and gas exports, which led to a supply shock that drove up the price of crude oil around the world (Adekoya, Oliyide et al. 2022). However, the strains placed on global energy supplies as a result of sanctions imposed on Russia's gas industry can encourage a more significant development of local energy sources such as coal and green energy (Boubaker, Goodell et al. 2022).

Policymakers in nations that are rich in resources and have thriving economies have been looking for effective methods of managing the economy, with the goal of boosting both improvements in physical and human capital. Since quite some time ago, they have had this as one of their primary focuses (Badeeb et al., 2017). Beyond the extraction and shipment of a single volatile good like oil, energy policies should strive for innovation and the achievement of economic transformation in addition to their primary objective of diversification. This is because innovation and economic transformation are key to the future of the global economy (Badeeb et al., 2017).

2.3 Electricity Overview

Electricity is the leading driver behind industrialisation, technological progress, economic expansion, and engineering transformation across the globe (Akuru, Onukwube et al. 2017). Electricity is utilised all over the world for a variety of purposes, including but not

limited to lighting, heating, cooling, cooking, transportation, and communication. It also has other applications in the fields of social work and environmental protection, such as the refrigeration of medicines in medical facilities.
Electricity is an essential component in a wide variety of manufacturing procedures. Additionally, it can assist in the reduction of air pollution in homes as well as other negative health effects brought on by the ongoing use of solid fuels such as charcoal and firewood (Best and Burke, 2018). Electricity not only illuminates the dark during the night but also enables households to cut down on the amount of time spent cooking by allowing them to store food in the refrigerator and reduces the amount of time spent searching for fuelwood, which ultimately results in healthier lifestyles. Because it enables workers to increase the number of hours per week that they can spend on productive work, the use of electricity in commercial and industrial settings also contributes to an increase in overall workforce productivity (World Bank, 2019b; Best and Burke, 2018).

The world's gross electricity production increased at an average annual rate of 3.3% between 1974 and 2017, going from 6,298 TWh to 25,721 TWh (IEA 2019a). Since 1974, there has been an average annual increase in the amount of electricity produced, except for the years 2008 and 2009, which were caused by the global financial crisis (IEA 2019). In 2017, 66.8 percent of the world's total gross production of electricity came from the combustion of combustible fuels such as natural gas, oil, coal, and biomass. This number represents a global average.

Figure 2.7 shows individual contributions made to the global electricity generation mix in 2017.

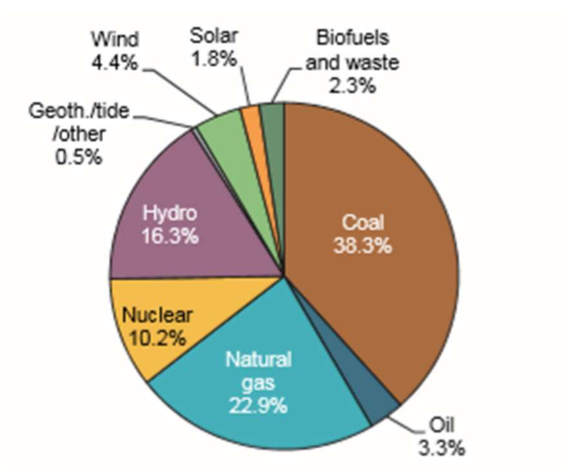


Figure 2.7 World gross electricity production by source in 2017
Source: IEA electricity information 2019 edition

Figure 2.8 shows that the consumption of electricity reached 21,372TWh in 2017, which is a 2.6% increase when compared to the previous year, 2016. In 2017, the commercial and public services sectors accounted for 31.7% of total electricity consumption, while the residential sector reported a 30.8 percent usage of the total electricity consumption. The industrial sector was the biggest end-user of electricity, consuming 32.2% of the total. The remaining end-users, such as transportation, agriculture, and forestry, accounted for a smaller portion of total electricity consumption (IEA, 2019c).

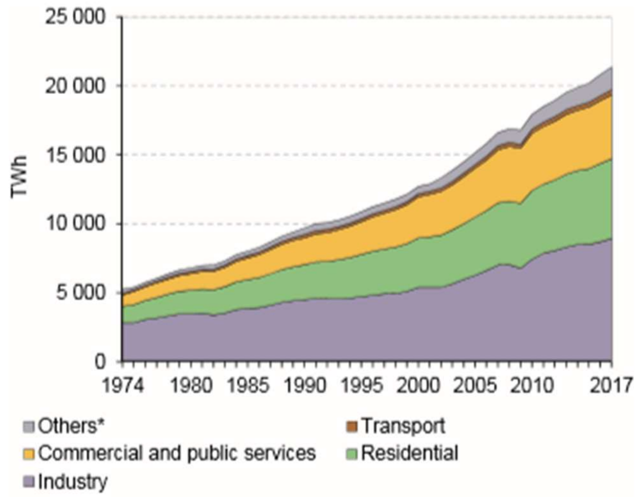


Figure 2.8 Global electricity final consumption by sector in 2017
Source: IEA electricity information 2019 edition

The rail industry is responsible for the majority of the industry's overall electricity consumption. Within the OECD countries in 2017, the road transportation sector experienced significant growth in the amount of electricity that it consumed. Since 2012, this growth has consistently been in the double digits, and in 2017, it reached a rate of 14%. This is because more electric cars are being sold in OECD countries, particularly in Europe, which has led to an increase in the electrification of the transportation sector overall (IEA, 2019a). According to the IEA, in 2018, nearly half of all newly purchased vehicles in Norway were electric vehicles. This marked the highest recorded sales of new electric vehicles in Europe, with 17% in Iceland and 8% in Sweden. In the United States, the percentage was lower at 8%. On the other hand, this only makes up 0.06% of the OECD's total road energy consumption and 0.08% of the OECD's total final electricity consumption (IEA, 2019b) As shown in Figure 2.9, the countries that consumed the most electricity that were not members of the OECD were China, India, Russia, and Brazil in 2017. China consumed the greatest proportion of the total amount, which was 46.7%.

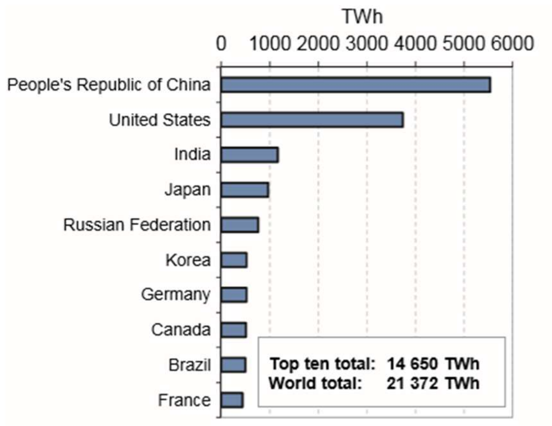


Figure 2.9 World Top ten electricity consuming countries in 2017
Source: IEA electricity information 2019 edition

2.4 Focus of Previous Studies

2.4.1 Electricity in Nigeria

Nigeria's power system is currently hampered by the losses between power generation and consumption. While power generation capacity is about 13 GW, just about 3.4 GW is consumed by the end-users, with a peak operating capacity of 5.2 GW attained in 2018 (IEA, 2019a). Figure 2.10 shows the peak electricity generated and consumed in Nigeria in 2018.

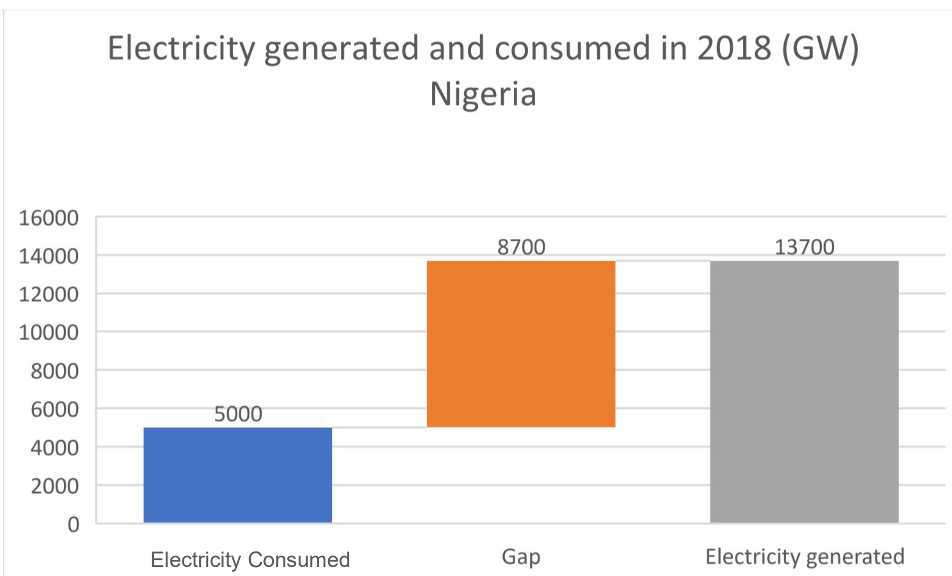


Figure 2.10 Electricity generation and consumption in Nigeria (IEA, 2019a)

The gap between electricity generation and consumption in Nigeria in 2018 was as due to a lack of gas availability, a shortage of water supply, constraints imposed by the grid, and technical issues (Siemens, 2019).

Up until the year 2005, when the Electricity Power Sector Reform Act (EPSRA) was passed into law, the Federal Government of Nigeria (FGN) was the only entity that was accountable for the policy design, regulation, and financing within the power sector. Even though the Federal Ministry of Power (FMP) oversaw regulating the power industry, the National Electric Power Authority (NEPA) oversaw managing the operation. Between the years 1972 and 2005, the Nigerian Electric Power Authority (NEPA) was the government agency in charge of generating, distributing, and transmitting the nation's electrical power. During this time period, NEPA maintained complete control over the distribution and transmission of electrical power, as well as approximately 94% of the generation.
The first two power generating sets in the country were installed in the colony of Lagos in 1896, marking the beginning of the generation of electricity in the country. The first electric utility company in Nigeria, which would later be known as the Nigerian Electricity Supply Company, was established in 1929. An act of the Nigerian Parliament in 1951 led to the establishment of the Electricity Corporation of Nigeria, also known as ECN. The Niger Dams Authority (NDA) was established in 1962 with the purpose of fostering the growth of hydroelectric power in Nigeria. National Electric Power Authority (NEPA) was established as a result of a merger that took place in 1972 between the Electricity Corporation of Nigeria (ECN) and the Niger Dams Authority (NDA) (Ikeme and Ebohon, 2005).

In 1998, the Federal Government of Nigeria made changes to the principal laws that were in effect at the time, which were the Electricity Act and the NEPA Act. These changes were made to address issues on the electric power sector's poor operational and financial performance. These changes included the elimination of NEPA's monopoly and the encouragement of private investments in the sector. The National Electric Policy was drafted in the year 2001 with the goal of elaborating on the planned changes and developing a competitive electricity market. The Electricity Power Sector Reform Act (EPSRA), which was passed in 2005, laid the legal groundwork for the privatisation of the companies, the establishment of successor companies, and the division of NEPA. In addition, the year 2005 saw the establishment of the Nigerian Electricity Regulatory Commission (NERC) and the Power Holding Company of Nigeria (PHCN). The Nigerian Electricity Regulatory Commission, also known as NERC, is an independent organisation that serves as a regulatory body for the Nigerian electricity sector. The National Electric Power Authority (NEPA) split into six generation companies, eleven distribution companies, and one transmission company, which resulted in the creation of 18 successor companies. One of these successor companies was the Power Holding Company of Nigeria (PHCN), which was a transitional corporation (GIZ, 2015).

During the phase before the transition, the Electricity Generation Companies (also known as GENCOs) were put up for sale (thermal and hydropower stations). Distribution was partitioned into the 11 companies that would go on to become the Successor Electricity Distribution Companies (DISCOs). The handover of the assets was the last step in the privatisation process, which was finished in November 2013, and there was a total of six GENCOs and eleven DISCOs. However, the federal government kept control of the transmission system through the Transmission Company of Nigeria (TCN). Transmission lines and generators are both connected to the same grid, which is managed from a centralised location in Oshogbo, which is located in the state of Osun.

After this, the Federal Government of Nigeria established the Nigerian Electricity Regulatory Commission (NERC) and the Nigerian Bulk Electricity Trading Plc (NBET), both of which will continue to operate until the complete privatisation of the electricity market. After the power purchase agreements have been finalised and signed, NBET's responsibilities will be transferred to the DISCOs. The Federal Government of Nigeria also established the Nigerian Electricity Market (ONEM) operator within the Transmission Company of Nigeria (TCN). ONEM is responsible for managing the metering systems used by all the generation, transmission, and distribution companies in Nigeria. ONEM is also the operator of the wholesale market and settlement.

The lack of new capacity added to the national grid and to any of the power stations in Nigeria is the root cause of the country's electricity woes. During the 1990s, fewer investments were made in the public power sector, which led to reduced maintenance budgets and a stagnation in the addition of new capacity. As a direct consequence of this, by the end of the 20th century, there was a continuously widening gap between the capacity for generating electricity and the actual amount that was generated. The unreliable and unstable nature of the country's electricity supply was not resolved by this issue, which remained a problem. The reliability of the country's electrical supply was one of the primary motivations behind the government of Nigeria's decision to privatise the power sector in 2013. In addition to the challenges, it is facing in the area of electricity, Nigeria is also dealing with problems in an industry that was historically successful: the oil industry (GIZ, 2015).
The availability of electricity is and will continue to be a significant factor in determining the location of industries and a powerful driver of social development. Hydropower, steam turbines, and gas turbines are the three primary methods that are utilised in the commercial production of electricity in Nigeria. The amount of installed capacity for the generation of electricity in 1991 was 5881.6 MW, following an increase that was equivalent to a factor of 6 during the time span spanning 1968 and 1991 (ECN, 2018). As a direct consequence of this, Nigeria's total generating capacity did not change over the course of the subsequent decade, even though its availability ranged from 27% to 60% of its installed capacity, with transmission and distribution losses accounting for approximately 28% of the electricity generated (ECN, 2018).

At the close of the year 2001, the total amount of generating capacity that was available across the nation reached 4,000 MW. Nevertheless, this decreased to 2,600 MW by the time the first quarter of 2002 had passed. The second quarter of 2018 saw the highest peak generation of 5,375 MW, and this dropped again to 3,027.4 MW at the beginning of the third quarter of 2018. The total installed capacity of the grid's generators was 12,910.40 megawatts (MW), while the average available capacity was 7,652.60 MW, and the transmission wheeling capacity was 8,100 MW. As a direct consequence of this, the annual consumption of electricity had skyrocketed over the course of the previous three decades, going from 1,273 GWh in 1970 to 29,573 GWh in 2012 before levelling off at 25,215 GWh in 2017 (ECN, 2018).

As can be seen in Figure 2.11, there is a significant gap between the amount of power that is installed capacity, the amount of power that is generated, and the amount of power that is distributed to consumers. Access to energy is currently at about 60 percent, but the government plans to increase that number to 90 percent by the year 2030 (Otobo, 2022; Emodi, N. V. and Boo, 2015).

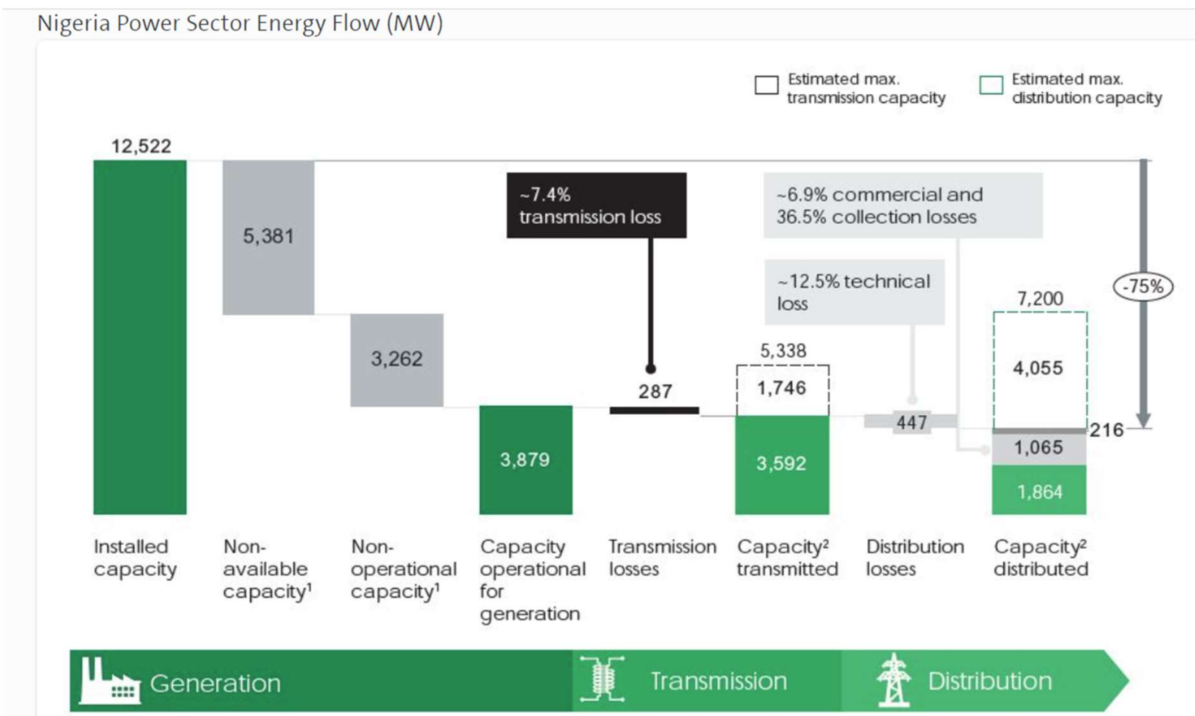


Figure 2.11 Capacity, demand, and losses across the Nigerian electricity network

Source: (Power Africa, 2015)

Recent statistics indicate that the residential sector in Nigeria is responsible for more than half of the country's overall consumption of grid electricity, while the industrial and commercial sectors each account for approximately one quarter of the total (ECN, 2018). Considering the growing demand for electricity in Nigeria, policymakers should develop reforms that will attract investment to the sub-sector, increase and maximise the available installed capacity, and decrease transmission and distribution losses.

2.4.2 Privatisation of Electric Power Utility companies

The privatisation of electricity utility companies has been debated for many years. The argument for privatisation is that it leads to increased efficiency and reduced costs, while the argument against it is that it can lead to higher prices and reduced access for low-income households.

Studies have shown the benefits of privatisation to include increased efficiency, improved service quality, and reduced costs (Anderson, 2009; Ariyo and Jerome, 1999; Adhekpukoli, 2018; Estache et al., 2009)

One of the main benefits of privatisation is increased efficiency. This is because private companies are driven by profit and are more likely to find innovative ways to reduce costs and increase productivity. In addition, this is because private companies have a greater incentive to increase profits, whereas political considerations often drive public companies. According to a study conducted by the World Bank, privatisation can increase efficiency by as much as 40% (World Bank, 2019a).

Private companies may respond more to market demands and have more significant incentives to invest in new technology and infrastructure. In addition, private companies can operate without government bureaucracy and regulations, leading to cost savings and increased productivity. According to the Organisation for Economic Co-operation and Development (OECD), on average, privatised utilities in developed countries have achieved more significant productivity gains than those under public ownership (OECD, 2016).

Another benefit of privatisation is improved service quality. Private companies are under pressure to provide high service to their customers to maintain their reputation and increase profits. This can lead to better customer service, faster response times, and improved reliability. A study conducted by the UK government found that the quality of service provided by privatised companies was higher than that provided by publicly owned companies (Anderson, 2009).

Privatisation can also lead to reduced costs for consumers. Private companies are more likely to find innovative ways to reduce costs and increase efficiency. This can lead to lower prices for consumers. For example, in Chile, the privatisation of the electricity sector led to a 20% reduction in electricity prices (Estache et al., 2009).

Studies have shown that the disbenefits of privatisation could include higher prices, reduced access for low-income households and loss of control (Estache et al., 2008; Estache et al., 2009; Ariyo and Jerome, 1999).

One of the main disbenefits of privatisation is higher prices for consumers. Private companies are driven by profit and are more likely to increase prices to increase profits. This can lead to higher prices for consumers, particularly for low-income households. A study conducted by the UK government found that privatisation led to higher prices for consumers, particularly for low-income households (World Bank, 2019). Opponents of privatisation argue that it can create monopolies or oligopolies in the electricity market, leading to higher consumer prices. In addition, private companies may be less inclined to serve rural or low-income areas with lower profits, reducing access for those populations (Anderson, 2009).

In some cases, the privatisation of electric utilities reduced access for low-income households. In addition, private companies may be less willing to provide services to low-income households as they may be less profitable (World Bank, 2019).

Privatisation can also lead to a loss of control over the electricity sector. Private companies may be less responsive to the needs of the public and may prioritise profits over public service. This can lead to a loss of control over the electricity sector, particularly in countries where the government has limited regulatory capacity. A study conducted by the UK government found that privatisation led to a loss of control over the electricity sector (Anderson, 2009; Ariyo and Jerome, 1999; Estache et al., 2008).

In conclusion, privatising electricity utility companies has benefits and disbenefits. The main benefits of privatisation are increased efficiency, improved service quality, and reduced costs. However, the main disbenefits are higher prices, reduced access for low-income households, and a loss of control over the electricity sector. Therefore, policymakers should carefully consider these factors when deciding whether to privatise electricity utility companies.

2.5 Load Forecasting

Load forecasting is a critical activity in planning, designing, and operating electric power systems. Both industrial and governmental sectors use it to create accurate electric load models required for planning and operation (Singh et al., 2013). Electric load forecasts allow system operators and policymakers to question consistent planning activities and make informed decisions about load electricity trading and electricity demand by providing an accurate electric power model (Mbuli et al., 2020).

Load forecasting is used to determine the quantity of electricity generated and the type and location of infrastructures required for electricity generation and distribution, load switching, and electricity trading. This is done by creating models based on historical performance data used to predict electric load over various timeframes within a defined planning horizon (Khwaja et al., 2020; Jacob et al., 2020; Mbuli et al., 2020).

Electric utility companies use load forecasting to maintain adequate electricity supply, reduce waste, and make profitable decisions regarding the market. This is especially helpful as it is difficult to store electricity. Forecasting predicts future load based on weather conditions, electricity tariffs, geographical locations or periods set like months or hours.

Electric load forecasting can be grouped into four main categories according to timescales known as ultrashort term, short-term, medium-term, and long-term predictions. The ultrashort term usually ranges between second minutes or several hours. Short-term forecasts are cover periods ranging from an hour to a week. Medium-term forecasts range from a week to a year, and long-term forecasts range between a year and decades (Harish and Kumar, 2016; Mbuli et al., 2020).

Several authors have proposed different ways of categorising load forecasting techniques. According to Singh et al., load forecasting techniques can be presented in three groups: traditional, modified traditional, and soft computing techniques, as shown in Figure 2.12 - Classifications of load forecasting techniques (Singh et al., 2013).

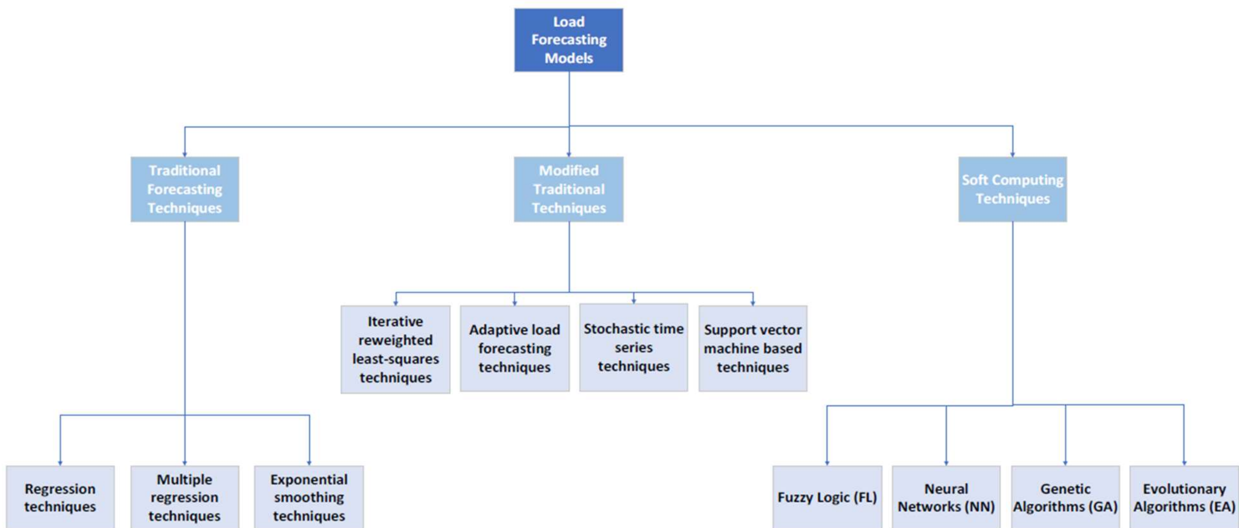


Figure 2.12 - Classifications of load forecasting techniques (Singh et al., 2013)

Estebsari et al. classify load forecasting into two broad groups based on time and geographical location, as shown in Figure 2.13.

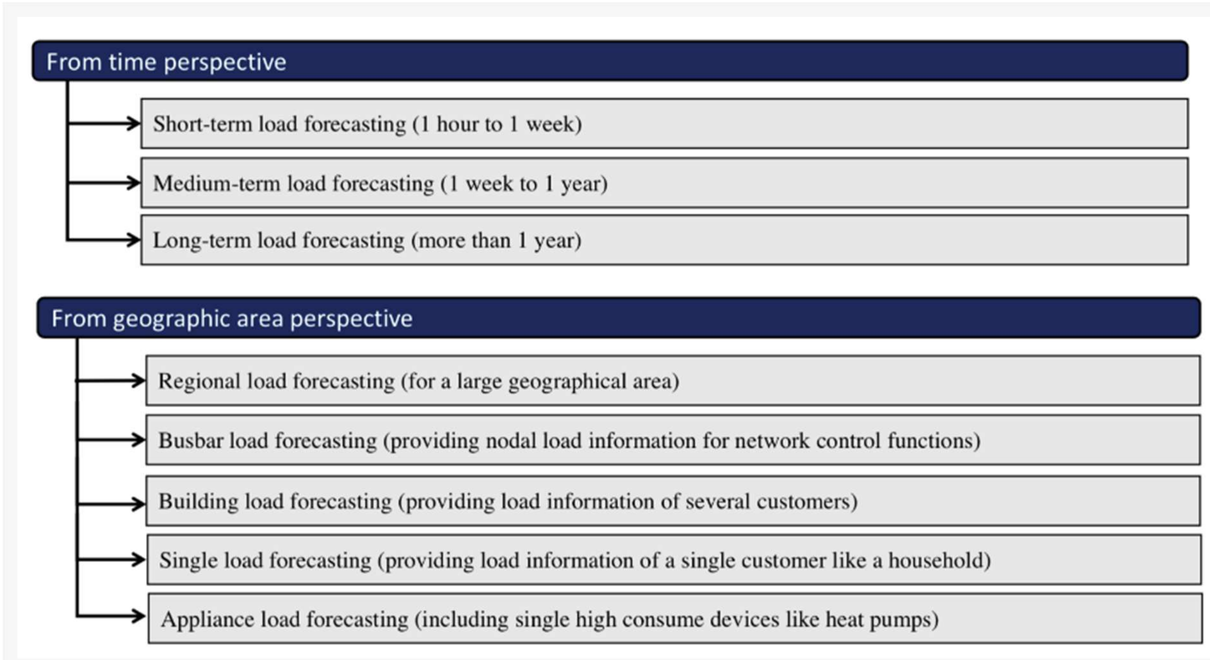


Figure 2.13 – Different types of load forecasting techniques (Estebsari and Rajabi, 2020)

There are different classifications for electric load forecasting, the fundamental techniques for creating these forecasts are primarily the same in all the literature that was reviewed. These techniques range from the more traditional methods to the more contemporary and sophisticated artificial intelligence/machine learning (ML) based methods. The conventional or tried-and-true methods of load forecasting include things like time series regression and multivalent regression, amongst others. Methods that fall under the umbrella of artificial intelligence or machine learning include fuzzy logic, support vector machines (SVM), convolutional neural networks (CNN), and artificial neural networks (ANN), amongst others. These alternative methods of forecasting produce better results than the traditional approaches. According to the research that was conducted for this study, it was discovered that demand forecasting techniques that are based on AI/ML or soft computing methods are regarded as being more accurate and effective.

Different methods of forecasting like, time series, regression genetic algorithms, neural networks, fuzzy logic, ARMA model, ARIMA model, and others, each have their own set of advantages and disadvantages. In order to get around the restrictions imposed by individual methods of forecasting; it is sometimes necessary to combine several different approaches to produce a hybrid method. Researchers are showing a growing preference for the use of hybrid methods (Khwaja et al., 2020; Singh et al., 2013).

One more method for classifying load forecasting techniques is based on the degrees of mathematical analysis involved. Methods can be considered as either quantitative or qualitative. Methods such as and the Delphi method fall under the category of qualitative forecasting techniques. Planning is where qualitative forecasting techniques find their primary application. Quantitative methods such as regression analysis and exponential smoothing are included (Singh et al., 2013).

When historical data is available for analysis, a specific type of quantitative method known as time series forecasting techniques is utilised. The historical data is gathered at consistent intervals in order to forecast future loads in the same patterns. For instance, if the historical data is gathered in months, then it is utilised to forecast load levels for the months that are to come.

It has been determined by Mbuli et al. that load forecasts can be broken down into three different components: trend, seasonality, and irregular components. The term "trend" refers to the data that is averaged over a predetermined number of time intervals or cycles for the purpose of presenting the predicted load forecast. The pattern of the same data repeating over the course of a period is what is meant to be presented by seasonality. Irregular components are the component of the time series that cannot be explained and influence the trend and seasonality of the data. Time series, trends, and seasonality can all be defined, but the irregular component is referred to as stochastic (Khwaja et al., 2020; Singh et al., 2013).

Artificial Neural Networks, also known as ANN, are the AI technique that is used the most frequently. ANN is intended to mimic the way in which human minds work to process information (Ahmed and Khalid, 2019; Jacob et al., 2020). A neural network may consist of one layer or multiple layers. In shallow learning, the neural networks have only one or two hidden layers and are designed to support rapid calculation. The use of multi-layered neural networks in deep learning software results in more precise predictions being made. However, one of the drawbacks of deep learning is that it can result in increased complexity and cost. As a result, it ought to be utilised in circumstances in which the essential prerequisite for the necessary forecasting models is either the availability of time or the efficacy of computation. As a result, shallow neural networks like the multi-layer perceptron (MLP) that only have one hidden layer are utilised more frequently (Jacob et al., 2020).

2.6 Overview of an Electric power system network

As seen in Figure 2.14 the electrical system comprises of generation, transmission, and distribution systems. Electricity generation is the process of converting one type of energy into electricity. Non-renewable sources of electricity include hydro, thermal, and nuclear power plants, as well as renewable sources such as solar, wind, and others. The transmission system transports bulk electricity, whereas distribution systems deliver power to users (Kumar, A., L and Sundaram, 2020).

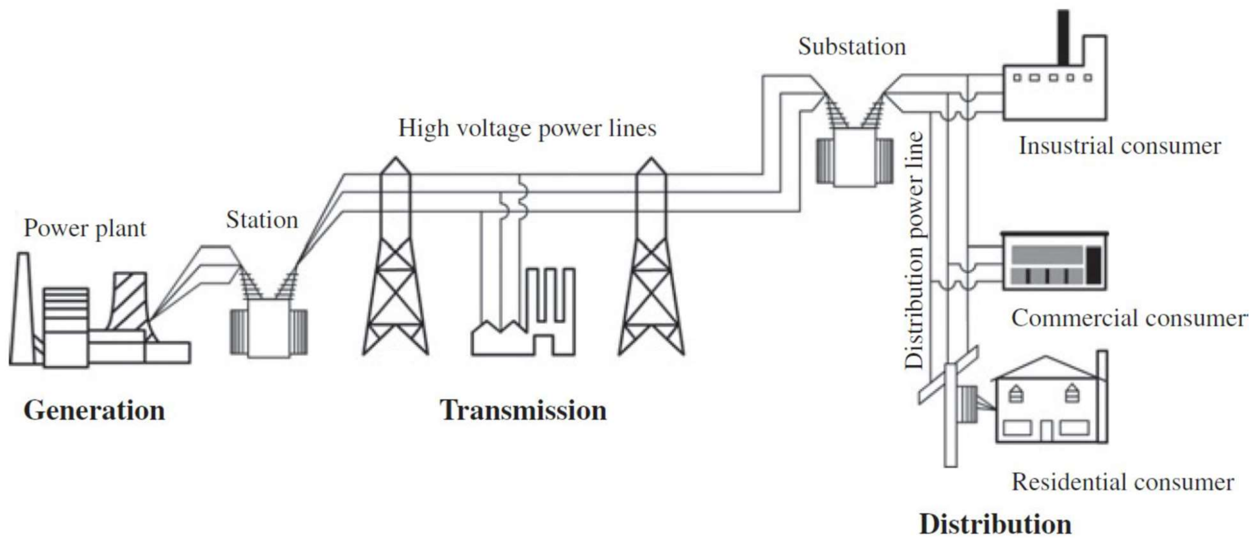


Figure 2.14 Layout of Electric Power Flow - Source: (Kumar, A., L and Sundaram, 2020)

2.6.1 Electrical System Components

Generators

A generator changes mechanical energy into electrical energy. The voltages at the producing side could be between 6.6 kV to 33 kV, but they can be increased up to 132 kV/330 kV in order to lower the amount of current flowing down the transmission line and cut down on the amount of energy lost during transmission. Real power (MW) and reactive power (MVAr) are both produced by generators (Kumar, A., L and Sundaram, 2020).

Transformers

It is a stationary instrument that constantly distributes electricity from one location to another. Transformers' primary job is to raise power from low to high generation levels, as well as to lower explosion rates from high to low transmission rates. When the transmission voltage is raised, the grid's current flow drops, and therefore the transmission loss lowers (Kumar, A., L and Sundaram, 2020).

Control Equipment

Under regular and exceptional situations, a circuit breaker is utilised to turn on and off the circuit (fault). Oil, SF6, vacuum, and air blast circuit breakers are examples of breakers. The error status will allow the circuit breaker to function during the transfer. Isolators are used in substations to isolate a portion of the system for repair. It can only function when there is no load. On each side of the circuit breaker, isolated switches are supplied. Busbar electrically links many lines that operate at the same voltage. It is constructed of either copper or aluminium. Single busbar, ring busbar, double busbar and other bus configurations are available (Kumar, A., L and Sundaram, 2020).

Transmission System
It only transmits massive blocks of electricity to bulk power plants or to extremely large users. It does this by connecting the producing stations that are near one another to form a power pool, which is the interconnection of two or more generating stations. Because of the fluctuation in load, the tolerance for the voltage of the transmission line is between 5% and 10% (Kumar, A., L and Sundaram, 2020).

Primary Transmission
After the power is generated, it is sent out along transmission lines. In order to cut down on the amount of electricity that is wasted, the voltage is increased while the line current is decreased. Step-up transformers are often installed in generating stations so that the output voltages may be increased to greater values. High-voltage lines consisting of three phases and three wires are used to carry electrical current from the substations at the sending end to those at the receiving end. Primary transmission voltages could be132 kV, 330kV, or 760 kV (Kumar, A., L and Sundaram, 2020).

Secondary Transmission
Step-down transformers are utilised in order to lower the voltage at the receiving end to a value that is either between 66 kV or 11 kV. The receiving end and the secondary station can communicate with one another due to the secondary transmission line. It operates on a three-phase, three-wire system, and the operators that it employs are referred to as feeders (Kumar, A., L and Sundaram, 2020).

The Distributional System
A distribution system is the portion of the power supply that links all customers to a point in a power source in bulk or a transmission line. Power is distributed to residential, commercial, and small users via the distribution channel. Distribution transformers are often positioned on stables or on a plinth near customers (Kumar, A., L and Sundaram, 2020).

Primary Distribution
At the secondary substations, step-down transformers bring the voltage down to a level between 11 kV or 6.6 kV, depending on the application. Power is sent to the primary distribution system through the primary distributor, which is the link between the secondary substation and the distribution substation. This system employs a three-phase, three-wire system.

Secondary Distribution
Step-down transformers bring the voltage down to the required voltage level. The distribution lines are laid along the roads, and the service connections to the customers

are plugged off from the distributors and use a 3-phase 4-wire system. Loads that only use one phase are connected to a phase wire and a neutral wire.
Electric power distribution is one of the most important aspects of electric power infrastructure since it is the part of the infrastructure that receives electricity from a high-voltage transmission system and distributes it to end-users. The key components that make up an electric power system are broken down visually in Figure 2.15. A power distribution system will typically begin with the distribution substation, which is the point at which the system begins to receive electricity from power generation plants using interconnected transmission networks. These networks are typically either low-voltage (LV) or medium-voltage (MV) (Anwar and Pota, 2014).

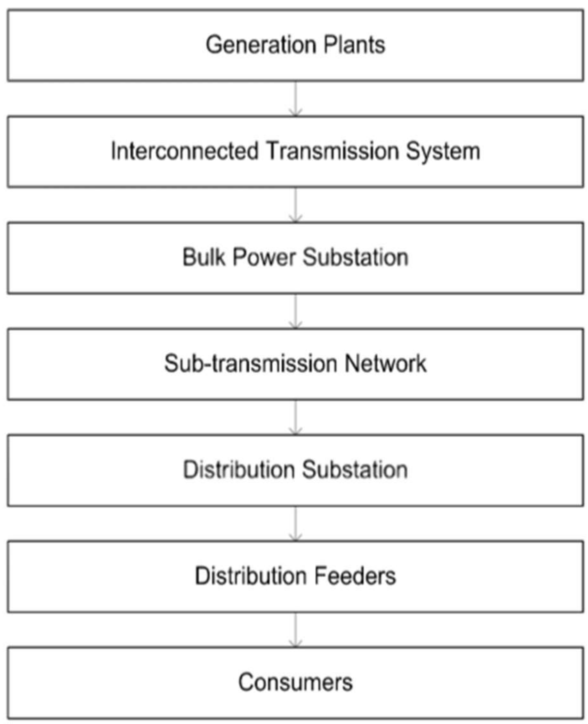


Figure 2.15 Overview of an Electric Power System

Figure 2.16 represents a power distribution system with a single distribution line. Its primary utility distribution equipment includes electricity supply lines, tap-changing transformers, protective devices, switches, voltage regulators, and reactive power compensation devices.

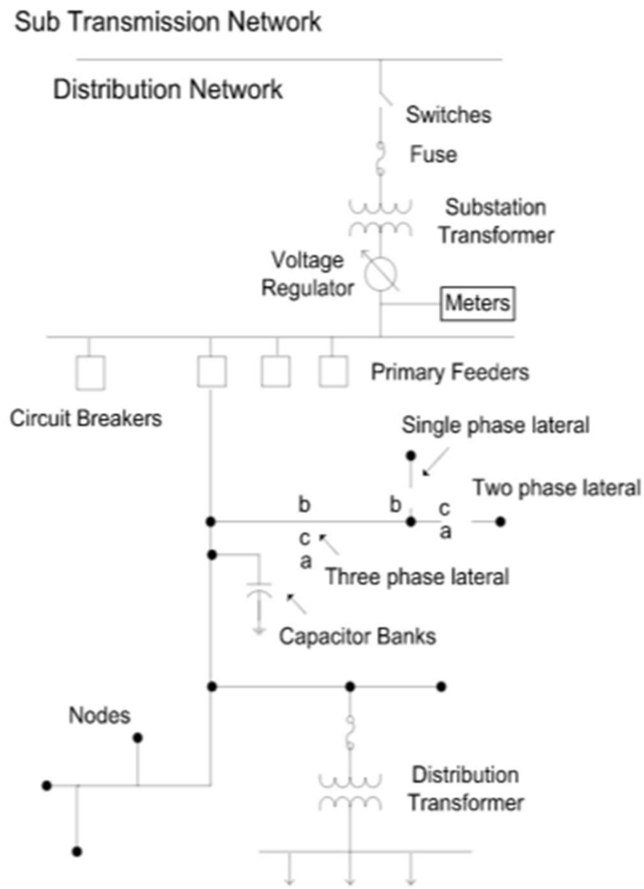


Figure 2.16 Components of a distribution system – Source (Anwar and Pota, 2014)

The substation transformer is considered the centre of a simple distribution substation. In addition to these functions, a substation's other functions include the performance of operating contingency metres and switching and protection. Power delivery lines' job is to transport electricity from a substation to the homes and businesses that need it. In electricity supply lines, overhead and subterranean conductors of varying kinds and capacities are utilised, ranging from low to extremely high. Voltage dips happen whenever electricity travels through electric distribution conductors because these conductors have a high resistance (R) to the reactance (X) ratio. These voltage drops result in a loss of power inside the system (Anwar and Pota, 2014).

Voltage regulators are used to keeping voltage variations within a safe range. Power distribution systems also use distribution transformers to alter the system voltage and current, as well as protective mechanisms to identify the location of faults and isolate malfunctioning components. Radial, loop, and networked distribution structures are all viable options. Most systems, however, are radial, with just one electricity route from a distribution substation to consumers (Anwar and Pota, 2014). As a result, this setup is less dependable than the other two, but it does have the following benefits that make it worth considering;

- Protection is easier to reach, and fault currents are reduced.
- Power and voltage regulation are improved.
- Savings in costs or resources
- Simpler repairs and upkeep
- Reduced planning complexity.

2.6.2 Optimal Power Flow (OPF) analysis

The current situation in electrical power system engineering is primarily characterised by issues such as power shortages, blackouts, load shedding, and an inability to adequately supply the necessary demand for electricity, amongst other related issues. As a result, either additional power plants are constructed, or existing plants are upgraded. Therefore, power flow analysis is essential in understanding the current system to plan optimal ways to add new plants or enhance the existing infrastructure. Furthermore, policymakers and engineers make use of power flow analysis when constructing power systems that are safe, stable, and dependable (Kumar, S. D., 2012).

Presently, the power industry faces several significant obstacles: providing customers with a quality and dependable electric power supply, minimising production cost, pollution, and loss, and increasing voltage levels. Furthermore, power systems' size and operating limitations are expanding due to the rising demand for electrical energy. Therefore, it is the responsibility of power system experts to offer customers with continuous, consistent, and high-quality electricity. These issues highlight the importance of understanding power system stability (Kumar, A., L and Sundaram, 2020).

Optimal power flow provides a basis for assessing a power system's security, dependability, and commercial performance. Optimal power flow is the distribution of the flow of electric power when the system satisfies the operation conditions and works within the optimal performance conditions by modifying the relevant variables (Zhijian et al., 2016).

Examining the power flow provides information regarding the active and reactive power flows down the lines, the phase angles, and the voltage magnitude of the buses. An Optimal Power Flow (OPF) analysis enables the process of transforming the system into one in which a practical application of load flow analysis may be utilised (Haque, 1996).

The current situation calls for greater efficiency in using electric power while also ensuring the safety and dependability of power distribution. Transmission line power flows that are not uniform harm system stability and security, leading to decreased voltage profiles overall. When compared to typical power flow levels, it is much lower or higher in some lines. Because of this, most power system loads are wired into distribution networks with low-voltage power. A system's electrical loads might be residential, industrial, or commercial. In practice, distribution system voltage and frequency changes affect loads' active and reactive powers. Therefore, active, and reactive power requirements are typically assumed to be given constant quantities in traditional load flow analyses.

However, in practice, the active and reactive power demands of the commercial, residential, and industrial loads are inconsistent (Kumar, A., L and Sundaram, 2020). Changes in the system's voltage and frequency cause changes in the system's active and reactive powers, respectively. When these factors are included, the outcomes of load flow and optimum power flow analyses can shift significantly. For example, when voltage-dependent load models are added to an OPF analysis, the difference in fuel costs is most apparent. This has repercussions for the amounts of active and reactive power needed, as well as for losses and voltage levels (Kumar, S. D., 2012).

The following are some of the benefits of using load modelling in OPF:

- The precise estimation of the power demand at each bus (active and reactive power)
- Adjusting the power demand with voltage offers improved control.
- Managing excessive and insufficient voltage on load buses
- Reduction of losses.
- Enhancement in voltage profile.
- A decrease in the cost of additional fuel used.

The results of the OPF analysis are primarily used to look at the current state of the system and compare the efficiency, safety requirements, and cost of different plans for expanding the system in the future to meet the growing requirement of the loads. When designing an existing power system extension or building a new one to meet rising demand, the crucial consideration is the load flow solution that must be satisfied. These assessments include various load flow solutions in normal and abnormal operating conditions (due to transmission line or generator failure). In addition, if the system's transient behaviour is examined, the load flow analysis will provide the starting conditions (Kumar, S. D., 2012).
The following processes must be followed to get the load flow analysis of any specific system:

1. The development of the equations that describe the current network.
2. Choosing an acceptable mathematical method or methodology for solving the equations

As loads and generation are constantly changing in a real power system, it is assumed that loads and generation remain constant at a specific rate for appropriate durations while trying to solve load flow problems. This is done to make the equations easier to understand. For example, depending on the data, this might be once every hour, once per month, etc (Kumar, S. D., 2012).
The following factors are considered in load power analysis:

- The amount and angle of voltage at each node along the feeder.
- The line flow must be specified in kilowatts (KW) and kilovolt-ampere-resistance (KVAr) for each line segment.
- Power decrease over the whole line.

- Total feeder input in kilowatts (KW) and kilovolt amperes (KVA).
- The feeders' overall power losses.

The Categories of Buses

Electric power system buses can be categorised into the following three groups:
1) The PQ (Load) bus
2) The PV (Generator) bus and
3) The Slack (Reference) bus.

PQ bus

This bus's active power (P) and reactive power (Q) are calculated and known. The magnitude and phase angle of the voltage, represented by (V), is unknown.

PV bus

In the PV bus, the active power (P), and voltage magnitude (V), are both known. As a result, both the phase angle and the reactive power (Q) must be calculated. These buses are sometimes known as generator buses or voltage-regulated buses. These buses offer the upper and lower bounds for the value of reactive power.

The Slack bus

This bus varies from the last two in that it does not specify the real and reactive powers (P and Q). This is the distinctive quality that sets it apart. Only the voltage and phase angle magnitude have values; the remaining quantities must be estimated. Only one of these buses is operating at any given time in most power systems. The swing bus or reference bus is another name for this vehicle. This bus adjusts for the difference in expected loads and generated power caused by network losses. The difference is made up by the power lost in the network.

2.6.3 Methods for Solving Load Flow

The following approaches are used to solve a Load Flow Problem.

- Gauss-Seidel
- Fast Decoupled
- Newton-Raphson

Gauss-Seidel Method

The method was developed by two German mathematicians, Gauss, and Seidel, and it is applied when solving linear system equations.

The approach is an advanced form of the Jacobian technique. It is designed for non-zero diagonal matrices; however, it only works if the matrix is diagonally symmetric. The Gauss-Seidel (GS) method can repeatedly solve a series of nonlinear algebraic equations.

The Newton-Raphson Method

This approach is used in a bus power system with a fixed number of equations for real power and reactive power. The number of equations to be solved is defined by the number of buses supplied and the real and reactive power of the buses in the system. The unknowns are power angles on all buses except slack and bus voltages on the load bus (Kumar, S. D., 2012).

When using the Newton method to solve OPF, the objective function is calculated as the total of the cost functions of the outputs of the generators' active power. The upper and lower bounds on the following are the inequality constraints: the power outputs of the generators, phase-shift angle, the buses' voltages, and the transformers' tap ratios (Das, 2017).

Fast-Decoupling Approach

This power flow analysis option needs additional implementations than the Newton-Raphson method; however, each iteration takes a lot less time so that the power flow solution can be found promptly. Therefore, this approach is highly beneficial for contingency analysis when modelling many outages or when an online control power flow solution is required.

The Newton-Raphson method was adopted in this study due to the data available about the IEEE 30 bus case and its suitability for the MATPOWER analysis tool on MATLAB.

2.6.4 Challenges faced in Optimal Power Flow

OPF's fundamental purpose is to minimise transmission loss while ensuring steady operation and high-quality power delivery. OPF is therefore used to minimise electricity production costs. The power balancing equation provides the equality constraint for the OPF issue; it is derived from load flow analysis, which stipulates that the generation of real and reactive power should equal the demand and losses of real and reactive power. Therefore, control and dependent variables in OPF problems have lower and upper limits, and the limitations on Power Flow in transmission lines generate inequality constraints. Real power generation, generator bus voltages, and transformer tap positions are the problem's control variables; the dependent variables are load bus voltages, reactive power generation, and MVA flow in the transmission lines (Kumar, A., L and Sundaram, 2020).

Nitrogen oxide, sulphur oxide, and carbon oxide emissions into the atmosphere are significant factors in power system design. Another issue with the current power system is that the utilities are struggling to keep up with the rising demand for electric power, even though there are widespread solutions like the extension of the transmission network and the construction of additional generating facilities. New generating stations and transmission lines are either delayed or avoided in many regions of the world due to

concerns about pollution and global warming, economic factors, and new legislation (Kumar, A., L and Sundaram, 2020).
In a deregulated power system, Electrical power engineers also have to deal with congestion and unstable voltage. In the modern world, people are using more power, so the power system must be restructured to meet their needs. When power systems are restructured, the transmission lines are used as much as possible. When the power system is deregulated, the generation, transmission, and distribution systems are broken up into separate companies. In a market for electric power that is so open to private players, power transactions are competitive. Because the sender and the buyer are selling and buying power in such a competitive way, the stability and reliability of the transmission line weaken over time. Some of the people in the electricity market violate the stability and thermal limits of transmission lines by overburdening them. These lines are called "congested lines." Congestion not just affect how safe and stable the power network works, but it will also have a big effect on how the grid is priced and how power plants bid for contracts. So, it is crucial to research and think about how to deal with power system congestion (Kumar, A., L and Sundaram, 2020).
When solving the power flow problem, the objective function must be created initially. Any parameter optimization, such as reducing fuel costs or active power losses, or any desired criterion, may be included. The formulation differs based on the derived objective function. The following approach, for instance, might be used to determine the formulation of the issue if the goal is to reduce the cost of gasoline. The most popular cost function is quadratic, with input to the units in terms of either total fuel energy per hour or total fuel heat per hour. A technique is then chosen to address these problems once the technical specifics have been written as equations. Any of the above-described approaches can be used to find the answer (Kumar, A., L and Sundaram, 2020).

2.7 Power Systems Expansion Planning

Because of the rise in population around the world, there is an ongoing need to make certain that the generation and supply of electric power are adequate to meet the requirements of the commercial, industrial, residential, and transportation sectors. Planning for the expansion of power systems is done to figure out the best approach to extending power generation, transmission, and distribution networks at the lowest possible cost while still making room for future expansion (Covarrubias, 1979).
The two most common kinds of planning for the expansion of a power system are referred to as Generation Expansion Planning (GEP) and Transmission Expansion Planning (TEP). GEP and TEP are immensely helpful in assessing the feasibility of obtaining the desired outputs from building new generation power plants or new transmission facilities due to the high capital investments that are required for these types of projects. (Hemmati et al., 2013; Bent and Toole, 2012).
The authors of the 2018 study by Gacitua, Gallegos, and others argue that the complexity of modern energy systems makes it difficult to construct models that accurately represent

long-term horizons while also preserving computational compliance. Because of this, several models have been developed for the purpose of expansion planning. These models have been designed in such a way that they permit each study to have adequate coverage while maintaining an overall perspective of the system. According to Zhu and colleagues, GEP is a difficult problem to solve because of the size, non-linearity, and long-term nature of power generation units.

GEP has always attracted more attention from investors and customers due to the high investment that is required to increase energy production. This is because GEP is more environmentally friendly. The investment planning for GEP should consider the following factors: timeframe, new generation units technology, size, investment recovery, and risks. This will ensure that investors get a good return on their capital and that end consumers are happy with the product. The primary goal of the GEP is to expand the existing power system in order to meet the anticipated increase in future demand while simultaneously meeting the criteria for system reliability (Hemmati et al., 2013).

Bent and all have acknowledged the benefits of conducting a combined transmission and generation expansion planning. Throughout history, TEP and GEP have been approached separately due to the computational difficulties involved in simultaneously solving both problems at the same time. Nevertheless, by utilising powerful multiprocessors, this issue was eventually resolved.

The TEP problem consists of determining which types of transmission lines are required as well as the appropriate time to build them. Transmission line impedance, voltage, impedance, and thermal capacity requirements are typical components of TEP problems, which are typically solved independently from GEP. TEP problems also typically involve a few other transmission line attributes. Typically, a TEP problem is solved after a GEP problem in order to support a generation investment plan by ensuring sufficient transmission capacity within the same period at a minimum cost. This is done to support a GEP problem. TEP models that have a centralised planner are typically designed to minimise the investment cost for additional transmission lines and operational costs while maintaining the system's integrity and reliability within the planning timeframe (Gacitua et al., 2018).

According to Hemmati et al. 2013, some researchers do not consider reliability and security a mandatory issue in expansion planning, while other researchers consider reliability a mandatory problem. They are of the opinion that carrying out this strategy will lead to the development of expansion planning that is dependable as well as adaptable. According to them, the goals of GEP and TEP are different in regulated power systems in comparison to unregulated power systems. When it comes to power systems that are regulated, the planning for expansion is done with the intention of reducing costs. Despite this, the maximisation of profit for each transmission and generation company is the primary objective of expansion planning in power systems that have been deregulate.

This is the case in both the United States and in countries where power systems have been deregulated.
It is recommended that both GEP and TEP be carried out in Nigeria simultaneously in order to obtain a comprehensive view of the system and to make the most of the benefits that each expansion planning can offer. Because Nigeria has a power system that is deregulated, it is also recommended that the goal of GEP and TEP be to maximise the profit for each generator or transmitter while maintaining the integrity, reliability, and safety of the system within the period that was agreed upon for the planning process.
An ongoing project related to the Nigerian Transmission Expansion Plan (NTEP) extends across the states of Abia, Imo, Anambra, Delta, Edo, Kaduna, and Kano, as stated in an evaluation of the Nigerian Transmission Expansion Plan (NTEP) carried out by the African Development Bank (AfDB) as shown in Table 2-2 and Table 2-3. The overall grid wheeling capacity will be strengthened and improved as part of the NTEP phase 1 project. This will be accomplished by strengthening the transmission corridors in the Northwest region, Southeast region, and South-South regions of Nigeria, which are the areas of the country with the most constrained transmission lines. NTEP1 has the following main activities:

i) Reconstruction of two 330kV double circuit quad transmission lines (Alaoji-Onitsha and Delta-Benin)
ii) Construction of one 330kV double circuit quad transmission line (Kaduna-Kano)
iii) Construction of two 330/132kV Substations at Zaria and Millenium City.
iv) Construction of two 132/33kV Substations at Rigasa and Jaji, respectively.

The Bank will finance the dismantlement of the two existing 330kV single circuit lines (Alaoji-Onitsha and Delta-Benin) and the construction of the three new 330kV double circuit quad transmission lines (Kaduna-Kano, Alaoji-Onitsha, and Delta-Benin). The Bank will also finance the construction of four new substations (Zaria, Millennium City, Jaji and Rigasa) (African Development Bank, 2019).

Table 2-2: NTEP1 components (African Development Bank, 2019)

	Project Components	**Component Description**
1	**Component 1: Transmission Grid Strengthening and Improvement**	
1.1	Subcomponent 1.1: Construction, Upgrade and Reconstruction of 330kV double circuit quad transmission lines	• Construction of the Kaduna (Mando) – Kano (Rimin Zakara)330kV, 204km quad transmission line • Reconstruction of the Delta – Benin 330kV, 125km quad transmission line • Reconstruction of the Onitsha – Alaoji 330kV, 138km transmission line

1.2	Subcomponent 1.2: Construction and Installation of 330kV and 132kV Substations	• Construction of Zaria 330/132/33kV Substation • Construction of Millennium City 330/132/33kV Substation • Construction of Rigasa 132 / 33kV Substation • Construction of Jaji 132 / 33kV Substation

Table 2-3 NTEP target areas and population (African Development Bank, 2019)

NTEP1 Sub-projects	Construction of the 204km, 330kV Rimin-Zakaria T-Line		Reconstruction of the 125km, 330kV Benin-Benin-Ugheli T-Line		Reconstruction of the 138km, 330kVAlaoji-Onitsha T-Line		
State	Kano	Kaduna	Delta	Edo	Abia	Imo	Anambra
Capital	Kano	Kaduna	Asaba	Benin City	Umuahia	Owerri	Awka
Population (million)	8.3	13	4.1	3.1	3.7	3.9	5.1
No. of Local Government Areas (LGAs)	44	23	25	18	17	27	21
No. of LGAs through which the T-Line crosses	6	3	1	5	5	8	4

2.8 Conceptual Framework

This study focuses on ways to improve the sustainable electricity supply in Nigeria by adopting the idea that an effective electricity policy is critical to achieving the target (Ajayi, Ajayi 2013, GIZ 2015, Edomah, Foulds et al. 2017, Emodi, Boo 2015, Gatugel Usman, Abbasoglu et al. 2015).

The review of the relevant literature unearthed several recurrent factors that influence the generation of electricity in Nigeria. The conceptual framework for this research is built upon the prominence and recurrence of these prominent factors. As a result, it is proposed that the subsequent important factors, which will have an impact on the improvement of electricity generation in Nigeria if they are investigated and addressed, are as follows: Figure 2.15 illustrates the factors, which are as follows: infrastructure (Ajayi, Ajayi 2013, GIZ 2015, Lin, Ankrah 2019, Akuru, Onukwube et al. 2017, Emodi, Boo 2015), investment (GIZ 2015, Akuru, Onukwube et al. 2017, Dada 2014, Gungah, Emodi et al. 2019, Iyke 2015, Emodi, Boo 2015), expertise / (Ikeme, Ebohon 2005, Emodi, Boo 2015).

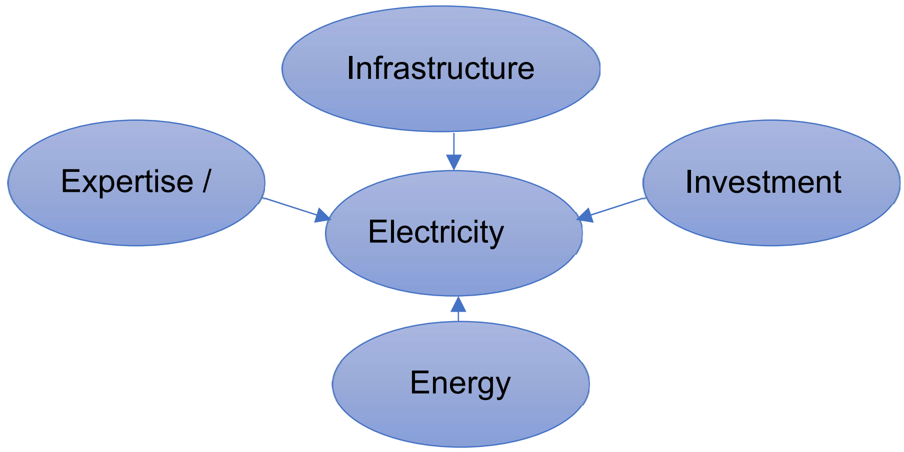


Figure 2.17 Research Conceptual Framework

2.9 Conclusion to Literature Review

In order to achieve a sustainable electricity supply in Nigeria, having effective electricity policies is necessary (Ajayi, Ajayi 2013, GIZ 2015, Edomah, Foulds et al. 2017, Emodi, Boo 2015, Gatugel Usman, Abbasoglu et al. et al. 2015b).

Despite the efforts that have been made by the government of Nigeria over the past few decades to reform the power sector, the country does not currently have sufficient electric energy to both feed the economy and provide sufficient electricity to residential homes, industrial businesses, and businesses in general (Lin, Ankrah 2019).

According to the review of the relevant literature, the problems that exist with the policies governing the generation and supply of electricity can be divided into four primary categories: the infrastructure, investments, energy sources, and expertise.

2.9.1 Infrastructure

According to Ajayi and Ajayi (2013), Edomah, Foulds et al. (2017), and Ikeme and Ebohon (2005), the current state of the electricity infrastructure in Nigeria is one of the primary reasons for the gap between the nation's generation and supply of electricity. This is one of the primary reasons why there is a gap between the generation and supply of electricity in the nation. Additional factors that cause many power plants to generate well below the installed capacity include, according to Lin, Ankrah 2019, and Dada 2014, the frequent shortfall of natural gas supply, the low maintenance culture of electricity facilities, the closing down of gas plants for maintenance, destruction of property or theft of power equipment and gas pipeline, and a shortage of water in the dams. All these factors contribute to the issue that many power plants generate a much lower amount of electricity than their installed capacity allows for. According to the research that was carried out in 2017 by Akuru, Onukwube, and colleagues, government monopoly, corruption, and unprofessionalism are all factors that have contributed to more than 20% of wheeling losses. In addition, corruption and a lack of maintenance have played a role in widening the gap between demand and supply, which has resulted in a smaller supply.

2.9.2 Investment

According to a report that was published by GIZ in 2015, the current state of the national grid and the fleet of power stations in Nigeria is primarily the result of a decrease in the amount of investment that has been made in the country since the early 1990s. Akuru, Onukwube, and others from 2017 postulate that even though the Nigerian government has made significant investments into the power sector in recent years, approximately 2.74 trillion naira (US$16 billion) was spent on revamping the electricity sector between 1999 and 2017, there is still a problem with electricity generation and supply, which results in Nigerians spending an estimated sum of US$4.65 billion annually on fuel to power generators, and this is in addition to an estimated sum of US$2.04 billion spent.

2.9.3 Technical Workforce / Manpower

Edomah 2020 contends that even though we face difficulties with investments, the opportunities to construct power plants that produce electricity through the various energy resources that are available in Nigeria have led to the entry of global players, which in turn acts as a motivator for investors to enter the market. Iyke's main conclusion from his research, which was published in 2015, was that the consumption of electricity is a primary factor in determining the rate of economic expansion in the Nigerian context. The study went on to suggest that policymakers could boost economic growth in Nigeria by increasing electricity consumption. This could be accomplished by lowering or moderating electricity prices to generate electricity demand, as well as by the government investing in alternative sources of electricity such as solar, wind, and biofuel, as this is the direction that many developed countries are heading.

2.9.4 Energy Sources

Concerning the several types of energy sources, a vast number of studies have demonstrated the extensive energy resource that is available for the generation of electricity. These sources can be either renewable or non-renewable. Ikeme, Ebohon 2005, and Edomah 2020 all point out that Nigeria possesses a variety of energy resources that are either not being adequately explored at the present time or are not being utilised. As a result, there has been a call for a more diversified energy mix in the power sector. According to Emodi and Boo (2015), the country's high reliance on conventional energy resources is due to the government's lack of effective policies and low participation in the development of clean energy; the creation of sustainable clean energy that is up to date is still a challenge.

2.9.5 Existing problems in the country’s electricity industry

According to the findings of the study, the issues that have plagued the power sector in Nigeria can be resolved if appropriate policies are put into place to attract investors in renewable energy to come to Nigeria. Akuru, Onukwube, and others in 2017 argue that the continued outlook in fossil generated electricity is the reason that the problem still exists even after massive investments were made to revive the power sector. They go on to suggest that Nigeria should divert its attention elsewhere vis-à-vis renewable energy, rather than the high dependence on fossil fuel, and they propose a framework for transitioning to 100% renewable energy as soon as possible. Lin, Ankrah in 2019, we propose that a more reasonable solution to drive Nigeria's economic and industrialization goals will be a policy that focuses on electricity that is efficiently generated by non-renewable energy in the interim, while at the same time maintaining a roadmap of gradually converting to renewable power in the long-term. This policy will be implemented in order to drive Nigeria's economic and industrialization goals.

According to Dada and Moser 2019, one of the reasons why there are problems in the Nigerian power sector is because there is not enough human capital to maintain the various parts of the infrastructure that is already in place. If nothing is done to address this trend, it is anticipated that this situation will become even more dire as new technologies are introduced. According to Edomah 2020, the challenges within the expertise context are visible in the following ways: non-professional actors appointed as energy ministers, employing a legal professional without the knowledge or understanding of the power sector to prepare and draught the policies, disregarding the contributions of experts involved in the previous development of the Nigerian power sector, which led to the sale of power plants and other infrastructure to parties that do not understand the sector, and leading to the sale of power plants and other infrastructure to parties that do not understand the implications of the sale In Dada and Moser 2019, the necessity of developing indigenous human and manufacturing capacities is emphasised. This will necessitate investments from both the government and the private sector in order to support education programmes in Nigeria.

3. Context of Study

According to the estimates provided by the International Energy Agency (IEA), Nigeria had a population of more than 200 million people in the year 2017, making it the most populous country on the African continent and the seventh most populous country in the world. The economy of Nigeria was the 20th largest in the world in the year 2015, according to the World Bank. According to the International Energy Agency's (IEA) Critical World Energy Statistics Report for 2018, which was published in 2018, Nigeria is the ninth largest exporter of petroleum and ranks as the 12th largest producer worldwide. The information presented in Table 3-1 focuses on some of the primary distinguishing features of Nigeria. A cursory investigation reveals that Nigeria possesses enormous energy resources that are in excess of what is required to meet the demands of its rapidly growing population. Despite this, these resources are not adequately used to generate sufficient electricity to meet the demands of the nation. One of Nigeria's greatest challenges is determining how its resources can be used to produce an affordable and sustainable power supply that is also reliable. According to the findings of many studies, the cost of electricity in Africa is significantly higher than the cost of electricity in any other region of the world (GIZ, 2015).

Despite this, Nigeria possesses the resources that are necessary to construct sufficient power stations across the country in order to satisfy the demand for energy in the country. This study will attempt to determine, why, despite the many efforts made by the government to provide sufficient power to the population, Nigeria continues to struggle with inadequate electric power supply by examining the current policies on electrification and the generation of electric power to better inform future policy decisions regarding the electrification of communities as well as the generation of electric power.

Nigeria continues to struggle with a significant lack of electric power despite the country's substantial oil and gas reserves as well as the income it receives from exports. This is even though Nigeria receives a significant amount of income from exports. As a result of the inadequate performance of the public power sector, there have been frequent power shortages, which have left residential areas, as well as commercial and industrial areas, without consistent access to electricity (GIZ, 2015).

Table 3-1 Key characteristics of Nigeria (2018)

Population (million)	**200**
GDP (current USD in billion)	**397.27**
GNI per capita PPP (current USD)	**5,700**
Urban population (% of total)	**51**
Access to electricity (% total population)	**60**
Rural access to electricity (% rural population)	**34**
Population density (people/km2)	**204**

Ease of doing business (2018), rank of 190	**146**
TI corruption index (2018), rank of 180	**144**

Source: (GET.invest) and (IEA 2019)

In order to generate revenue that is capable of supporting investments in infrastructure, the government of Nigeria has taken steps to reform the energy sector. These steps were taken in order to generate revenue that can do so. The power sector will be privatised, and the oil and gas industries will be deregulated and reorganised as part of these steps. The privatisation of power generation and distribution was carried out by the government in two stages so that investments could be increased while the power sector was going through the process of being reorganised. This was done in order to make the process go more smoothly and quickly. This process, the end goal of which is to reinvest the proceeds in the expansion of hydropower plants across the country, is still in the process of being carried out at this time. This process is still in the process of being carried out. It is difficult to say with any degree of certainty whether the current crop of independent power producers will be able to keep their businesses profitable in the future. On the other hand, the government of Nigeria has established programmes to promote the utilisation of renewable energy sources and to enhance energy efficiency. These programmes are a positive step in the right direction. The development of energy efficiency in Nigeria is still in its infancy, and the government is actively encouraging investments in energy efficiency by developing policies and strategies in this area. This is even though Nigeria is one of the world's most energy-hungry countries.

According to the Organisation of Petroleum Exporting Countries (OPEC), Nigeria exported more than 8% of the total amount of liquefied natural gas that was traded globally in 2012. This is even though the country's natural gas reserves have not been depleted. Both the state of Enugu and the state of Kogi contain significant coal mines, but those mines have not been exploited to a significant degree yet. Significant coal mines can be found in both states.

In 2017, approximately 75% of the population's energy needs were satisfied by energy that was generated from natural gas and this number has risen to 78% as at 2020 as shown in Figure 3.1.

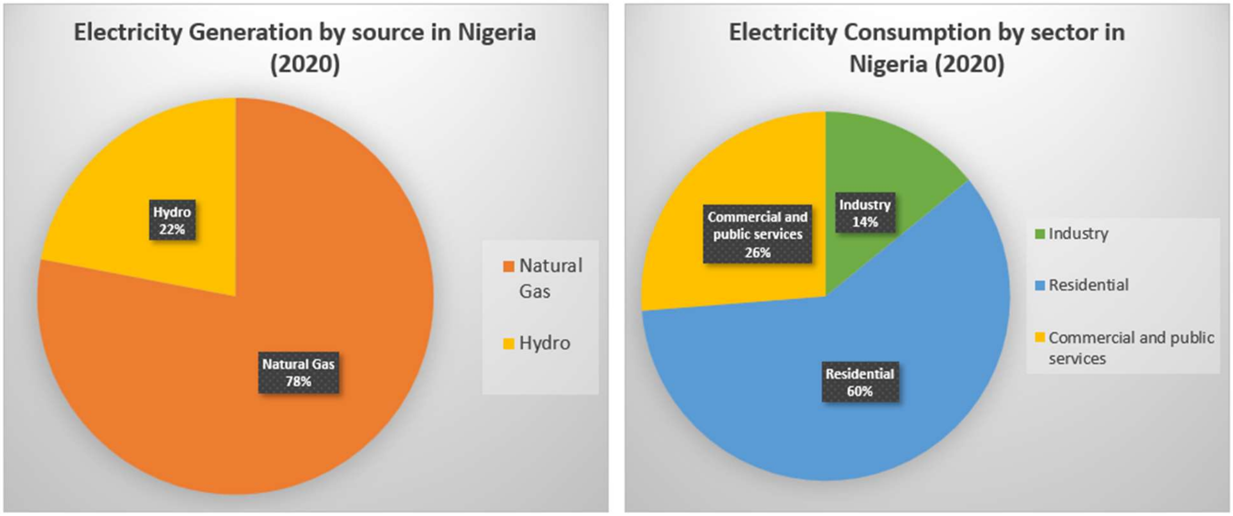


Figure 3.1 Electricity Generation and Consumption in Nigeria, 2020

3.1 Overview of Energy in Nigeria

Nigeria is not only one of the largest oil producers in Africa, but it is also one of the largest exporters of liquefied natural gas (LNG) in the world. Oil is a major contributor to the economy of Nigeria, ranking among the top 20 percent of all contributors. Despite this, it only makes up 16% of the country's total gross domestic product, 75% of the country's revenues, and 90% of the country's total export earnings (GIZ, 2015). Theft of oil and disruptions in the supply chain caused by sabotage or malfunctioning pipelines are both factors that have a negative impact on the amount of oil that is produced in Nigeria.
Although Nigeria is a major exporter of crude oil, the country imports approximately 85 percent of its refined petroleum products. This is because Nigeria's domestic oil refineries only operate at approximately 30 percent of their capacity. The price of privately generated electricity has significantly increased as a direct result of a significant rise in input costs brought about by the subsidy on gasoline and the deregulation of the price of diesel. This rise in input costs has directly led to the significant increase in the price of privately generated electricity. Nigeria has been severely impacted by fluctuations in the price of oil on international markets as a result of the high degree to which the country relies on its oil industry. The price of oil experienced a significant decline between the years 2014 and 2015, which led to a decline of 28% in the country's revenue during that time period (GIZ 2019).

The gas industry in Nigeria is currently not being utilised to its full potential because there is a lack of infrastructure that is necessary to fully exploit the gas that is produced as shown in Figure 3.2. This is even though the gas industry has a lot of potential. According to data compiled by the World Bank in 2017, Nigeria ranked as the seventh-largest gas flarer in the world. During that time period, the nation's annual emission of gas into the atmosphere was close to 8 billion cubic metres. On the other hand, during that same year, there were an estimated 75 million people out of a total population of 190 million who did not have access to electrical power (World Bank, 2017). In addition to having an annual rainfall that is typically higher than 4,000 millimetres on average, it is significant to keep in mind that Nigeria possesses one of the largest natural gas reserves in the entire world. It is also important to note that Nigeria has a high average annual temperature (GIZ, 2015).

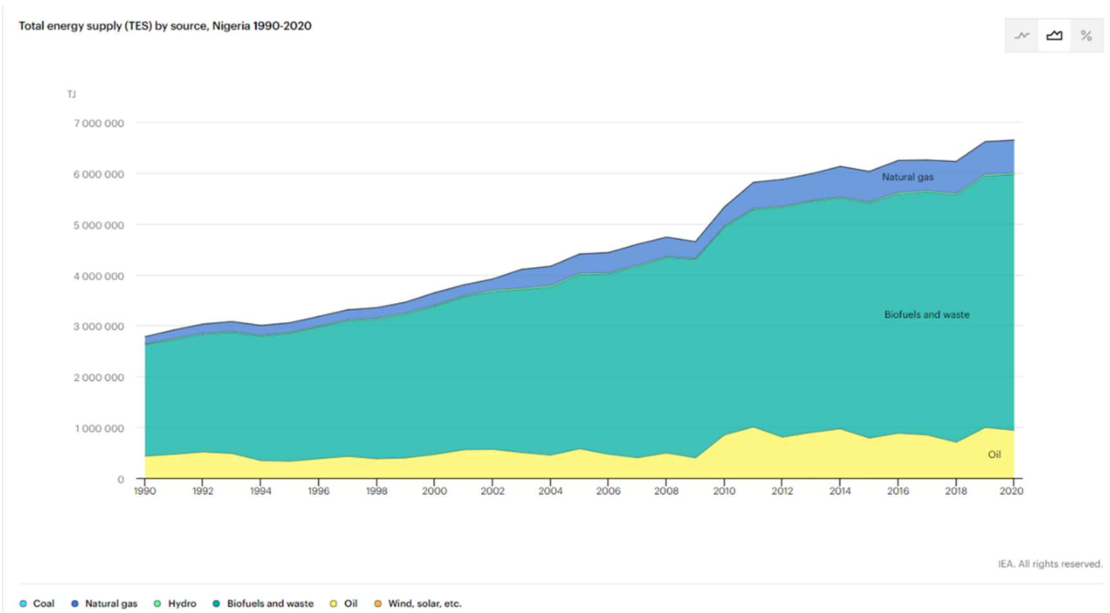


Figure 3.2 Total Primary Energy Supply (TPES) by source in Nigeria (1990 – 2020)

3.1.1 Coal

Coal was the first fuel to be used in the country for any kind of commercial purposes. It was not until 1906 that the state of Enugu became the location of the initial excavation of the substance from the ground. After the discovery of oil, production eventually returned to its previous level. Prior to that time, however, it had skyrocketed. In 1906, 24,500 tonnes of coal were produced; by the 1950s, production had reached a new all-time high of 905,500 tonnes, with more than 70 percent of that quantity being consumed by the country's commercial sector.

In the late 1950s, when crude oil was discovered in Nigeria, coal production in the country began to decline. This was a direct result of the discovery of oil in the country. During this same time period, diesel fuel began to be used in place of coal in the process of powering locomotives for railways. Additionally, because of the civil war that broke out in Nigeria between the years of 1967 and 1970, a substantial number of coal mines were forced to close their doors. The quantity of coal that was produced decreased to 52,700 tonnes by the year 1983 as a direct consequence of this situation. By the year 2000, the country's

annual coal production had reached 14,390 tonnes, but by the following year, coal accounted for less than 0.02% of the country's total commercial energy consumption (ECN 2018).
When it was established in 1950 with the purpose of managing the exploitation of the country's coal reserves, the Nigerian Coal Corporation (NCC) was the only institution that was actively involved in the coal industry. The NCC was given permission by the federal government in 1990 to work hand in hand with private investors in the operation of coal mines while it approved the full commercialisation of the corporation in the same year.

There is evidence that there is sub-bituminous grade coal present in 33 coal fields that are dispersed across 16 states in Nigeria. These coal fields are spread out across the country. It is estimated that the country has approximately 2.75 billion tonnes of coal reserves, of which 49% are sub-bituminous, 39% are bituminous, and 12% are lignitic coals. The country is estimated to have approximately 2.75 billion tonnes of coal reserves, compared to the verified reserve total of approximately 650 million tonnes. The use of sub-bituminous coals in coal-fired power plants is a particularly good fit for these types of coal (ECN 2018).

The coal that is mined in Nigeria is found to be suitable for a wide variety of applications, such as the production of high calorific gas, domestic heating, briquettes, formed coke, and the manufacture of a variety of chemicals, such as waxes, resins, adhesives, and dyes. These are just some of the applications that can make use of the coal. These are just some of the applications for coal that can be found (ECN 2018).

The utilisation of coal in Nigeria possesses a sizeable amount of unrealized potential that needs to be realised in its entirety as a component of the overall energy strategy for the country. Additional efforts could be concentrated on expanding the participation of the private sector and local businesses in order to maximise the efficiency with which coal is utilised within the Nigerian energy sector. This would allow for a greater degree of effectiveness in the utilisation of coal.

3.1.2 Crude Oil

Nigeria is one of the most significant participants in the crude oil export market worldwide (World Bank, 2019b). The first discovery of crude oil in quantities sufficient for commercial use was made in 1956; however, oil production in Nigeria did not begin until the following year, in 1958. Commercial quantities of crude oil were found for the first time. It is estimated that Nigeria has crude oil reserves with a total volume of approximately 37 billion barrels as of the end of the year 2018, the vast majority of which are made up of light crude oil that has a low percentage of sulphur.
Over the course of the last decade, the country's crude oil reserve has remained the same because there have been insufficient opportunities for investment and exploration in the sector. In 1979, annual oil production reached an all-time high of approximately 845

million barrels, which set a record for the commodity. After this, in 1983, there was a decrease in production of 451 million barrels due to a significant market collapse that lasted from 1981 until 1987. This collapse lasted for a total of ten years. This downward spiral continued for an entire decade after it began. After that, it increased once more in the year 1998, and in 2005, the nation recorded its highest production ever, which was 2.5 million barrels per day. Following that, it increased once more in the year 1998. The daily production that was recorded on average from 2002 through the first quarter of 2018 was approximately 1.896 million barrels per day. This figure is based on the data collected. There are four oil refineries in Nigeria, and their combined capacity is 445,000 barrels per day. These refineries are installed in the country (ECN 2018). However, the country is still suffering from a low-capacity utilisation of the refineries. As a direct consequence of this problem, Nigeria is forced to rely on oil imports to supplement the country's domestic production in order to satisfy the demand for consumption within the country.

It is estimated that the sale of crude oil accounts for more than 80 percent of total revenue. However, because of the country's heavy reliance on crude oil or its foreign exchange, the economy is extremely susceptible to the volatile nature of the global oil market. This is because of the country's heavy reliance on crude oil or its foreign exchange (ECN, 2018).

It is projected that Nigeria's oil reserves will remain adequate for the next 52 years (ECN 2018). Therefore, there is a need to diversify Nigeria's domestic energy mix away from the ever-increasing consumption of crude oil and petroleum products in general to provide a more efficient, reliable, sustainable, and economically friendly energy production to meet its consumption demand as stated in its Sustainable Development Goals. This will allow Nigeria to meet its consumption demand in a manner that is consistent with its commitment to achieving its Sustainable Development Goals. As a result, Nigeria will be able to live up to the commitments it has made toward achieving its Sustainable Development Goals (SDG).

3.1.3 Natural Gas

At the present time, the gas industry is not being utilised to its full potential because there is a lack of the infrastructure that is required in order to fully exploit all the gas that is produced. In 2018, production accounted for only about a quarter of the total amount that was available. Natural gas reserves in this country are currently estimated to be worth approximately 202 trillion standard cubic feet (tscf), making them the largest in all of Africa as of the year 2018 (ECN, 2018).

In 2017, Nigeria flared an annual average of almost 8 billion cubic metres of gas, making it the seventh largest gas flarer in the world according to the World Bank. On the other hand, the practise of flaring gas has seen a consistent decrease, falling from approximately 50 percent in the year 2001 to 11 percent in 2017 and 7 percent in 2018.

Not only does this contribute to the pollution of the atmosphere, but it also wastes energy that could be used to generate electricity in a country in which the electrification rate is less than 60 percent (ECN, 2018).
The national policy for gas has the overarching goal of replacing oil with gas and derivatives of gas in order to increase the amount of oil that is available for export. This is done with the intention of increasing the quantity of oil that can be exported. This will also encourage the conservation of the oil reserves, which will lead to benefits for both the economy and the environment. This is because gas is a cleaner fuel than oil, which means that gas is more environmentally friendly than oil. In addition to this, the outcome of this will be the protection of the oil reserves (ECN, 2018).

As of the year 2018, the country had an installed capacity in the electricity sector of approximately 13 GW; however, due to an inadequate supply of gas, less than 5 GW was accessible in the grid. Despite this, the nation had an installed capacity of approximately 13 GW. The Nigerian government has established as one of its priorities the generation of an additional 30 gigawatts (GW) of electricity by the year 2030. If extraction continues at the same rate as it has been, there should be enough natural gas in Nigeria to last for another 67 years, according to the country's estimated reserves. Because of this, it is of the utmost importance to make significant investments in the gas sector in order to transform gas into an alternative to oil in terms of the requirements for domestic use and the amount of foreign exchange that is required. Because of this, it is of the utmost importance to take the necessary actions to put an end to the common practise of gas flaring (ECN, 2018).

As of the year 2019, the primary source of fuel used in the production of electricity in Nigeria was gas. The generation of most of the power that was still available was accomplished primarily by oil. According to a report published by the International Energy Agency in 2018, Nigeria had the highest number of oil-fired backup generators than any other country in Africa (IEA, 2019a).

3.1.4 Shale Hydrocarbon

Oil shale is the source of two different types of hydrocarbons: shale oil and shale gas. Both things have the potential to serve as viable substitutes for conventional crude oil and natural gas. Even though Nigeria possesses significant quantities of conventional petroleum, the country has not yet reached its full potential in terms of fossil fuel. Therefore, any future discoveries of shale oil and shale gas in commercial quantities should be welcomed in order to increase the crude oil reserves and improve the country's energy mix. This is because shale oil and shale gas can be extracted from the same rock formations as conventional oil and gas (ECN, 2018).
On the other hand, the extraction of shale oil and shale gas from oil shale is a more expensive process than the production of crude oil and natural gas, both in terms of the amount of money it costs and the amount of environmental damage it causes. Despite

this, the discovery of shale hydrocarbon resources in commercial quantities in states that are associated with conventional petroleum reserves will result in an improvement to the economy of the entire country (ECN, 2018).

3.1.5 Nuclear Energy

In 1947, a significant amount of pyrochlore that was found to contain uranium was found in the region of Jos Plateau in Nigeria. By 1979, over 690,000 km^2 of land had been enclosed for the purpose of surveying. Additional research reveals that Nigeria's Benue Trough contains traces of nuclear minerals as well (ECN, 2018).

The Nigeria Atomic Energy Commission (NAEC) was endorsed in 1976, which led to the establishment of two nuclear energy research centres in 1977. This endorsement marked the beginning of research and development in the field of nuclear science in Nigeria. Since 1993, a growing number of nuclear science and technology centres have been established (ECN, 2018). However, in order to ensure the security and efficacy of the utilisation of nuclear power as part of Nigeria's overall energy portfolio, it is essential to cultivate and educate a workforce in this area. In addition to this, investigations need to be expanded to include any other regions of the country that might have traces of radioactive minerals.

There is a wide range of potential applications for nuclear energy, and it is currently one of the most important sources of electricity generation around the world. Nevertheless, harnessing nuclear energy calls for a high level of care and specialised knowledge. As a result, it necessitates stringent safety requirements, meticulous planning of the development of human resources, productive stakeholder involvement, and the availability of and utilisation of material resources.

Other applications of nuclear energy include health care delivery systems, the petroleum industry, agriculture, the preservation of food and animals, animal husbandry, the management of water resources, pest control, industry, materials analysis, and mineral exploration. These applications will receive a boost from the country's appropriate utilisation of its research and investment funds. To support the use of nuclear energy in Nigeria, however, the existing institutional and regulatory frameworks need to be fortified and improved in order to meet the country's needs.

3.1.6 Hydropower

Hydropower is the process of extracting energy from moving water for the purpose of powering electrical generators. Even though it requires a large investment to get started, hydropower is one of the cleanest and least expensive sources of electricity. It is also one of the most reliable sources. As a direct consequence of this, hydroelectric power is currently recognised as one of the most important sources of baseload electricity generation in Nigeria. In 2018, the capacity of the grid to produce electricity from hydropower sources accounted for 19% of the total capacity of the grid (ECN, 2018).

The presence of numerous large rivers and waterfalls in Nigeria makes it ideally suited for the generation of hydropower, a form of renewable energy. The River Niger and the River Benue, in addition to the rivers' respective tributaries, are the principal rivers that contribute to the Nigerian river system. The following is a general classification of the several types of hydropower schemes in Nigeria:

- Pico scheme: ≤ 5 kW
- Micro schemes: ≤ 500kW
- Mini schemes: 500kW < Mini ≤ 1 MW
- Small hydropower: 1MW < Small ≤ 30 MW
- Medium Hydropower: 30 MW < Medium ≤ 100 MW
- Large hydropower: > 100 MW

The total large-scale hydropower potential of Nigeria is estimated at over 14,120 MW, with the capacity to produce 50,832 GWh of electricity annually. Sadly, only about 13.50% of the nation's considerable hydropower potential has been used. Some of the significant hydropower stations in Nigeria are Kainji (760 MW), Jebba (540 MW) and Shiroro (600 MW), ongoing Zungeru (700 MW), Mambilla (3050 MW). The Small hydropower potential of Nigeria is estimated at 3,500MW, of which only about 1.7% is utilised (ECN 2018). There is the pressing need to build more small Hydropower Plants to provide electricity to the rural areas and remote settlements.

3.1.7 Solar

The sun is the primary source of solar energy, which is a type of renewable energy that can be used in various applications. Because of its location close to the equator, Nigeria receives a significant amount of sunlight each day, which results in solar radiation that is evenly dispersed across the country. The amount of solar radiation that reaches the surface of the earth varies in strength depending on geographic location, the time of year, the day of the month, the time of day, and several other external factors. The annual average of total solar radiation in Nigeria ranges from about 12.6 MJ/m^2 in coastal areas to approximately 25.2 MJ/m^2 in the northernmost parts of the country.

Solar power is less harmful to the environment than other forms of energy. The competitiveness of solar energy is undeniable, particularly for applications requiring low to medium power levels, even though the cost to install solar panels is quite high. Even though there is sufficient solar radiation to provide a sizeable amount of energy during the daytime, the challenge lies in the ability to store the excess energy so that it can be utilised during the night-time hours when the sun is not shining. Despite this, incorporating storage systems that are more effective into solar energy conversion systems will help mitigate the issue with the variable availability of solar radiation (ECN, 2018).

It is possible to use Solar energy to provide electricity to outlying communities that are not connected to the national grid. In addition, electricity generated from solar energy can be fed into the national grid (ECN, 2018).

In Nigeria, there has been an increase in the utilisation of solar energy technologies, particularly in the areas of street lighting, water-pumping, and the electrification of rural areas. Nevertheless, a significant amount of work remains to be done in order to develop solar technology equipment as well as standards for the materials, design, and manufacture of solar technology equipment.

Solar panel manufacturing has begun in Nigeria thanks to the efforts of two different organisations: the National Agency for Science and Engineering Infrastructure (NASENI) and the Sokoto Energy Research Centre (SERC). Most solar-thermal technologies can be supported by the technical expertise already present within the country. Nevertheless, in order to make practical use of this technology, the solar power infrastructure in Nigeria needs to be improved. This is because the production of PV system components, in particular PV cells, necessitates the use of more advanced manufacturing processes (ECN, 2018). Table 3-2 shows the available renewable energy sources in Nigeria.

3.1.8 Wind

The wind is a natural and renewable source of energy that can be used for a variety of purposes, including the pumping of water and the milling of grains as well as the generation of electricity. Wind energy in Nigeria has the potential to be harnessed to generate electricity both for off-grid areas and for the national grid as a result of the country's geographic position and the seasonal variations that it experiences (ECN, 2018).

In Nigeria, the annual average wind speed at a height of 10 metres varies from about 2 metres per second in the coastal regions to about 4 metres per second in the country's northern borders (ECN, 2018). Since there is energy to be harvested from the wind, it is recommended that a programme for the development of wind energy should be initiated in Nigeria.

3.1.9 Hydrogen

Hydrogen, which makes up the third most abundant element on the surface of the earth, can be obtained primarily from water and organic compounds. The process of extracting hydrogen, on the other hand, is complex and expensive because it requires direct thermal, thermoelectric, and electrolytic methods in order to separate hydrogen from its carriers (ECN, 2018).

Combustion of hydrogen results in the release of thermal energy and the sole production of water as a by-product. Hydrogen is a fuel that can be burned and is good for the environment. It is a fuel that does not require much space and has a strong record of accomplishment of being safe for storage, transportation, and use.

Most thermal applications that currently make use of fossil fuel could benefit from the utilisation of hydrogen as an alternative fuel source. Its primary application is in fuel cells, which are devices that convert chemical fuels into electricity, as well as thermal energy conversion systems that need fuels with a high power-to-weight ratio (ECN, 2018).

3.1.10 Geothermal Energy and Ocean Waves

Other forms of naturally occurring renewable energy, such as ocean waves, tidal energy, ocean thermal gradients, and geothermal energy, are all available in Nigeria but have not yet been utilised. These are currently being used in various other regions of the world as a means of producing energy. There is still a significant amount of work to be done in Nigeria in order to fully exploit these energy resources, which, once completed, could make future contributions to the energy mix of the country (ECN, 2018).

Because it is surrounded by the Atlantic Ocean and has a coastline of approximately 853 kilometres, Nigeria has a significant amount of potential for the generation of energy from ocean waves. In contrast, the states of Bauchi, Jos, and Nasarawa all have geothermal potentials available to them. The utilisation of these potential energy sources could add more power to the mix of energy sources used in Nigeria (ECN, 2018).

3.1.11 Biomass

The organic form of non-fossil material known as biomass is derived from living organisms and their associated biological matter. There is a wealth of biomass resources in Nigeria, such as wood, animal and forestry waste, forage grasses and shrubs, industrial, agricultural, and municipal activities, and aquatic biomass. Some of these resources are listed below. In addition to this, it is estimated that Nigeria possesses significant amounts of biomass energy resources (ECN, 2018).

Many homes in Nigeria rely on fuelwood, a solid form of plant biomass, for their primary source of heat and cooking material. In addition, biomass can be used as a fuel in thermal power plants, or it can be used to produce briquettes, which are then utilised in more specialised industries (ECN, 2018). As a result, the effective utilisation of biomass should be taken into consideration for inclusion in the nation's overall energy mix through the development of an all-encompassing programme.

3.1.12 Fuelwood

Over sixty percent of the country's population relies on fuelwood for their cooking and other household needs. The high dependence on fuelwood is caused by the common practise of employing ineffective methods of cooking, such as cooking over an open fire. This is a system that has a low thermal efficiency and produces smoke that contains carbon particles that are harmful if inhaled for an extended period. This is especially dangerous for women and children, who are the ones who do most of the cooking in homes (ECN, 2018).

The widespread consumption of fuelwood is another activity that contributes to environmental damage. The rate at which it is consumed far exceeds the rate at which trees are planted, which has led to soil erosions, desert encroachment, and reduced soil fertility, all of which are problems that Nigeria is currently attempting to address.

In order to lessen households' reliance on fuelwood and better protect the open forests, communal woodlots, and private farmlands that are currently used to source fuelwood, alternative fuel sources such as liquid petroleum gas (LPG) and biofuels should be made more widely available to consumers. Additionally, this will protect the forests, which are necessary for maintaining a healthy environment.

3.1.13 Biofuels

The Nigerian National Petroleum Corporation (NNPC) was given the directive to carry out the Automotive Biomass Programme in 2005 by the Federal Government of Nigeria. This directive was given in August of that same year (ECN, 2018).

Based on the demand for gasoline in the country and the assumption that it will be blended with fuel ethanol at a ratio of 10%, it was estimated that approximately 1.3 billion litres of gasoline will be required in the year 2018. By the year 2022, it is anticipated that this will have increased to approximately 2 billion litres. In comparison to the current market capacity of approximately 480 million litres for a 20% blend of biodiesel, it is anticipated that the demand for biodiesel will reach approximately 900 million litres by the year 2022. Through its biofuel production programme, the government aims to meet the nation's demand for all the biofuels it consumes by 2022 by producing all those biofuels on domestic soil (ECN, 2018).

The production of biofuels in Nigeria is a significant step toward integrating the country's agricultural and petroleum industries, as evidenced by the country's biofuel programme. The benefits of biofuel include environmentally friendly fuel, increased tax revenue for the government from the economic activities of the sector, job creation, increased economic development and empowerment of rural communities, improved farming techniques, increased agricultural research, increased crop demand, and a reduction in overall emissions of greenhouse gases (GHG). The Nigerian National Petroleum Corporation (NNPC) was given the directive to carry out the Automotive Biomass Programme in 2005 by the Federal Government of Nigeria. This directive was given in August of that same year (ECN, 2018).

Based on the demand for gasoline in the country and the assumption that it will be blended with fuel ethanol at a ratio of 10%, it was estimated that approximately 1.3 billion litres of gasoline will be required in the year 2018. By the year 2022, it is anticipated that this will have increased to approximately 2 billion litres. In comparison to the current market capacity of approximately 480 million litres for a 20% blend of biodiesel, it is anticipated that the demand for biodiesel will reach approximately 900 million litres by the year 2022. Through its biofuel production programme, the government aims to meet the nation's demand for all the biofuels it consumes by 2022 by producing all those biofuels on domestic soil (ECN, 2018).

The production of biofuels in Nigeria is a significant step toward integrating the country's agricultural and petroleum industries, as evidenced by the country's biofuel programme. The benefits of biofuel include environmentally friendly fuel, increased tax revenue for the government from the economic activities of the sector, job creation, increased economic

development and empowerment of rural communities, improved farming techniques, increased agricultural research, increased crop demand, and a reduction in overall emissions of greenhouse gases (GHG) (ECN, 2018).

Table 3-2 Nigeria Renewable Energy Sources

Resource	**Energy Potentials**
Hydropower (large scale)	11,000 MW
Hydropower (small scale)	3500 MW
Wood fuel	43.1 billion tons/year
Animal waste	61 million tons/year
Crop residue	83 million tons/year
Solar radiation	3.5–7.0 kWh/m^2/day
Wind speed	2–4 m/s (annual average) at 10 m height

Source: (Gatugel Usman, Abbasoglu et al. 2015b)

3.2 Energy Policies

While conducting this study's literature review, several electricity policies in Nigeria were reviewed. The nine policies outlined in Table 3-3 have been chosen for the purpose of receiving an in-depth analysis as part of this research project in order to gain a better comprehension of how they will affect the nation's capacity for the generation and distribution of electricity between the years 2001 and 2020. The amount of electricity consumed on a per-person basis, the total amount of electricity generated, and the years in which the policies were implemented are presented in

Figure 3.3. The characteristics of the policies that influenced the generation and supply of electricity in Nigeria over a period of 20 years will be investigated in this study.

Table 3-3 Electricity Policies in Nigeria

#	Electricity Policy in Nigeria
1	National Electric Power Policy (NEPP), 2001
2	National Energy Policy (NEP), 2003
3	National Power Sector Reform Act (EPSRA), 2005
4	Renewable Energy Master Plan (REMP) 2005

5	Renewable Electricity Policy Guidelines (REPG), 2006
6	Multi-Year Tariff Order (MYTO I), 2008
7	Multi-Year Tariff Order (MYTO II), 2012
8	Nigerian Electricity Regulatory Commission Mini-Grid Regulation, 2016
9	Rural Electrification Strategy and Implementation Plan (RESIP), 2016

Source: Author's compilation

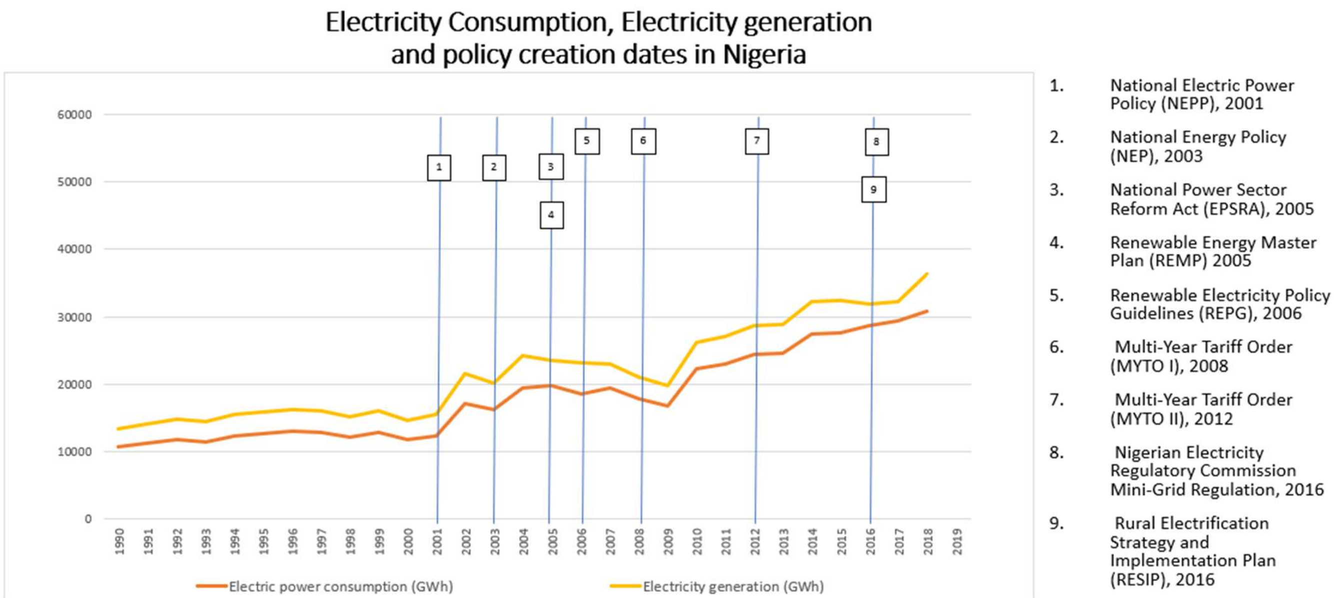


Figure 3.3 Electricity Consumption per capita, electricity generation and policy creation date in Nigeria (Source: Author's compilation)

3.2.1 National Electric Power Policy (NEPP), 2001

The first step in the reform of the electricity sector is marked by the adoption of this policy. The Electrical Power Implementation Committee (EPIC), which was the central body responsible for the reform and restructuring of the power sector, was the inspiration for the development of the National Electric Power Policy (NEPP), which was created in March of 2001. The NEPP outlined three distinct phases that must be completed before the power industry can be completely transformed. The first thing that happened was the privatisation of NEPA, followed by the establishment of Integrated Power Producers (IPPs), which are companies that generate electricity. The second stage brought about an increase in the level of competition between market participants, which led to a reduction in subsidies and the sale of surplus power to DISCOs. The completion of this stage was denoted by the introduction of total cost pricing, an expanded selection of suppliers that went beyond the local DISCOs, and a market that was open to full competition (Emodi, Nnaemeka and Ebele, 2016).

3.2.2 National Energy Policy (NEP), 2003, 2013, 2018

The NEP serves as a guide for the expansion of the energy industry by providing a framework for its growth. It specifies the policies that will be implemented by the FGN regarding the production, supply of all energy resources, and the consumption of energy across various industries. The primary objective of the policy is to establish energy security through the utilisation of a diverse array of energy sources in order to bring about sustainable development and to protect the surrounding natural environment. The NEP went through a round of revisions in 2013 in order to consider recent developments in the energy sector, with an increased focus on energy efficiency and renewable energy (Emodi, Nnaemeka and Ebele, 2016; Gungah et al., 2019; Emodi, N. V. and Boo, 2015). The National Energy Policy (NEP) admits that the way the country currently uses energy is inefficient and promotes effective strategies for energy utilisation (Emodi, Ebele 2016). In addition, the NEP encourages the use of off-grid and standalone electricity generation systems in order to increase rural electrification and supply electricity to areas of the country that are inaccessible to the national grid. Nevertheless, it is important to point out that the NEP did not establish any quantitative goals for the utilisation of renewable energy sources, nor did it establish any goals for energy efficiency and conservation (Emodi, Ebele 2016).

3.2.3 National Economic Empowerment and Development Strategy (NEEDS), 2004

In 2004, the National Planning Commission (NPA) produced the idea for the Needs Assessment and Evaluation System (NEEDS) in order to address issues relating to the reduction of poverty, the creation of wealth, the generation of employment, and the reorientation of values in the country. It encourages the privatisation of the public sector's infrastructure as a vital tool for improving service delivery in order to maximise efficiency (Emodi, Ebele 2016).

This strategy encourages the FGN to fund projects with high investment requirements or low attractiveness to investors. It also emphasises the need for an increased share of renewable energy in the national mix through the Electric Power Sector Act (also known as the National Power Sector Reform Act) (Emodi, Ebele 2016).

3.2.4 National Power Sector Reform Act (EPSRA), 2005

In 2005, this act was passed to liberalise the operations of the Nigerian power sector. The NEPP was passed in 2001, which led to the creation of ESPSRA, which is a new legal and regulatory framework for the sector. This resulted in the unbundling and privatisation of the power sector, which was done to increase rural electrification, introduce competition in the electricity market, develop performance standards, and safeguard consumer rights (Emodi, Ebele 2016).

- The reform act kicked off the horizontal and vertical unbundling and privatisation of the NEPA in the following steps:

- NEPA assets were transferred to the PHCN holding company and its successive companies comprising of eleven generations, six distribution and one transmission companies.
- Development of a competitive electricity market by the formation and operation of a wholesale electricity market in Nigeria
- The Nigerian Electricity Regulatory Commission (NERC) was created as the national regulatory body to oversee the market and administer licences.
- Introduction of tariffs and corresponding calculation methodologies by NERC.
- Consumer rights and consumer protection were implemented, including the Power Consumer Assistance Fund to subsidise the tariff for less privileged consumers;
- Adoption of guiding standards and codes in the sector
- Establishing a Rural Electrification Agency to fund and expand access to electricity to the rural areas (Emodi, Ebele 2016)

3.2.5 Renewable Electricity Policy Guidelines (REPG), 2006

The REPG was published by the Federal Ministry of Power and Steel in 2006, and it mandated the FGN to increase the amount of electricity generation in the country that comes from renewable energy sources to at least 5% of the total amount of electricity generated and a minimum of 5 TWh of the electricity generation in the country by the year 2016. (Emodi, Ebele 2016). The use of renewable energy to bring electricity service to areas that are not currently connected to supply sources is a factor considered in this document. In it, the plans, policies, strategies, and goals of the Nigerian government to increase the use of renewable energy sources in the country's power sector are detailed (Emodi, Ebele 2016).

3.2.6 Renewable Electricity Action Programme (REAP), 2006

The Renewable Electricity Policy Guidelines are being put into action, and the Renewable Electricity Action Programme is providing the road map for how to get there. This programme highlights the use of renewable energy sources for the generation of electricity and emphasises potential gaps, professional valuation, and financial implications (Emodi, Ebele 2016). In addition to this, it examines the roles of various government ministries and agencies, outlines the procedures for financing projects through the Renewable Electricity Fund (REF) and other sources, and concludes with a risk assessment and the structures necessary for continuous monitoring and evaluation (Emodi, Ebele 2016).

3.2.7 Nigerian Biofuel Policy and Incentives (NBPI), 2007

The primary goal of this policy was to develop and promote the country's fuel ethanol industry using agricultural products in order to improve the export properties of automotive fossil-based fuels produced in the country. This policy also had the secondary goal of reducing greenhouse gas emissions. In addition, the NNPC was given the responsibility of fostering an atmosphere conducive to the introduction of the ethanol industry (Emodi, Ebele 2016). Additionally, the policy sought to lessen the nation's reliance on gasoline that was imported from other countries, cut down on the amount of pollution in the environment, and foster the growth of profitable industries. The alleviation of poverty through the creation of jobs, the generation of additional tax revenue, the stimulation of agricultural activities, the stimulation of economic activities and the empowerment of residents of rural communities, and the reduction in the consumption of fossil fuels are the intended benefits of this policy (Emodi, Ebele 2016).

3.2.8 Renewable Energy Master Plan (REMP) 2005 and 2012

In 2005, the Energy Commission of Nigeria (ECN) and the United Nations Development Programme (UNDP) worked together to develop the Renewable Energy Master Plan (REMP), and in 2012, the ECN oversaw its revision. This plan lays out a road map for increasing the role that renewable energy plays in achieving sustainable development in Nigeria and highlights the necessity of incorporating renewables into buildings, electricity, and off-grid electrical systems. Additionally, this plan outlines how to increase the role that renewable energy plays in achieving sustainable development in other countries. In addition to this, it highlights the significance of solar power as a component of the nation's overall energy mix (Emodi, Ebele 2016).

According to the REMP, Nigeria has plans to increase the amount of renewable electricity supply from 13% of total electricity generated to 23% in 2015 and 36% by 2030. This will result in renewable electricity accounting for 10% of the nation's total energy consumption by 2025. (Emodi, Ebele 2016)

The Renewable Energy Master Plan (REMP), on the other hand, has not yet been formalised into a law that would regulate the growth of renewable energy across the country because it is still waiting for approval from the government (Emodi, Ebele 2016).

3.2.9 National Renewable Energy and Energy Efficiency Policy (NREEEP), 2014

The Nigerian National Renewable Energy and Energy Efficiency Policy (NREEEP) is a document that outlines the several ways in which the country can increase its use of renewable energy and its energy efficiency (GIZ 2015). The optimal utilisation of the country's energy resources for sustainable development is the primary focus of the policy. In addition to this, the policy addresses issues such as the pricing and financing of renewable energy; legislation, regulation, and standards; capacity building and training; renewable energy efficiency and conservation; planning and policy implementation; and so on (IEA 2017, Emodi, Ebele 2016). The Federal Executive Council is currently deliberating on whether to sanction the policy, which was formulated by the Federal Ministry of Power (FMP) (Emodi, Ebele 2016).

3.2.10 Multi-Year Tariff Order (MYTO I), 2008-2013

The Nigerian Electricity Regulatory Commission (NERC) established the Multi-Year Tariff Order (MYTO 1) in 2008 as a roadmap towards more cost-reflective tariffs. This roadmap covers a period of fifteen years. The goal of the first two stages, which ran from 2008 to

2017 and 2012 to 2017, was to keep prices low for consumers while gradually increasing those prices. The final regime is intended to deliver the necessary incentives for power producers and investors to operate and maintain electricity infrastructure so that it can continue to function properly (Emodi, Ebele 2016).

3.2.11 Multi-Year Tariff Order (MYTO II), 2012-2017

In June 2012, the North American Electric Reliability Corporation (NERC) issued the Multi-Year Tariff Order 2 (MYTO 2), which is comparable to MYTO 1 but includes some enhancements. It will be in effect from June 2012 until May 2017. In MYTO 2, there was going to be a review of the retail tariff every other year. Because of this, modifications may be made for all the electricity that is generated at wholesale contract prices. These modifications may include adjustments for the inflation rate in Nigeria, the daily generation capacity, the exchange rate for US dollars, as well as the accompanying actual Capex and OpEx requirements that will differ from those that were used in the previous tariff calculation (IEA 2017, Emodi, Ebele 2016).

3.2.12 Biofuels blending mandate, 2013.

The Nigerian government issued the biofuels blending mandate in 2013, with the dual goals of fostering the growth of Nigeria's domestic biofuels industry and lessening the country's reliance on gasoline imports (IEA, 2017)

The strategic objective of the mandate is to achieve a production rate of 100% biofuels by the year 2020 and this will be accomplished by combining up to 10% ethanol with gasoline to create the E10 blend, and by combining up to 20% biodiesel with petrol diesel (IEA, 2017)

3.2.13 Nigeria Feed-in Tariff for Renewable Energy Sourced Electricity, 2016

Late in the year 2015, the feed-in tariff regulation was drafted, and it was put into effect in February of the following year. The Multi-Year Tariff Order 2 has been rendered obsolete as a result of this regulation (MYTO II). The purpose of this new regulation is to encourage investment in the renewable energy sector with the end goal of making use of the country's vast and largely unutilized potential for renewable energy (IEA, 2017) It also encourages the distribution companies (DISCOs) to obtain at least fifty percent of their total procurement from renewable sources, with the expectation that the remaining fifty percent will be acquired from the Nigerian Bulk Electricity Trading Company (NBET) (IEA, 2017)

In addition, it differentiates between large power generation plants (more than 30 MW) and small power generation plants (1 MW to 30 MW). The electricity that is purchased from smaller power plants will be considered as renewable energy, while a competitive bidding process will be established for the larger renewable energy projects (IEA, 2017)

3.2.14 Nigerian Electricity Regulatory Commission Mini-Grid Regulation, 2016

The Mini-Grid regulation was enacted in 2016, with the intention of regulating the mini-grids sector and creating an environment conducive to further investments, with the end goal of accelerating the electrification process across the country. According to the information presented here, a mini grid is defined as a system that can generate electricity with a generation capacity that ranges from 0 kW to 1 MW and provide power to more than one customer (IEA, 2017).

Within the scope of this thesis, two distinct kinds of mini grids were examined. Isolated mini-grids, also known as stand-alone systems, are the first type of mini-grids and have the capacity to produce up to 100 kW of electricity. In order to run an independent mini-grid, one must either submit an application for a mini-grid permit or register with NERC. To run an off grid Mini grid that has a maximum generating capacity of one hundred kilowatts (kW), a permit is not required to be obtained. However, to operate, mini grids with a generation capacity of between 100 kW and 1 MW are required to apply to the NERC in order to obtain an operating permit (IEA 2017). The second type of mini-grid is one that is interconnected with other mini-grids and is connected to the network. Once more, to enter a triparty contract with the community and the pertinent distribution company (Disco), a permit from NERC is required to be obtained (IEA, 2017).

3.2.15 Rural Electrification Strategy and Implementation Plan (RESIP), 2016

The Rural Electrification Strategy and Implementation Plan (RESIP) was initially developed in 2006. However, it was revised in 2014 and 2016 to define a roadmap for expanding access to electricity rapidly and cost-effectively to rural areas of the country. It considers utilising on-grid, off-grid, and standalone systems for electricity supply with subsidies focused on expanding access rather than on consumption (Emodi, Ebele 2016). The plan includes the nation’s target to achieve a 75% electronification rate by 2020 by electrifying 471,000 rural households annually from 2007 to 2020. In addition, Nigeria aims to attain 100% electrification by 2040 by connecting 513,00 households annually from 2020 to 2040 (IEA 2019).

3.3 The Nigerian Electricity Sector

When it comes to the production of goods and services, electricity is an indispensable resource that is utilised extensively across the entire economy. Utilisation of a nation's available energy sources is the primary factor that determines both the level of economic development and the standard of living in that nation (Monyei et al., 2018). Therefore, a nation or region needs to have sufficient access to energy, as well as an understanding of, and the ability to satisfy, the energy requirements of its population (Trotter et al., 2017). The most common type of energy consumption is for the generation of electric current. In addition to the uses that have been mentioned previously, it sees widespread application in commercial and industrial settings, where it is used to power machinery in addition to its application in residential homes for the provision of lighting, refrigeration, and the operation of other types of household appliances (IEA, 2018). However, many developing countries, including Nigeria, are still unable to provide adequate and sustainable energy to their populations, which is required to improve their standard of living and to drive economic growth. This is a barrier to economic development in these nations (IEA, 2017; Iyke, 2015; Akpan, 2015).

In Nigeria, one of the country's most pressing challenges continues to be meeting the nation's energy demands in a reliable and sustainable manner, specifically through the generation of electricity. It is estimated that the Federal Government of Nigeria (FGN) committed a massive investment of 2.74 quadrillion Naira, which is equivalent to approximately 16 billion United States dollars, for the purpose of restoring the nation's electricity sector between the years 1999 and 2017. Nevertheless, the outcomes continue to be out of proportion with the investments made (Akuru et al., 2017).

If the country's abundant primary energy resources are utilised in an appropriate manner, Nigeria will be able to meet both its immediate and long-term requirements for economic growth (Akuru et al., 2017).

However, fossil fuel remains the primary source of electric power in the country (Adesanya and Schelly, 2019). Due to its susceptibility to the risk of fuel price volatility and availability, the country's economy has been significantly harmed by fluctuations in oil prices on the international market. Nigeria's economy is highly dependent on its oil industry (Akuru et al., 2017; Iwayemi and Fowowe, 2011).

In Nigeria, there is currently a capacity for producing approximately 13,700 megawatts worth of electricity that has already been installed. Nevertheless, in 2014, 46% of Nigeria's electricity generation capacity was generated, whereas in 2018, only 33% of this was accessible due to a lack of available gas, a shortage of water, constraints on the grid, and technical issues. This discrepancy can be attributed to a combination of a lack of available gas, a shortage of water, constraints on the grid, and technical issues.

In order to generate revenue that is capable of supporting investments in infrastructure, the government of Nigeria has taken steps to reform the energy sector. These steps include deregulating and restructuring the oil and gas sectors, as well as privatising the power sector. The government privatised the power generation and distribution industries so that more money could be invested in the reorganisation of the power sector. The government has also developed programmes to encourage the use of energy-saving and environmentally friendly practises, such as renewable energy and energy efficiency (NERC, 2019).

Up until the year 2005, when the Electricity Power Sector Reform Act (EPSRA) was passed into law, the Federal Government of Nigeria (FGN) was the only entity that was accountable for the formulation of policy, regulation, and investment within the power sector. Even though the Federal Ministry of Power (FMP) oversaw regulating the power industry, the National Electric Power Authority (NEPA) oversaw managing the operation. Between the years 1972 and 2005, the Nigerian Electric Power Authority (NEPA) was the government agency in charge of generating, distributing, and transmitting the nation's electrical power. During this period, NEPA maintained complete control over the distribution and transmission of electrical power, as well as approximately 94% of the generation.

Electricity generation began in Nigeria in the year 1896 in Lagos state and the Nigerian Electricity Supply Company (NESC), the first electric utility company in Nigeria, was established in 1929. Following this, an act of the Nigerian Parliament in 1951 led to the establishment of the Electricity Corporation of Nigeria, also known as ECN. The Niger Dams Authority (NDA) was established in 1962 with the purpose of fostering the growth of hydroelectric power in Nigeria. National Electric Power Authority (NEPA) was established from a merger that took place in 1972 between the Electricity Corporation of Nigeria (ECN) and the Niger Dams Authority (NDA) (Ikeme, Ebohon 2005).
In 1998, the Federal Government of Nigeria made changes to the principal laws that were in effect at the time, which were the Electricity and NEPA Acts. These changes were made in order to address issues on the electric power sector's poor operational and financial performance. These changes included the elimination of NEPA's monopoly and the encouragement of private investments in the sector. The National Electric Policy was drafted in the year 2001 with the goal of elaborating on the planned changes and developing a competitive electricity market. The Electricity Power Sector Reform Act (EPSRA), which was passed in 2005, laid the legal groundwork for the privatisation of the companies, the establishment of successor companies, and the division of NEPA. In addition, the year 2005 saw the establishment of the Nigerian Electricity Regulatory Commission (NERC) and the Power Holding Company of Nigeria (PHCN). The Nigerian Electricity Regulatory Commission, also known as NERC, is an independent organisation that serves as a regulatory body for the Nigerian electricity sector. The National Electric Power Authority (NEPA) split into six generation companies, eleven distribution companies, and one transmission company, which resulted in the creation of 18 successor companies. One of these successor companies was the Power Holding Company of Nigeria (PHCN), which was a transitional corporation (GIZ 2015). The history of the changes in the transitions in the Power sector is summarised in Figure 3.4.

Figure 3.4 Timeline of Nigeria's Transitional Stage Electricity Market (TEM)

The time line below shows the evolution of the electricity market until commencement of the Transitional Stage Electricity Market (TEM):

2001	adoption of the National Electric Power Policy
2005	enactment of the Electric Power Sector Reform Act (EPSRA)
2005 – 2007	establishment of the Nigerian Electricity Regulatory Commission (NERC); formation of the Power Holding Company of Nigeria (PHCN); unbundling of the PHCN into 18 independent companies
2008 – 2009	publication of the Multi Year Tariff Oder (MYTO); the Power Sector Reform Committee was formed
2010 – 2012	the Nigeria Vision 20:2020 was launched; the Presidential Action Committee on Power (PACP) and the Presidential Task Force on Power (PTFP) were established; the Roadmap for Power Sector Reform was released; the Bulk Trader was established
2012	MYTO II was approved and released
2013	full privatisation of the generation and distribution subsectors; the transmission subsector was retained by Government but its management is currently under concession
2015	MYTO 2.1 was approved and released. Petitions by various consumer groups, evoked by electricity price increases of up to 80%, led to amendment of MYTO 2.1 and a price drop of ~50%
1st of February 2015	commencement of TEM, after NERC declared all Conditions Precedent listed in the market rules as satisfied
May 2015	unbundling of TCN into an Independent System Operator (public) and a Transmission Service Provider (private) has begun

Source: (GIZ 2015)

During the phase before the transition, the Electricity Generation Companies (also known as GENCOs) were put up for sale (thermal and hydropower stations). Distribution was partitioned into the 11 companies that would go on to become the Successor Electricity Distribution Companies (DISCOs). The handover of the assets was the last step in the privatisation process, which was finished in November 2013, and there was a total of six GENCOs and eleven DISCOs. However, the federal government kept control of the transmission system through the Transmission Company of Nigeria (TCN). Transmission lines and generators are both connected to the same grid, which is managed from a centralised location in Oshogbo, which is located in Osun state.

Following this, the FGN founded the regulator NERC and a bulk trader Nigerian Bulk Electricity Trading Plc (NBET), which will exist until the complete privatisation of the electricity market. Once the power purchase agreements are signed, NBET will be passed on to the DISCOs. The FGN also founded the Operator of the Nigerian Electricity Market (ONEM) within the Transmission Company of Nigeria (TCN), the wholesale market and settlement operator, and the manager of the metering systems across the generation, transmission, and distribution companies.

The issues with electricity in Nigeria result from the diminished investments made in the public power sector in the 1990s, with cut maintenance budgets and no lack of new capacity to the national grid and all the power stations. As a result, the gap between capacity and actual generation widened continuously by the end of the 20th century. It remained a problem in the reliable and stable electricity supply in Nigeria. In 2013, the Nigerian Government privatised the power sector to improve the reliability of the electricity supply. In addition to the issues faced by Nigeria in the electricity sector, it also has issues with its previously strong oil industry (GIZ 2015).

The Nigeria Electricity Supply industry has undergone significant changes designed along four key stages: Pre-transition, transition, medium-term, and long-term. The pre-transition stage marked the end of NEPA’s monopoly, the organisation's division, and the privatisation of the successor companies. The Power Holding Company of Nigeria (PHCN) was formed during this phase. PHCN acted as a state-owned agency responsible for generating, distributing, and transmitting electricity for the whole country between 2007 and 2013. During this period, the Federal government worked to sell off the state-owned shares in the electricity service industry, keeping only the transmission grid as a state-owned entity (GIZ 2015). Table 3-4 shows the organisations in the Nigeria Electricity Supply Industry (NESI) and their respective responsibilities. The Nigeria Electricity Supply Industry (NESI) consists of the following:

1. Federal Ministry of Power (FMP)
2. Nigerian Electricity Regulatory Commission (NERC)
3. Electricity Generation Companies (GENCOs)
4. Transmission Company of Nigeria (TCN)
5. Electricity Distribution Companies (DISCOs)
6. Nigerian Bulk Electricity Trading Plc (NBET)
7. Gas Aggregator Company of Nigeria
8. Nigerian Electricity Management Service Agency (NEMSA)
9. the grid-connected generating plants supplying power in the country

Source: The Nigerian Electricity Supply Industry (NESI)

Table 3-4: NESI Institutions and their Responsibilities

Institution	Roles/responsibilities	Year Established
Nigeria Electricity Supply Industry (NESI).	Implementation of the National Electric Power Policy (NEPP) of 2001, the Electric Power Sector Reform (EPSR) Act of 2005	2001
Six Electricity Generation Companies (GENCOs)	Electric Power Generation	2005
Transmission Company of Nigeria (TCN)	Electric Power Transmission	2005

Eleven Transmission Company of Nigeria (TCN)	Electric Power Distribution	2005
The Nigerian Electricity Regulatory Commission (NERC)	Regulatory body - technical and economic regulation of the Nigerian Electricity Supply Industry	2005
Federal Ministry of Power (FMP)	Provisions of the National Electric Power Policy (NEPP) of 2001, the Electric Power Sector Reform (EPSR) Act of 2005, and the Roadmap for Power Sector Reform of August 2010.	* Created from existing ministry in 2019*
Nigerian Bulk Electricity Trading (NBET) Plc	Management and administration of the electricity pool in the Nigerian electricity supply industry (NESI).	2010
Nigerian Electricity Supply Statistics (NESISTATS)	Provide vital statistics on the power sector for participants of the Nigerian Electricity Supply Industry (NESI)	2015
Gas Aggregation Company Nigeria Limited (GACN)	Stimulating the growth of natural gas utilization in the Nigerian domestic market.	2010
Nigerian Electricity Management Service Agency (NEMSA)	Enforcement of Technical Standards and Regulations, Technical Inspection, Testing and Certification of All Categories of Electrical Installations, Electricity Meters, and Instruments to ensure the Efficient Production and Delivery of Electricity	2015

Source: Author's compilation from (Dagnachew, Hof et al. 2020)

In spite of the efforts that have been made by the government of Nigeria over the course of the last few decades to reform the energy sector, the country does not currently have sufficient electric energy to both feed the economy and provide sufficient electricity to residential homes, industrial homes, and commercial businesses (Lin and Ankrah, 2019). Previous research has pointed the finger of blame at a lack of investment, the vandalism of gas pipelines, system losses, a poor maintenance culture, and limited power evacuation as the root causes of the country's current energy crisis (Akuru et al., 2017). Additionally, several studies have pointed the finger at political factors as the primary reason for Nigeria's ongoing energy crisis (Ogunmodimu and Okoroigwe, 2019; Iwayemi, 1994).

The accessibility of electricity continues to be a crucial component in determining the placement of industries and is a potent impetus for the progression of social development. Hydropower, steam turbines, and gas turbines are the three primary types of commercial generators of electricity in Nigeria. The amount of installed capacity for the generation of electricity in 1991 was 5881.6 MW, following an increase that was equivalent to a factor

of 6 during the time span between 1968 and 1991. The generating capacity in Nigeria remained the same over the subsequent decade, whilst the availability fluctuated between 27% to 60% of installed capacity, with transmission and distribution losses accounting for about 28% of the electricity generated (ECN 2018).
The available generating capacity in the country increased to 4000 MW at the end of 2001. However, this dropped to 2,600 MW within the first quarter of 2002. 2018 saw the highest peak generation of 5,375 MW in the second quarter, and this dropped again to 3,027.4 MW at the beginning of the third quarter of 2018. The installed grid generating capacity was 12,910.40 MW with an average available capacity of 7,652.60 MW and transmission wheeling capacity at 8,100 MW. As a result, t annual electricity consumption had seen a rapid increase over the last 30 years from 1,273 GWh in 1970 to 29,573 GWh in 2012 and decreased to 25,215GWh in 2017 (ECN 2018). Table 3-5 shows a summary of the country's population, and power generation capacity and available supply.

Table 3-5 Nigeria's population installed and available power generation.

Year	Population (Million)	Installed capacity (MW)	Available power (MW)
1980	73.7	2507	783
1985	83.9	4192	1133
1990	95.6	4548	1537
1995	108	4548	1810
2000	122.9	5580	1738
2005	139.6	6538	2494
2010	159.7	6904	3358
2014	177	8876	3795
2018	190	12,522	4000

Source: (Gatugel Usman, Abbasoglu et al. 2015) and (IEA 2019)

This points to a reduced demand that may be the result of a lack of proximity to the national grid as well as issues with the provision of electricity. Because of this, many industries and residential consumers have installed generators, and the total capacity of these generators is estimated to be at least 80% of the installed capacity of the national grid. In 2017, it was estimated that 75 million people in the country did not have access to electrical power, which is equivalent to forty percent of the total population (World Bank 2017). It is estimated that only about 10% of Nigerians who have access to electricity reside in rural areas; this results in a non-linear relationship given that more than half of the country's overall population lives in rural areas (Akuru, Onukwube et al., 2017). In addition, the current energy crisis in Nigeria has made the country expensive and unattractive for foreign investors; as a result, businesses have chosen to relocate neighbouring African countries rather than risk an increase in the cost of production (Akuru, Onukwube et al. 2017). In addition, businesses and residential homes run noisy electric power generators that were fuelled by fossil fuels in order to generate electricity for their homes and places of business. It is reported that Nigeria spends an estimated sum of 796.4 billion naira (USD 4.65 billion) annually to fuel power generators. This does not include the estimated 350 billion naira (USD 2.04 billion) spent by industries to fuel their generating sets (Akuru, Onukwube et al. 2017).

Recent statistics indicate that the residential sector in Nigeria is responsible for more than half of the country's overall consumption of grid electricity, while the industrial and commercial sectors each account for approximately one quarter of the total (ECN 2018). Considering the growing demand for electricity in the country as well as the vast amount of natural resources that are discussed in section 3.1 of this report, the policymakers and reforms should attract investment to the sub-sector in order to increase and maximise the available installed capacity as well as decrease transmission and distribution losses. This should be done in order to fulfil the objectives of this report. Figure 3.5. illustrates the current organisational structure of the Nigerian power sector.

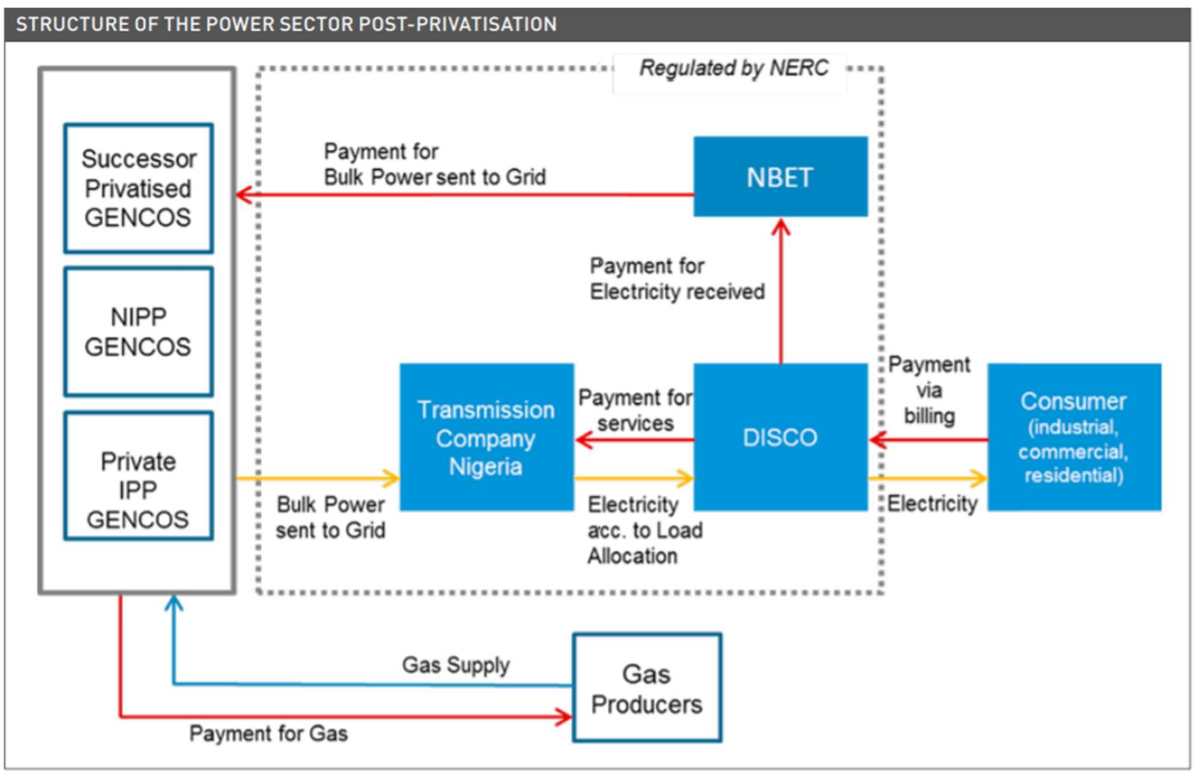


Figure 3.5 Structure of the Nigerian Power Sector (Source; (GIZ 2015))

3.3.1 Electricity Generation

The first two power generating sets in the country were installed in the colony of Lagos in 1896, marking the beginning of the generation of electricity in the country. The first electric utility company in Nigeria, which would later be known as the Nigerian Electricity Supply Company, was established in 1929. An act of the Nigerian Parliament in 1951 led to the establishment of the Electricity Corporation of Nigeria, also known as ECN. The Niger

Dams Authority (NDA) was established in 1962 with the purpose of fostering the growth of hydroelectric power in Nigeria. National Electric Power Authority (NEPA) was established as a result of a merger that took place in 1972 between the Electricity Corporation of Nigeria (ECN) and the Niger Dams Authority (NDA) (Ikeme and Ebohon, 2005).

Hydropower, steam turbines, and gas turbines are the three most common types of commercial generators of electricity. The number of megawatts of installed capacity for the generation of electricity in 1991 was 5881.6, representing an increase by a factor of 6 compared to the number of megawatts installed in 1968 (ECN, 2018).

The accessibility of electricity continues to be a crucial component in determining the placement of industries and is a potent impetus for the progression of social development. Hydropower, steam turbines, and gas turbines are the three primary types of commercial generators of electricity in Nigeria. The amount of installed capacity for the generation of electricity in 1991 was 5881.6 MW, following an increase that was equivalent to a factor of 6 during the time span between 1968 and 1991. (ECN 2018).

The GENCO's, Independent Power Producers (IPPs), and Gen Stations that are part of the Nigerian Integrated Power Project are all included in the Nigerian electricity generation sub-sector (NIPP). IPPs plants include the Agip operated – Okpai (480MW), Ibom Power, Shell operated – Afam VI (642MW), NESCO and AES Barges (270MW), and other similar facilities (NERC 2019). In 2004, the Federal Government of Nigeria established the Niger Delta Power Holding Company (NDPHC) with the purpose of managing the National Integrated Power Projects (NIPP) through the construction of infrastructure for the generation, transmission, and distribution sub-sectors. This was done as part of the Federal Government's effort to increase the amount of power that was being generated (NERC 2019). Figure 3.6 shows locations of the power generation stations in Nigeria.

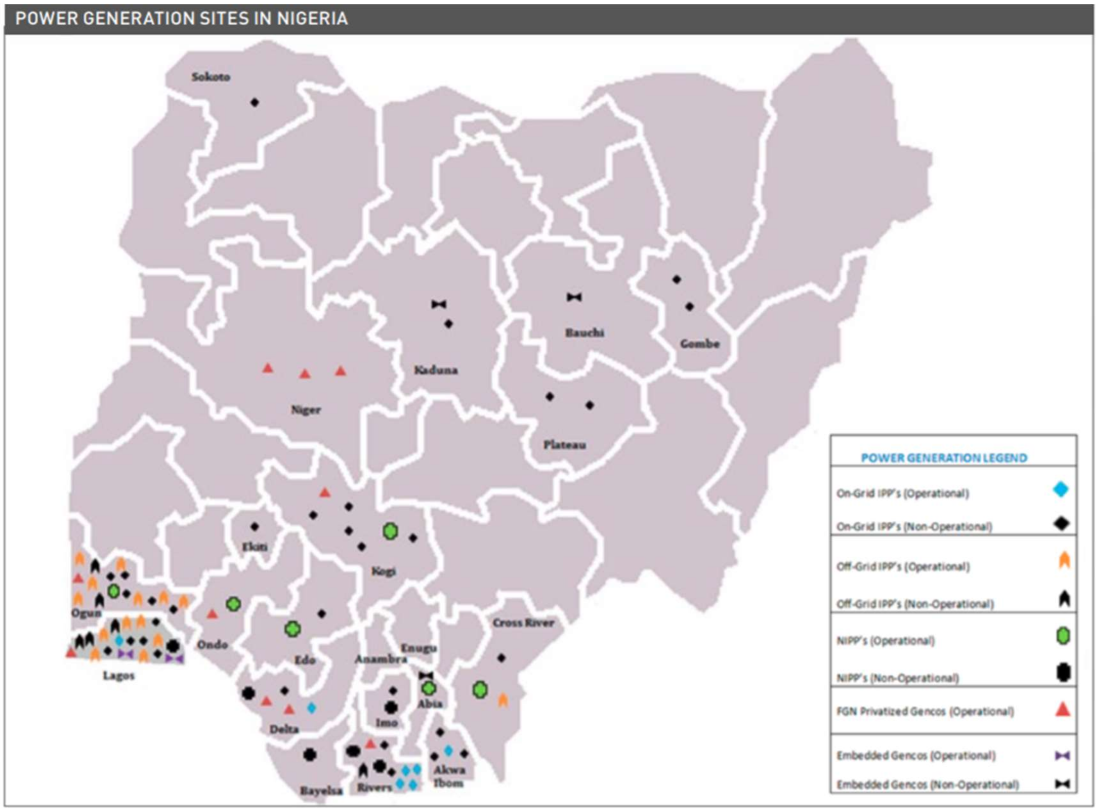


Figure 3.6 Nigerian Electricity Generation sites - Source: (GIZ 2015)

The NDPHC was tasked with the responsibility of constructing ten new gas-fired power stations so that these facilities could contribute to the national power grid. It is important to point out that while some of these projects have been finished and put into operation, others are still in the process of being built in a variety of stages. It is anticipated that the NIPP power stations will supply the national grid with approximately 4,774MW of power (NERC 2019). Table 3-6 shows the power stations in Nigeria, including the NIPP power stations.

Unfortunately, Nigeria was not able to meet its objective of increasing the nation's total generating capacity to 40,000MW by (NERC 2019) as part of the reforms that were intended to be implemented in the ESPRSA.

Table 3-6 - Nigeria's Power plants - Capacity and Utilisation

Power station	Source	Location	Type	Build Year	Installed capacity in MW	2011 Available capacity in MW	2011 National Grid contribution
Kainji	Hydro	Niger	GENCO	1968	760	480	14.3
Jebba	Hydro	Niger	GENCO	1985	576.8	450	13.4
Shiroro	Hydro	Niger	GENCO	1989	600	450	13.4
Egbin	Gas	Lagos	GENCO	1986	1320	1100	32.8
Geregu 1	Gas	Kogi	GENCO	2007	414	276	8.2
Omotosho	Gas	Ondo		2006	335	76	2.3
Olorunsogo / Papalanto	Gas	Ogun		2007	335	76	2.3
Delta (Transcorp - Ughelli)	Gas	Delta		1966	972	300	8.9
Sapele	Gas	Delta		1981	1020	90	2.7
Afam (1 to 5)	Gas	Rivers		1963	977	60	1.8
Calabar	Gas			1934	561	Nil	Nil
Orji River	Gas			1950	10	Nil	Nil
Kwale Okpai	Gas	Delta	IPP	2005	480		
Afam (6)	Gas	Rivers	IPP	2010	642		
Ibom	Gas	Akwa Ibom	IPP	2009	190		
AES Barge	Gas	Lagos	IPP	2001	270		
Omoku	Gas	Rivers	IPP	2005	150		
Trans-Amadi	Gas	Rivers	IPP		136		
Rivers	Gas	Rivers	IPP		180		
Aba	Gas	Abia	IPP	2012	140		
Geregu 2	Gas	Kogi	NIPP	2012	434		
Sapele	Gas	Delta	NIPP	2012	450		
Olorunsogo 2	Gas	Ogun	NIPP		675		
Egbema	Gas	Imo	NIPP	2013	338		
Ihovbor	Gas	Edo	NIPP	2013	451		
Azura	Gas	Edo	IPP	2019	450		
Alaoji	Gas	Abia	NIPP	2015	1074		
Omotosho 2	Gas	Ondo	NIPP	2012	450		
Omoku 2	Gas	Rivers	NIPP		225		
Gbarain	Gas	Bayelsa	NIPP		225		
				Total	**14840.80**	**3358.00**	

Source: Author's compilation from (NDPHC) *and* (Aliyu, Ramli et al. 2013)

3.3.2 Electricity Transmission

To generate revenue to support investments in infrastructure, the government of Nigeria has taken steps to reform the energy sector. These steps include deregulating and restructuring the oil and gas sectors, as well as privatising the power sector.

As a result of the merger that took place between the Transmission sector and the Operations sector on April 1st, 2004, NEPA eventually evolved into the Transmission Company (TCN) in the year 2005. Transmission Company of Nigeria (TCN) is wholly owned by the government of Nigeria, which also manages the company. TCN oversees the operation of the electrical system as well as the trading of electrical power. It is responsible for the transmission of the electric power that has been generated by the GENCO's. In addition to this, it is responsible for wheeling the power that is generated to the Discos by providing the transmission infrastructure between the GENCO's and the Feeder Sub-stations of the Discos (TCN) (NERC 2019). Figure 3.7 displays Nigeria's electricity transmission network.

Figure 3.7 Nigeria's Transmission Network - Source: TCN & NESI

3.3.3 Electricity Distribution

In 2010, the Nigerian Bulk Electricity Trading Plc, also known as NBET, was established with the purpose of supervising the distribution of electricity from GENCOs to DISCOs (Akuru, Onukwube et al. 2017). The power that is generated by the GENCO's and IPPs is purchased by NBET at prices that are established in Power Purchase Agreements (PPA), and then this power is resold to the Discos. The Discos are responsible for delivering the power to the end consumers (NERC 2019).

In Nigeria, there are a total of 11 Electricity Distribution Companies, also known as Disco's. The cities of Abuja, Benin, Eko, Enugu, Ibadan, Ikeja, Jos, Kaduna, Kano, Port Harcourt, and Yola are all included in the coverage areas. Figure 3.8 maps out the 11 power distribution zones in Nigeria.

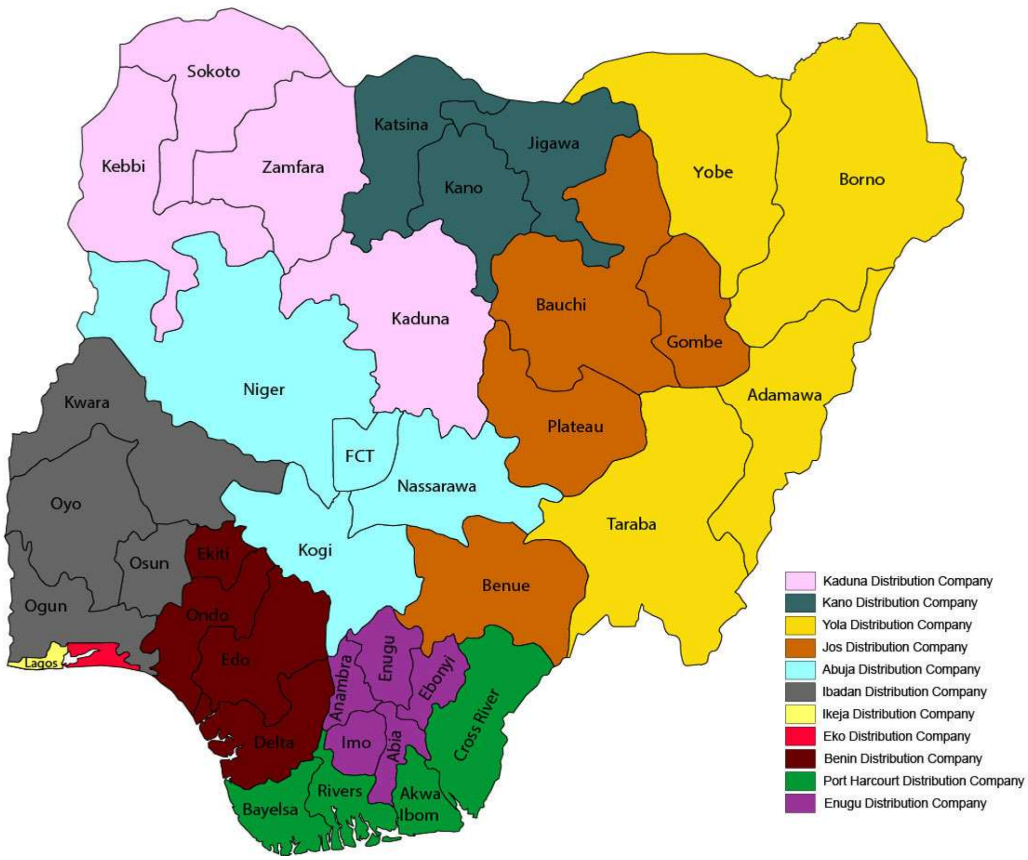


Figure 3.8 The 11 Nigerian Power Distribution Zones - Source – NESI

Sadly, some of the Discos have experienced challenges for example in January 2022, the Asset Management Corporation of Nigeria (AMCON) took over the assets of the Ibadan Electricity Distribution Company (IBEDC) after the company defaulted on a loan repayment. AMCON is a government agency that was established to recover bad debts from banks and other financial institutions (The Guardian, 2022). Similarly, AMCON took over the assets of Abuja Electricity Distribution Company (AEDC) in December 2021 after the company defaulted on a loan repayment (The Guardian, 2022). Finally, the Enugu Electricity Distribution Company (EEDC) experienced a 40% decrease in revenue due to the insecurity in the southeastern Nigeria which made it difficult for the company to collect payments from customers (The Guardian, 2022). The takeover of IBEDC, AEDC, and the decline in revenue of EEDC are part of the major challenges facing the electricity sector in Nigeria. These challenges need to be addressed to improve the reliability and affordability of electricity in the country.

3.4 Summary of recent Generation and Transmission expansion projects in Nigeria

Despite having the largest economy in Africa, Nigeria also has one of the largest energy gaps in the world, with only about 45% of the population having access to electricity. This is even though Nigeria is the largest economy on the African continent. Because of the ever-increasing population, there is an immediate and critical need to increase both the supply of and demand for electricity. In addition, there is a significant disparity between the capacity that has been installed in the power stations and the amount of electricity that is generated. The current goal of the government is to raise the percentage of people who have access to electricity from its current level of 45% to 90% by the year 2030.

In order to generate revenue that will support investments in infrastructure, the government of Nigeria has taken steps to reform the energy sector. These steps include deregulating and restructuring the oil and gas sectors, as well as privatising the power sector. The government privatised the power generation and distribution industries in two stages so that additional investments could be made in the process of reorganising the power sector. The reinvestment of the proceeds into the expansion of hydropower plants across the nation is a process that is still currently underway. It is difficult to determine whether the current crop of independent power producers will be able to sustain themselves financially. On the other hand, the government of Nigeria has developed programmes to encourage the use of energy efficiently as well as renewable sources of energy. Energy efficiency is still in its infancy stage in Nigeria, with the government encouraging investments in energy efficiency by developing policies and strategies.

The National Electric Power Authority was subdivided based on the Electric Power Sector Reform Act of 2005 (EPSRA), which served as the legal basis for the division (NEPA). The creation of successor companies and their subsequent privatisation resulted in the formulation of new policies with the intention of bringing about transformations in the electricity sector. The National Renewable Energy and Energy Efficiency Policy (NREEP) highlights the potential of clean energy resources that can be utilised to promote sustainable electricity.

The National Electric Power Policy, also known as the NEP, is intended to serve as a blueprint for the expansion of the energy industry. It specifies the policies that will be implemented by the FGN regarding the production, supply of all energy resources, and the consumption of energy across various industries. The primary objective of the policy is to establish energy security through the utilisation of a diverse array of energy sources in order to bring about sustainable development and to protect the surrounding natural environment. The NEP went through a round of revisions in 2013 in order to consider recent developments in the energy sector, with an increased focus on energy efficiency and renewable energy (Emodi, Ebele 2016). The National Energy Policy (NEP) admits that the way the country currently uses energy is inefficient and urges the implementation of more effective strategies for using energy (Emodi, Ebele 2016). In addition, the NEP encourages the use of off-grid and standalone electricity generation systems in order to increase rural electrification and supply electricity to areas of the country that are inaccessible to the national grid. Nevertheless, it is important to point out that the NEP did not establish any quantitative goals for the utilisation of renewable energy sources, nor did it establish any goals for energy efficiency and conservation (Emodi, Ebele 2016).

There is clear evidence that work is being done to translate the policies into actual actions. However, the findings indicate that more work needs to be done, and that the policies need to be periodically reviewed and revised in order to keep up with global, national, and local changes. For instance, there was a recent announcement to stop the production of electricity from coal-powered stations in order to support the goals regarding climate change. In this scenario, the energy policy of Nigeria requires a re-examination. Another illustration of this can be seen in the recent emphasis placed by the international energy industry on the widespread implementation of smart meters in the planning and design of energy systems and energy infrastructures. As a result, Nigeria ought to make certain that the policies that are currently in place are resilient and adaptable so that they can accommodate changes at the global, national, and regional levels.

The Nigerian government were optimistic that the 2013 privatisation of a portion of the power sector would boost efficiency, encourage private investment, and lead to an increase in the amount of electricity produced, but so far, this strategy has not produced the desired outcomes. The Nigerian government has undertaken projects to increase the use of renewable energy sources, modernise the country's energy infrastructure, and solve the country's power supply problems. They help achieve broader targets like cutting down on carbon emissions, increasing access to energy, and encouraging sustainable economic growth. This is demonstrated by the construction of the Ashama village solar farm and the Siemens project.

In Nigeria, the 200 MW solar power farm in Ashama village, Delta State, is a significant renewable energy project. It is widely regarded as one of West Africa's largest solar power farms. The Federal Government of Nigeria and a few private companies are working together on this project. It symbolises the government's commitment to diversifying the country's energy sources and reducing its reliance on fossil fuels. Solar power farms like this, use photovoltaic panels to generate electricity by harnessing the energy of the sun. The project in Ashama village entails a large array of solar panels spread across the area to capture sunlight and convert it into electricity. The 200MW capacity is significant, and it can provide a significant amount of clean energy to the region, contributing to Nigeria's overall energy mix and assisting in the reduction of greenhouse gas emissions (Financial Nigeria, 2021).

The Siemens project to increase power generation in Nigeria is a major infrastructure initiative with the goal of resolving the country's persistent power shortage. German multinational corporation Siemens AG is working with the government of Nigeria on this project. The plan's primary objective is to increase the reliability and efficiency of Nigeria's electrical grid and power plants. The addition of 2 GW of electrical capacity to the grid is a primary goal of the Siemens project. Since Nigeria's energy demand has been steadily rising, this would be a huge step towards ensuring that the country has enough power to function (Siemens, 2019).

Furthermore, businesses in Nigeria are increasingly interested in using renewable energy solutions to power their operations, as evidenced by the recent commissioning of a 663.6 kWp solar plant at the Nigerian Breweries Plc factory in Ibadan. The peak power output of the solar panels at this plant is 663.6 kilowatts. Nigerian Breweries Plc plans to lessen its impact on the environment and its bottom line by increasing its use of solar power. This solar power plant generates electricity during the day, when it is needed by the factory. These kinds of corporate efforts demonstrate the value of sustainable business practises and help reduce Nigeria's energy sector's reliance on fossil fuels (Faminu, 2021).

These projects collectively represent Nigeria's efforts to embrace renewable energy sources, improve its energy infrastructure, and address the challenges associated with power supply in the country. They contribute to the broader goals of reducing carbon emissions, increasing energy access, and supporting sustainable economic development.

3.5 The Rural Electrification Agency (REA)

The Federal Government of Nigeria established an agency known as the Rural Electrification Agency (REA) in order to meet the demand for electricity in the nation's more remote rural areas. Following the delivery of many off-grid power stations that run on renewable energy, the Renewable Energy Agency (REA) has begun several new initiatives, one of which is the Economic Sustainability Plan (ESP), in order to support Nigeria's response to the economic recovery that has ensued as a result of the COVID-19 pandemic. In areas that are not currently connected to the national grid, the ESP plans to install five million new connections that are powered by solar energy.

The Rural Electrification Authority (REA) was established in 2005, and it is tasked with carrying out rural electrification in accordance with the requirements outlined in the following three policies: the National Energy Policy (NEP) 2003, the Electric Power Sector Reform Act (EPSRA) 2005, and the Rural Electrification Strategy and Implementation Plan (RESIP) 2016. The purpose behind the establishment of the Rural Electrification Agency (REA) was to bring electricity to rural areas and communities that are not currently connected to the national grid (Otobo, 2022; REA, 2021).

Since its inception, the REA has been successful in completing a variety of electrification projects. These projects include the installation of seven mini-grids and over 6,000 Standalone Solar Home Systems. In addition, the REA is currently engaged in several programmes that are being supported financially by both the World Bank and the African Development Bank AfDB (REA 2021).

4. Methodology

Even though the government has made efforts to increase generation over the course of the last few decades, a thorough review of the relevant literature reveals that Nigeria's Electricity sector is still struggling with several issues and there are several policies that have been enacted to address these issues however, there is still a lack of reliable electricity even in the major cities throughout the country. This research was conducted using the research onion model developed by Saunders et al. (2015) as a framework to direct the selection of data collection and data analysis methods.
Due to the complexity of this study, a mixed-method (qualitative-quantitative) methodology was adopted to include a combination of literature review, research surveys like questionnaires, and semi-structured face-to-face interviews while using both quantitative and qualitative approaches to analyse the data collected in the process of validating the findings from the various sources (Weinberg, 2002).

4.1 The Research Onion

Saunders *et al*. conceived of the "research onion" to provide a graphical representation of a methodical strategy for organising the myriad of steps that are carried out across the many stages of a research project. In this representation, the various stages of the research process are represented by different layers of an onion. This is of the utmost significance in the process of linking the research methodology to the development of the research objectives in order to guarantee the achievement of the aim(s) of the research. This model is composed of six layers, and similarly to the layers of an onion, they are arranged so that the outermost layer is on the outside and the innermost layer is on the inside. As can be seen in Figure 4.1 the six layers that make up this model are the research Philosophy, Approach, Methodology, Strategy, Choices, Time Horizon, Techniques, and Procedures (Saunders et al., 2019).

The research onion framework was used for this study because of the structured approach it takes for transitioning through the various stages of research. The most visible layer of the research onion is a representation of the research philosophy, which is characterised by the assumptions that underpin the research. Researching philosophy entails developing one's knowledge of both nature and the world, and it provides essential insight into one's perspective of the world (Saunders et al., 2019; Dawson, 2019; Creswell, 2014). Research philosophy is a system of beliefs and assumptions that is used to aid in the development of knowledge, according to Saunders et al. The various approaches to research are referred to as positivism, critical realism, interpretivism, postmodernism, and pragmatism, respectively.

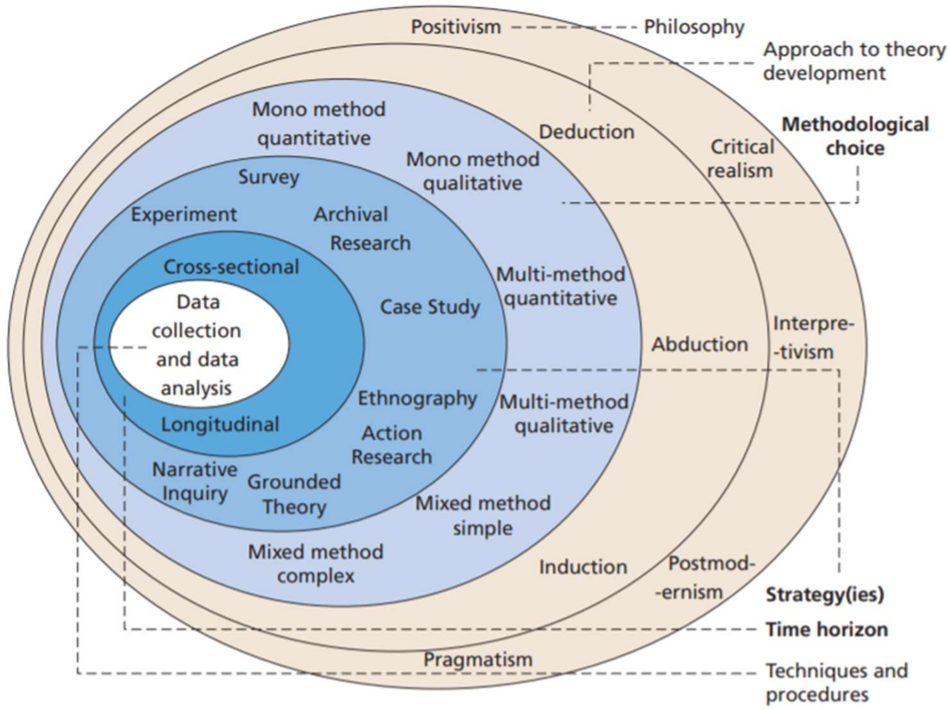


Figure 4.1 The research onion (Source: Saunders et al., 2019)

Epistemological, ontological, and axiological are the three ways of looking at research philosophies, and the assumptions that form the basis for research philosophies can be broken down into these categories (Saunders et al., 2019). Therefore, having a good understanding of these assumptions will be helpful in making philosophical decisions, and it will also have implications for the methods that were used in the research.

4.2 Methodological Process for the study

The methodological process for this research was designed in line with the research onion of Saunders *et al*. (2015) to show the processes undertaken to achieve the research aim and objectives. The research onion for this study can be seen in Figure 4.2.

The philosophical stance for this study is pragmatism which is a middle ground between objectivism and subjectivism, and positivism and interpretivism (Saunders *et al.*, 2015). This philosophical stance was adopted because the research begins with identifying a problem – the lack of sufficient electricity generation and supply in Nigeria and aims to conduct a critical examination of Nigerian government policies on electricity to determine whether they support national electrification. This position is supported by the fact that the research will involve numerous ways of interpreting the multiple realities (Saunders *et al.*, 2015) as electricity in Nigeria cannot be seen from a single point of view.

Abduction, an approach to theoretical development posited by Saunders et al., combines deduction and induction and will be adopted by this research. Saunders et al. (2015) argue that a set of possible determined premises is given in abduction as enough reason to explain a conclusion. For example, previous research has shown that policies need to be in place to support adequate electricity supply. Even though policies exist in Nigeria for electricity, inadequate electricity supply remains a significant problem. Abduction will enable the researcher to develop a conceptual framework, inform the research design, strategies and methodological choice and produce practical outcomes.

To achieve coherence in research design, this pragmatic research with an abductive approach will be conducted using a mixed-method research design that combines the qualitative and quantitative methodological choices to provide depth and breadth and a better understanding of the research problem. The quantitative approach gives breadth as it provides many views from which conclusions will be drawn. Because of the complex nature of this research, the qualitative approach is also adopted. Mixed-method research provides more insight than either model could (Creswell, 2014). This method of inquiry is most suited for addressing the research aims and objectives of this research.

The research design for this study is exploratory because it seeks to find out more about the issue of inadequate electricity supply in Nigeria by being pragmatist, to propose practical solutions.

The research strategies that this study's research questions and objectives, guided and enabled the data collection and analysis while reflecting the research philosophy as a survey and case study. The survey was chosen for being coherent with the abduction research approach and the exploratory nature of this research. This allowed for the collection of quantitative data.

This study was time-bound, hence the chosen time horizon is cross-sectional, even though it involved data collected over a lengthy period.

The research instruments for data capture to meet the objectives of this research was varied – questionnaires and semi-structured interviews with stakeholders. Questionnaires are cost-effective and covered many respondents and improved the quality of the results (Creswell, 2014).

An analysis of the performance of the Nigerian electric power generation and supply in the past decade will be evaluated for patterns and trends. Key informants for the qualitative part of the study will be identified and recruited using purposive sampling. These data collection techniques have been chosen because they will inform the research on patterns in policies, electricity generation and provide some insight into any underlying reasons for the inadequate power supply in Nigeria. The qualitative data generated will be analysed using the NVivo software, while the quantitative data will be analysed using the SPSS software. Table 4-1 shows the research objectives concerning the research instruments.

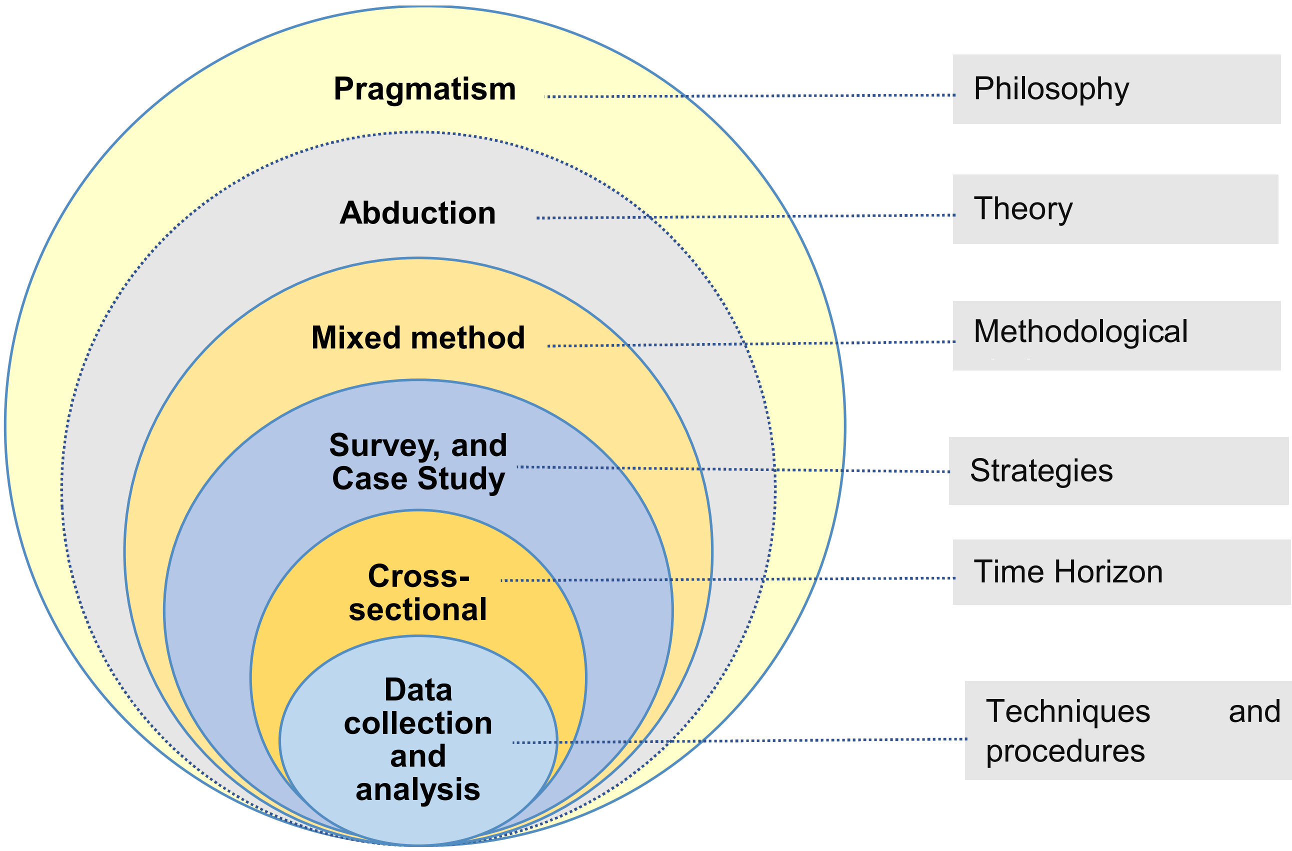


Figure 4.2 The methodological process for this study

Table 4-1 Research objectives with the research instruments

S/N	Objectives	Instrument
1	To conduct a critical review of the electricity generation, supply, and storage in Nigeria between 2001 to 2020	Literature review Interviews
2	To evaluate the impact of policies on the Nigerian electricity sector	Literature review Questionnaire Interviews

3	To evaluate forecasting techniques and expansion planning methods and identify the best option for this study.	Literature review Questionnaire Interviews
4	To develop a model to explain and predict the electricity generation capacity	Interviews Questionnaire

4.3 Data management

To ensure accuracy, the LSBU guideline was adhered to throughout each stage of the data collection, analysis, and documentation processes. The researchers who took part in the study were the only ones who have access to the responses obtained from the surveys and interviews. All the documents were kept secure within a locked cabinet in accordance with the ethical considerations of the University. As a direct result of this, the documents were not left on the desks. The electronic files were be stored on a computer that was either protected by a password or by an external storage device, such as a USB stick or a secure location in the cloud. The confidentiality of passwords was maintained, and administration of passwords adhered to the policies established by the University. Instead of being stored in several places, the information was kept in a specific location in order to minimise the possibility of inappropriate use of the data. In accordance with the regulations of the university, the responses from the surveys will be saved for an appropriate amount of time following the conclusion of the PhD research. When it is determined that the information is no longer required, it will be deleted in a secure and careful manner. The Data Management policy recommends that any discs that contain sensitive information should be physically destroyed rather than having that information simply erased. Additionally, physical documents that contain sensitive and confidential data must be shredded before they can be stored.

After the approval of the ethics submission for this research, a survey was designed to collect data from subject matter experts in the Nigerian power sector. The purpose of the survey was to determine how each of the nine policies contributed to the electricity generation and supply in Nigeria between the years 1990 and 2020. During this period, the researcher took part in several conferences while receiving research skill training.

4.4 Testing Procedure

The purpose of this research project required the use of a variety of approaches to data analysis, the majority of which fell into one of three categories. First, the information obtained from the survey was utilised to carry out an analysis of the impact that nine different policies would have had on the generation and supply of electricity between the years 1990 and 2020. This analysis was carried out with the intention of determining which policies would have been the most effective in meeting the demand for electricity. This analysis was conducted with the purpose of determining which policies would have been the most effective had they been put into place. JISC, SPSS, and NVivo were the computer programmes that were utilised in the process of conducting the analysis on the data that was obtained from the questionnaire.

The second analysis projects future levels of electricity generation and consumption in Nigeria based on historical information regarding electricity generation and consumption in Nigeria. The basis for these projections is historical information regarding electricity generation and consumption in Nigeria. The use of historical data regarding Nigeria's electricity generation and consumption as the foundation for these projections. An ARIMA Artificial Neural Network (ANN) that was built in SPSS was utilised to assist in the process of developing a model for making forecasts.

The construction of a deterministic model of the 330kV transmission grid in Nigeria will be the primary focus of the final analysis, which will be carried out in MATLAB. With the help of the forecast data that was acquired from the analysis that came before this one, this model is going to be used in order to carry out an analysis of the power flow of both the current grid as well as the future grid. This will be done with the assistance of the data that was obtained from the analysis that came before this one. During the preliminary examination of the policies, the deterministic model will make use of the recommendations that have been made by the experts in the relevant fields. At the end of the day, it will be determined whether the policies that are currently in place permit an adequate amount of electricity generation and supply across the country. These findings will also be used in the process of formulating recommendations for the design and implementation of future electricity policies in Nigeria, which will take place because of this research. This procedure is going to take place after the conclusions and recommendations that were drawn from the findings have been drafted.

4.5 Participant Selection Criteria

Subject matter experts from the Nigerian Power Sector were identified with the help of the networking opportunities that were made available at conferences. Participants were contacted through email and asked if they have any knowledge or experience in the Nigerian power sector regarding the generation or supply of electricity. The goal of the questionnaire was to collect general information about the participants, such as the number of years of experience they have had and the relevant areas they have worked in while working within the power sector.

The participants in this study were primarily classified into two groups: generation and supply for the purposes of this investigation (transmission and distribution). The purpose of the study was to determine how each of the nine policies contributed to the generation of electricity and supply of electricity in Nigeria between the years 1990 and 2020. The period covered by the study was from 1990 to 2020. The questionnaire was made available to participants of the online survey that was carried out by JISC in accordance with the data management policy of the LSBU.

4.6 Survey results

Participants were tasked with ranking nine distinct policies according to the amount of growth in electricity generation or supply that they brought about in Nigeria between the years 1990 and 2020. The rankings were to be determined based on the period covered by the study, which was from 1990 to 2020. Additional questions were asked of them, and they were asked to explain how the policies contributed to the power industry.

Figure 4.3 provides an overview of the information that was collected from the survey's participants. The number of years of experience held by the participants, the kind of organisation for which they are employed, and the power sector in which they are active are all included in this data.

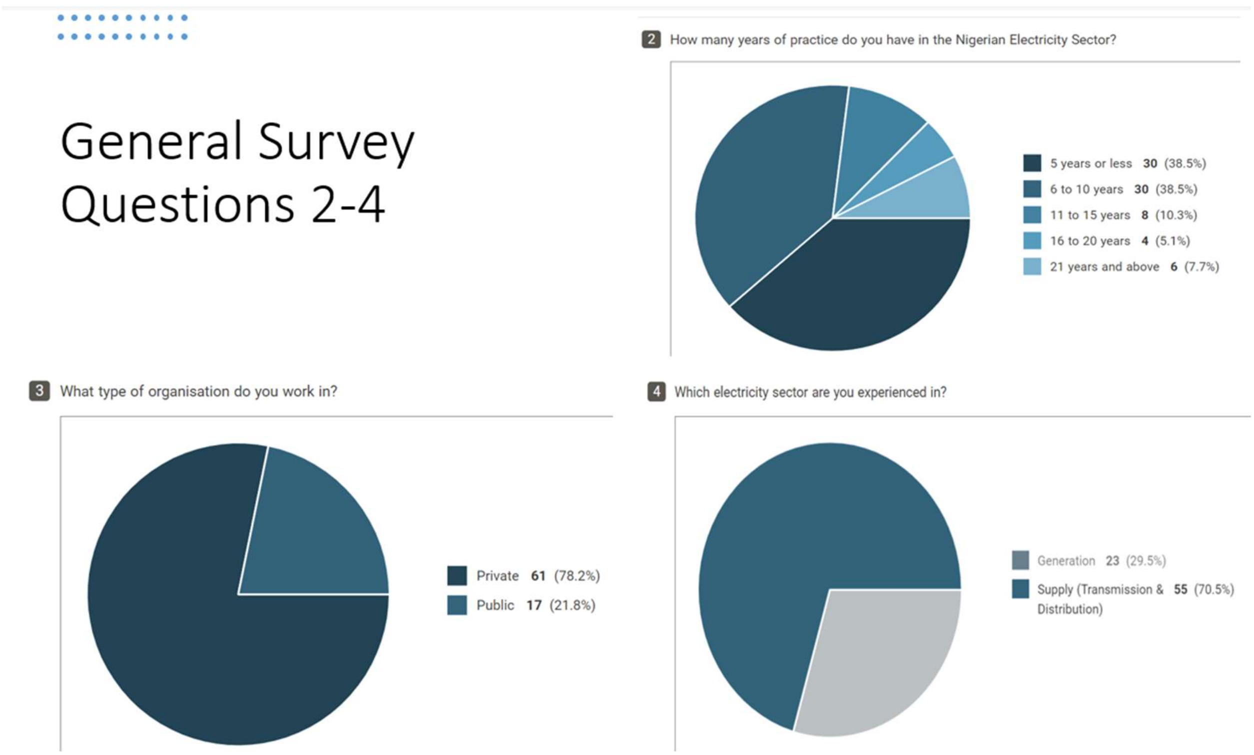


Figure 4.3 General information on survey participants

According to the results of the study, the policies referred to as Mini-grid (2016) and RESIP (2016) were the ones that performed the best in terms of both generation and supply. Both policies were introduced in 2016. The results of further research show, as depicted in Figure 4.4 and Figure 4.5, that these two policies made it easier for the Rural

Electrification Agency to bring electricity to areas that were previously unconnected to the primary transmission grid by means of mini-grids and to provide power to communities that were previously unreached by the primary transmission grid. The Rural Electrification Agency was responsible for the accomplishment of this goal through their work (REA). This indicates that decision-makers and the government should either encourage more forms of electricity generation that are independent of the existing grid or continue with the current grid expansion programmes in order to support the goal of electrifying the entire country.

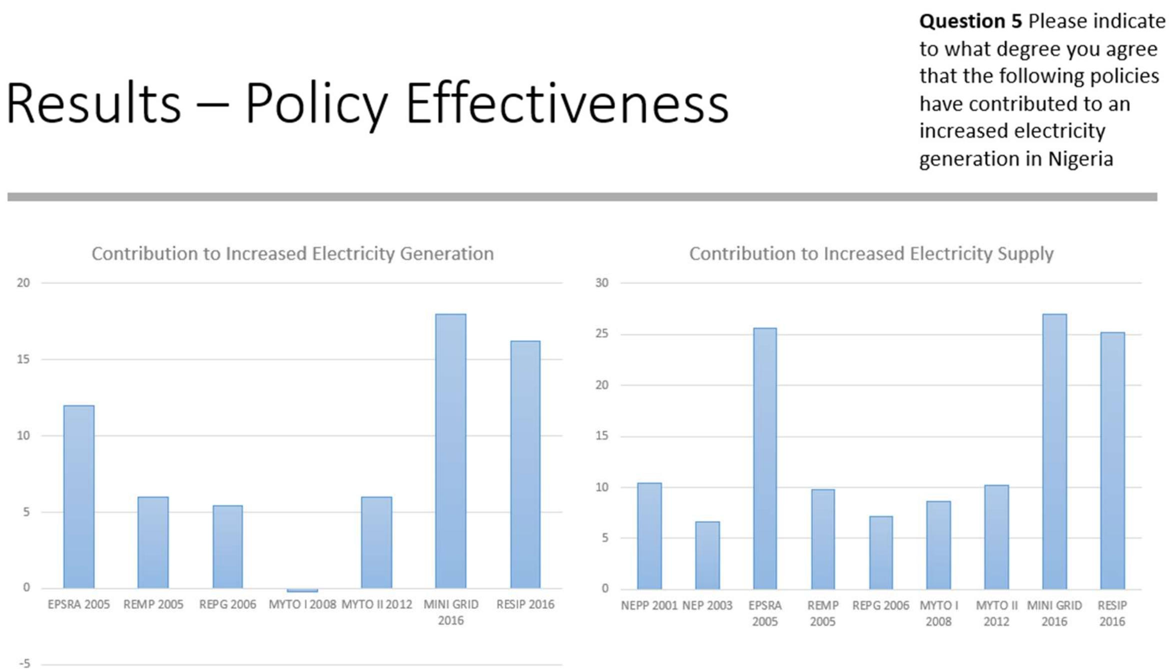
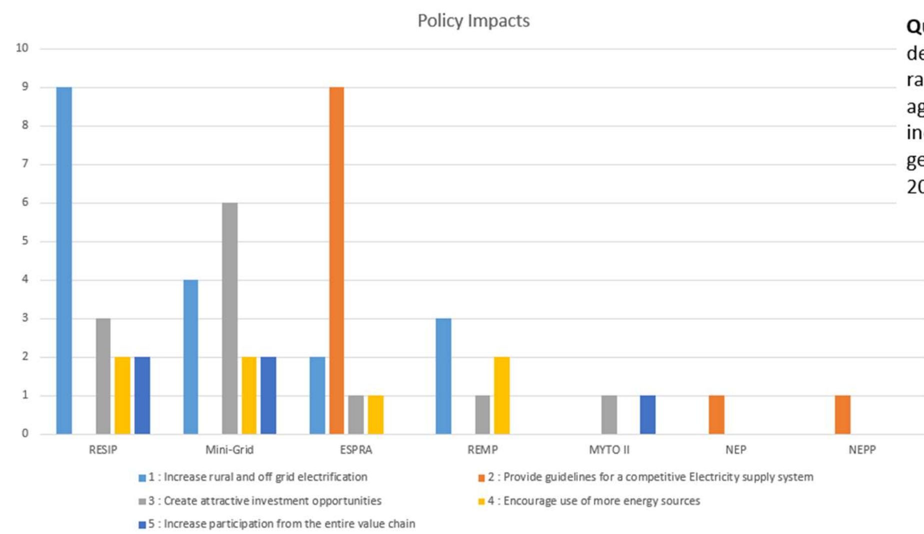


Figure 4.4 Survey results 1

Why Policies were selected as effective



Question 6. Briefly describe how the policy(s) ranked as 5 (strongly agree) contributed to the increased electricity generation/supply from 2001 to 2020

Figure 4.5 Survey results 2

Figure 4.6 shows that overall, the policies have contributed to an increase in investment in the power sector (28%), improved infrastructure (27%), enhanced energy mix (26%) and improved human capital (18%) in the Nigerian electricity sector.

Question - Please indicate to how the policies have contributed to an increased electricity generation/supply relevant factors that have brought about this change. Select as many options as possible

Survey Question 7

Policies	Investment	Infrastructure	Energy Resources / mix	Expertise / technical manpower
National Electric Power Policy (NEPP), 2001				
National Energy Policy (NEP), 2003				
National Power Sector Reform Act (EPSRA), 2005				
Renewable Energy Master Plan (REMP) 2005				
Renewable Electricity Policy Guidelines (REPG), 2006				
Multi-Year Tariff Order (MYTO I), 2008				
Multi-Year Tariff Order (MYTO II), 2012				
Nigerian Electricity Regulatory Commission Mini-Grid Regulation, 2016				
Rural Electrification Strategy and Implementation Plan (RESIP), 2016				

Results

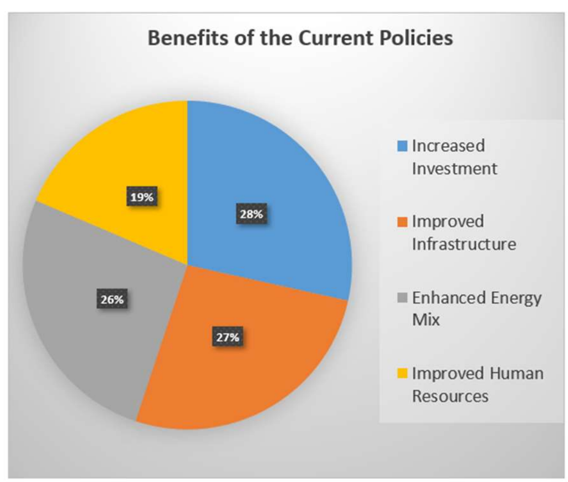


Figure 4.6 Survey results 3

In conclusion, the participants discussed a variety of strategies for improving the nation's electricity generation and supply through the implementation of new policies soon. The recommendations are laid out in Figure 4.7 according to the frequency with which the occurrences occur.

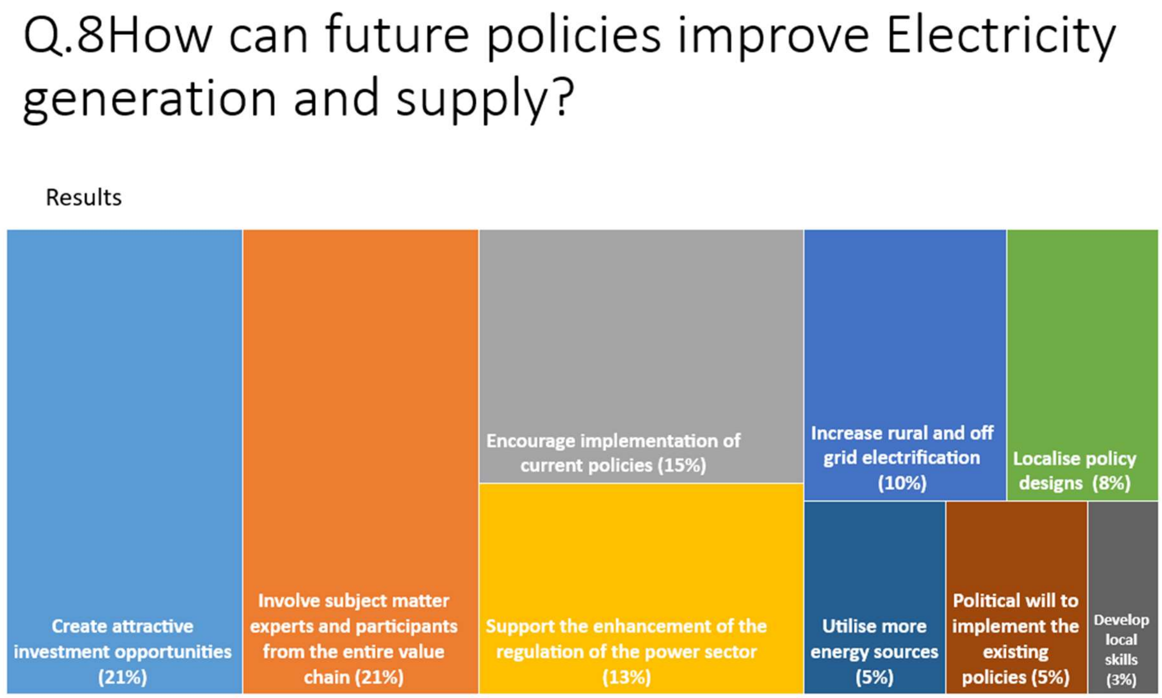


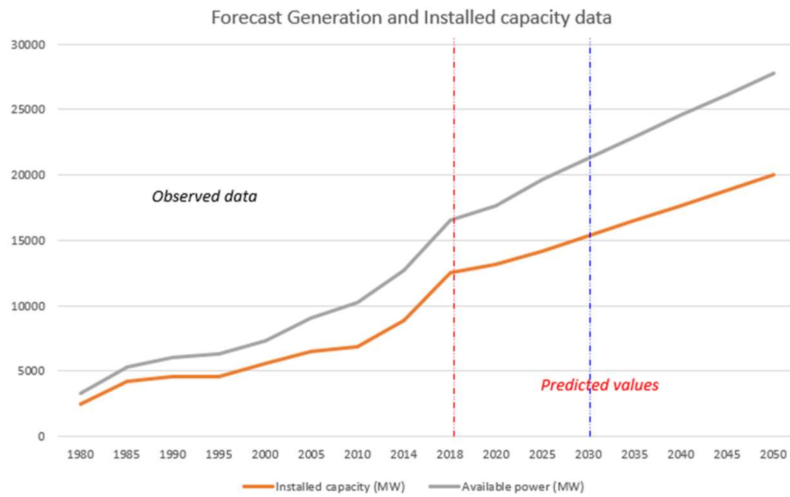
Figure 4.7 Survey results 4

4.7 Forecasting results

Observed electricity generation data and installed capacity between 1980 and 2018 were used to create forecast data between 2020 and 2050 in SPSS. The forecast data was used in the deterministic model to create new scenarios, combined with the survey outputs, to assess the feasibility of future policies in increasing electricity generation and supply. Figure 4.8 shows the forecast data created in SPSS using the time series ARIMA model.

A comparison of the performance of the system in its current vs the forecast state in 2030 and against the Policy case in 2030 was made in the tool by modelling multiple scenarios to observe the performance of each scenario and to identify areas for optimisation using the optimal power flow analysis provided via MATPOWER.

	Year	Installed capacity (MW)	Available power (MW)
Observed	1980	2,507	783
	1985	4,192	1,133
	1990	4,548	1,537
	1995	4,548	1,810
	2000	5,580	1,738
	2005	6,538	2,494
	2010	6,904	3,358
	2014	8,876	3,795
	2018	12,522	4,000
Forecast	2020	13,166	4,469
	2025	14,166	5,469
	2030	**15,332**	**5,937**
	2035	16,498	6,406
	2040	17,664	6,874
	2045	18,829	7,343
	2050	19,995	7,811
Policy	**2030**	**40,000**	**25,000**



2030 capacity and load increase
Forecast – 108%
Policy – 204%

Figure 4.8 Forecast Generation data (SPSS)

4.8 Load Modelling

The forecast data from SPSS was used to create possible scenarios by adjusting the generation data and load data. This information, in addition to the existing infrastructure, formed the inputs to the model. MATPOWER is an open-source tool used in MATLAB to run simulations and power flow analyses in this study. Power flow analyses were run on the scenarios to assess the technical feasibility of the options and the system's status at the end of each run. In addition, the output will be used to recommend future policy designs to increase electricity generation and supply. Figure 4.9 shows the process flow for the model developed in this study, and Figure 4.10 depicts the logic that was used to design the load modelling tool in MATLAB using the MATPOWER tool.

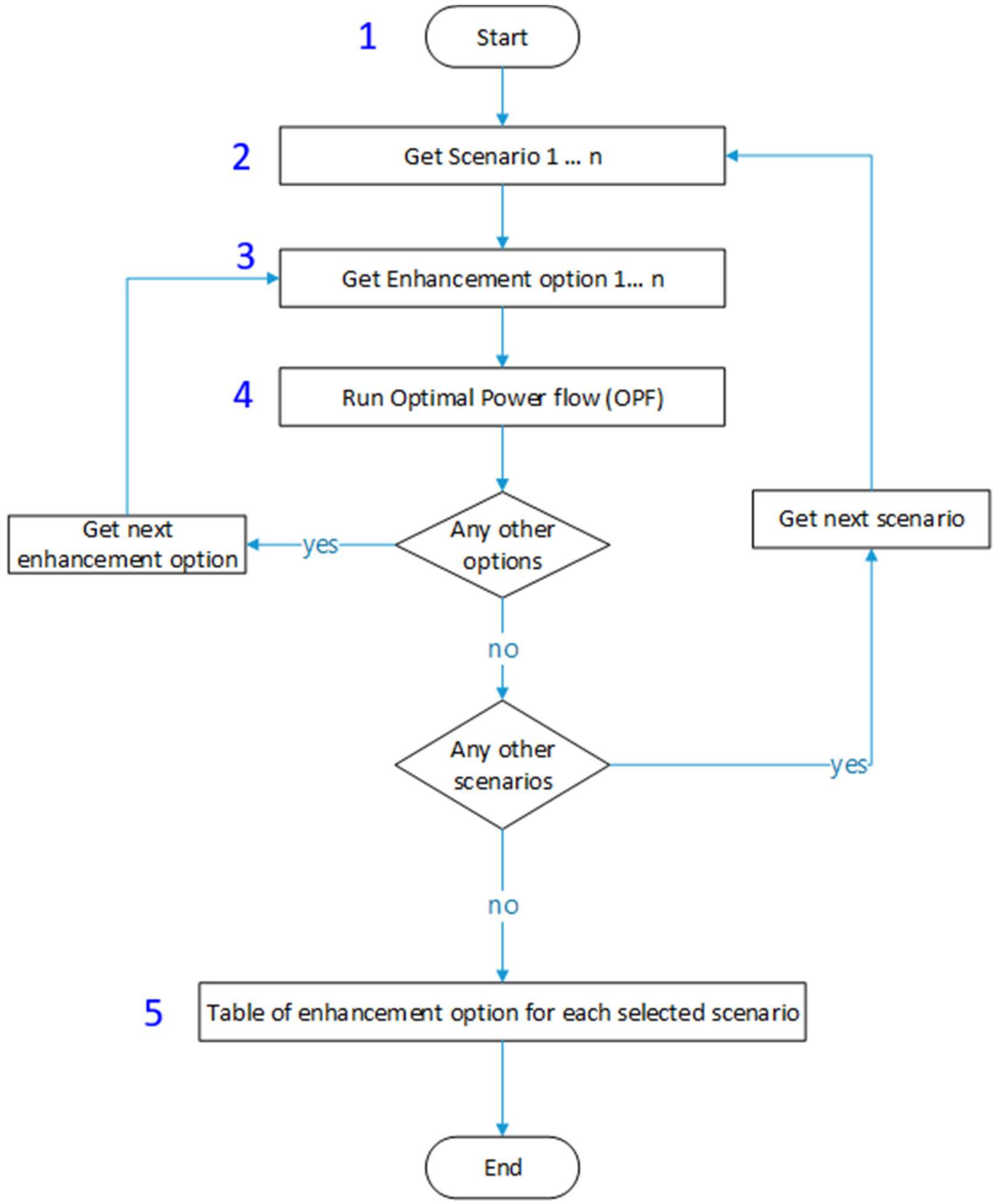


Figure 4.9 Flow chart for the load modelling in this study

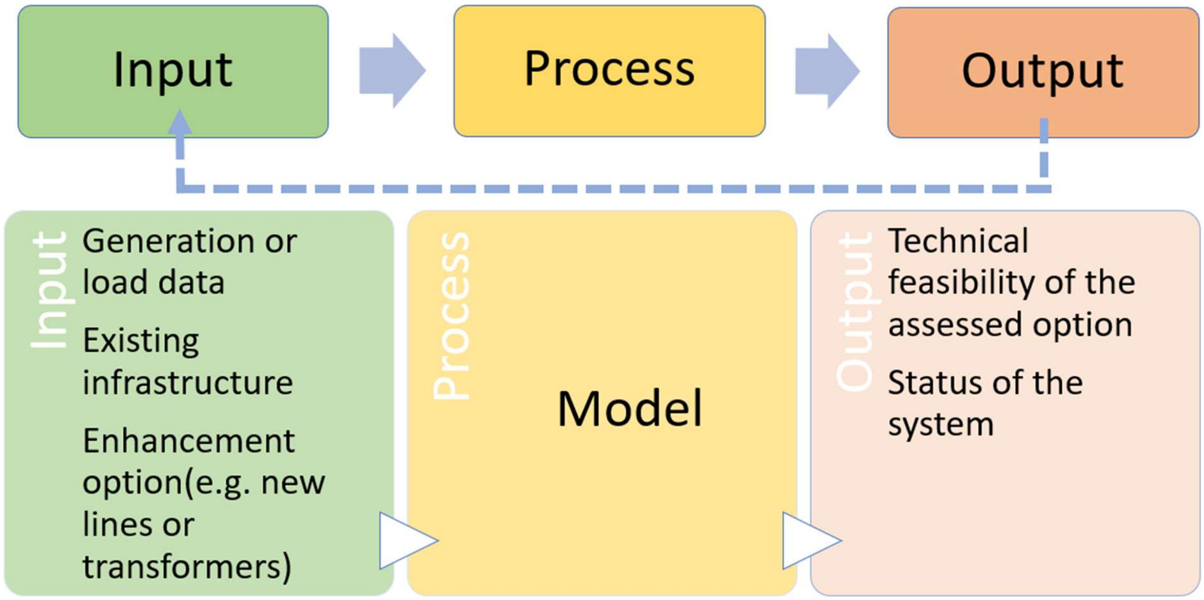


Figure 4.10 Process flow diagram for the study's modelling

Even though the researcher had demand data on the existing 330kV transmission grid in Nigeria, as shown in Figure 4.11, reliable load data for each bus was unavailable. Nevertheless, in MATPOWER, a model was constructed with the Nigerian case as the basis. Although the power flow analysis on the 52-bus network converged, the result showed that the system was unstable. This was because there was insufficient reliable load data. As a consequence of this, the researcher concluded that the IEEE 30-bus case in MATPOWER, which is depicted in Figure 4.12, would be the best option for developing a proof-of-concept model that would be able to carry out the necessary analysis based on the alterations that were stated in the policies and the forecast data.

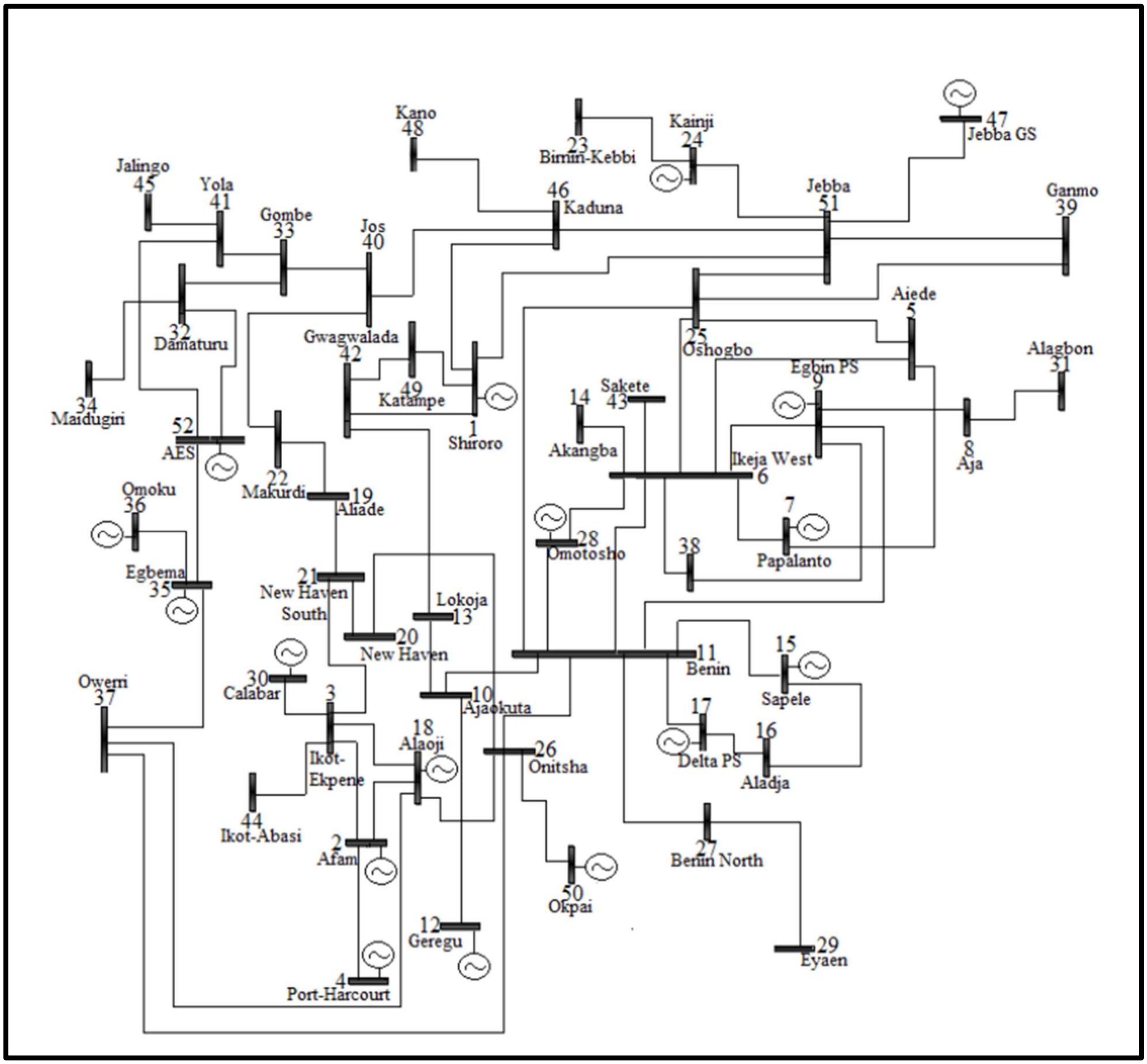


Figure 4.11 Nigeria's 52 Bus system line diagram (Akwukwuegbu et al., 2017)

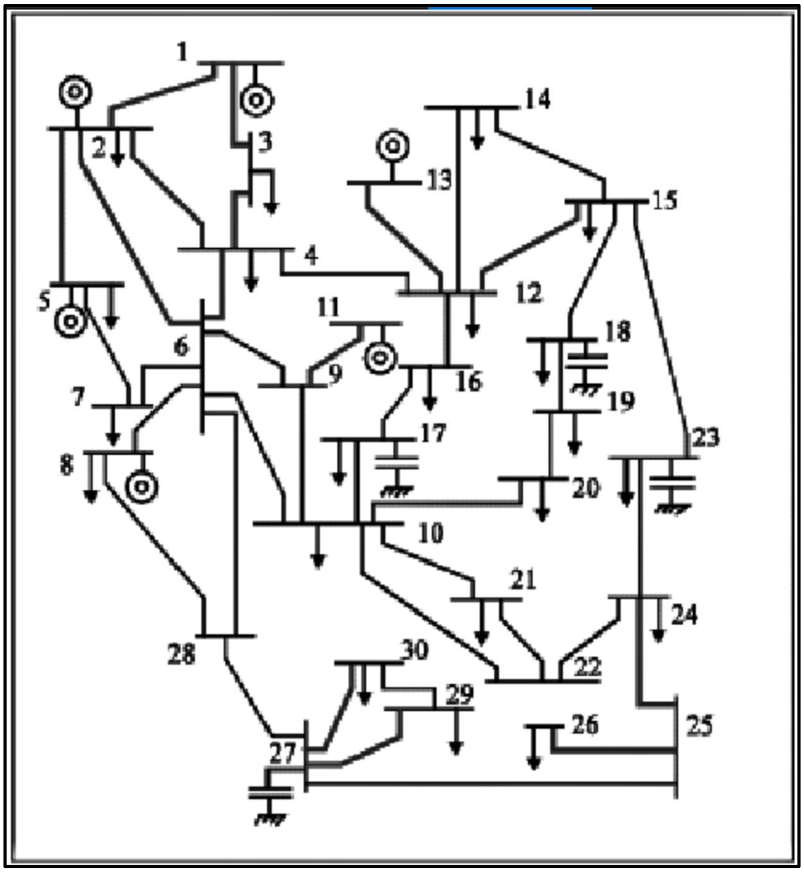


Figure 4.12 Single line diagram of IEEE 30 Bus System (Soeprijanto, A., Abdillah, M., 2011)

The Newton-Raphson method was adopted in this study due to the data available about the IEEE 30 bus case and its suitability for the MATPOWER analysis tool on MATLAB. This study employed an adapted IEEE 30 bus system, and the simulations were performed with the MATPOWER package for the MATLAB Power system. Table 4-2, Table 4-4, and Table 4-6 provide information on the IEEE 30 Bus System used to perform the load modelling in this study. In addition, descriptions of the fields in generator, branch and bus data are provided in Table 4-3, Table 4-5, and Table 4-7 as adapted from the MATPOWER instruction manual (Zimmerman and Murillo-Sánchez, 2020).

Table 4-2 – IEEE 30 bus branch data

F BUS	T BUS	R	X	B	RATE A	RATE B	RATE C	RATIO	Angle	STATUS	ANGMIN	ANGMAX
1	2	0.02	0.06	0.03	130	130	130	0	0	1	-360	360
1	3	0.05	0.19	0.02	130	130	130	0	0	1	-360	360
2	4	0.06	0.17	0.02	65	65	65	0	0	1	-360	360
3	4	0.01	0.04	0	130	130	130	0	0	1	-360	360
2	5	0.05	0.2	0.02	130	130	130	0	0	1	-360	360
2	6	0.06	0.18	0.02	65	65	65	0	0	1	-360	360
4	6	0.01	0.04	0	90	90	90	0	0	1	-360	360
5	7	0.05	0.12	0.01	70	70	70	0	0	1	-360	360
6	7	0.03	0.08	0.01	130	130	130	0	0	1	-360	360
6	8	0.01	0.04	0	80	80	80	0	0	1	-360	360
6	9	0	0.21	0	65	65	65	0	0	1	-360	360
6	10	0	0.56	0	32	32	32	0	0	1	-360	360
9	11	0	0.21	0	65	65	65	0	0	1	-360	360
9	10	0	0.11	0	65	65	65	0	0	1	-360	360
4	12	0	0.26	0	65	65	65	0	0	1	-360	360
12	13	0	0.14	0	60	60	60	0	0	1	-360	360
12	14	0.12	0.26	0	32	32	32	0	0	1	-360	360
12	15	0.07	0.13	0	32	32	32	0	0	1	-360	360
12	16	0.09	0.2	0	32	32	32	0	0	1	-360	360
14	15	0.22	0.2	0	16	16	16	0	0	1	-360	360
16	17	0.08	0.19	0	16	16	16	0	0	1	-360	360
15	18	0.11	0.22	0	30	30	30	0	0	1	-360	360
18	19	0.06	0.13	0	16	16	16	0	0	1	-360	360
19	20	0.03	0.07	0	32	32	32	0	0	1	-360	360
10	20	0.09	0.21	0	32	32	32	0	0	1	-360	360
10	17	0.03	0.08	0	32	32	32	0	0	1	-360	360
10	21	0.03	0.07	0	32	32	32	0	0	1	-360	360
10	22	0.07	0.15	0	32	32	32	0	0	1	-360	360
21	22	0.01	0.02	0	45	45	45	0	0	1	-360	360
15	23	0.1	0.2	0	50	50	50	0	0	1	-360	360
22	24	0.12	0.18	0	30	30	30	0	0	1	-360	360
23	24	0.13	0.27	0	16	16	16	0	0	1	-360	360
24	25	0.19	0.33	0	30	30	30	0	0	1	-360	360
25	26	0.25	0.38	0	16	16	16	0	0	1	-360	360
25	27	0.11	0.21	0	20	20	20	0	0	1	-360	360
28	27	0	0.4	0	65	65	65	0	0	1	-360	360
27	29	0.22	0.42	0	16	16	16	0	0	1	-360	360
27	30	0.32	0.6	0	16	16	16	0	0	1	-360	360
29	30	0.24	0.45	0	16	16	16	0	0	1	-360	360
8	28	0.06	0.2	0.02	32	32	32	0	0	1	-360	360
6	28	0.02	0.06	0.01	50	50	50	0	0	1	-360	360

Source: (Zimmerman and Murillo-Sánchez, 2020)

Table 4-3 – IEEE 30 bus branch data description

Field Name	Description
F BUS	" from" bus number
T BUS	"to" bus number
R	resistance
X	reactance
B	total line charging susceptance
RATE A	MVA rating A
RATE B	MVA rating B
RATE C	MVA rating C
RATIO	transformer off nominal turns ratio
Angle	transformer phase shift angle (degrees)
STATUS	initial branch status, 1 = in-service, 0 = out-of-service
ANGMIN	minimum angle difference (degrees)
ANGMAX	maximum angle difference (degrees)

Source: (Zimmerman and Murillo-Sánchez, 2020)

Table 4-4 – IEEE 30-bus Generator data

bus	Pg	Qg	Qmax	Qmin	Vg	mBase	status	Pmax	Pmin
1	23.54	0	150	-20	1	100	1	80	0
2	60.97	0	60	-20	1	100	1	80	0
22	21.59	0	62.5	-15	1	100	1	50	0
27	26.91	0	48.7	-15	1	100	1	55	0
23	19.2	0	40	-10	1	100	1	30	0
13	37	0	44.7	-15	1	100	1	40	0

Source: (Zimmerman and Murillo-Sánchez, 2020)

Table 4-5 – IEEE 30-bus Generator data description

Gen Field	Column	Description
GEN BUS	1	bus number
PG	2	real power output (MW)
QG	3	reactive power output (MVAr)
QMAX	4	maximum reactive power output (MVAr)
QMIN	5	minimum reactive power output (MVAr)
VG‡	6	voltage magnitude setpoint
MBASE	7	total MVA base of machine, defaults to base MVA
GEN STATUS	8	machine status
PMAX	9	maximum real power output (MW)
PMIN	10	minimum real power output (MW)

Source: (Zimmerman and Murillo-Sánchez, 2020)

Table 4-6 – IEEE 30-bus Bus data

bus_i	type	Pd	Qd	Gs	Bs	area	Vm	Va	baseKV	zone	Vmax	Vmin
1	3	0	0	0	0	1	1	0	135	1	1.05	0.95
2	2	21.7	12.7	0	0	1	1	0	135	1	1.1	0.95
3	1	2.4	1.2	0	0	1	1	0	135	1	1.05	0.95
4	1	7.6	1.6	0	0	1	1	0	135	1	1.05	0.95
5	1	0	0	0	0.19	1	1	0	135	1	1.05	0.95
6	1	0	0	0	0	1	1	0	135	1	1.05	0.95
7	1	22.8	10.9	0	0	1	1	0	135	1	1.05	0.95
8	1	30	30	0	0	1	1	0	135	1	1.05	0.95
9	1	0	0	0	0	1	1	0	135	1	1.05	0.95
10	1	5.8	2	0	0	3	1	0	135	1	1.05	0.95
11	1	0	0	0	0	1	1	0	135	1	1.05	0.95
12	1	11.2	7.5	0	0	2	1	0	135	1	1.05	0.95
13	2	0	0	0	0	2	1	0	135	1	1.1	0.95
14	1	6.2	1.6	0	0	2	1	0	135	1	1.05	0.95
15	1	8.2	2.5	0	0	2	1	0	135	1	1.05	0.95
16	1	3.5	1.8	0	0	2	1	0	135	1	1.05	0.95
17	1	9	5.8	0	0	2	1	0	135	1	1.05	0.95
18	1	3.2	0.9	0	0	2	1	0	135	1	1.05	0.95
19	1	9.5	3.4	0	0	2	1	0	135	1	1.05	0.95
20	1	2.2	0.7	0	0	2	1	0	135	1	1.05	0.95
21	1	17.5	11.2	0	0	3	1	0	135	1	1.05	0.95
22	2	0	0	0	0	3	1	0	135	1	1.1	0.95
23	2	3.2	1.6	0	0	2	1	0	135	1	1.1	0.95
24	1	8.7	6.7	0	0.04	3	1	0	135	1	1.05	0.95
25	1	0	0	0	0	3	1	0	135	1	1.05	0.95
26	1	3.5	2.3	0	0	3	1	0	135	1	1.05	0.95
27	2	0	0	0	0	3	1	0	135	1	1.1	0.95
28	1	0	0	0	0	1	1	0	135	1	1.05	0.95
29	1	2.4	0.9	0	0	3	1	0	135	1	1.05	0.95
30	1	10.6	1.9	0	0	3	1	0	135	1	1.05	0.95

Source: (Zimmerman and Murillo-Sánchez, 2020)

Table 4-7– IEEE 30-bus Bus data description

Bus Field	column	description
BUS I	1	bus number (positive integer)
BUS TYPE	2	bus type (1 = PQ, 2 = PV, 3 = ref, 4 = isolated)
PD	3	real power demand (MW)
QD	4	reactive power demand (MVAr)
GS	5	shunt conductance
BS	6	shunt susceptance
BUS AREA	7	area number (positive integer)
VM	8	voltage magnitude
VA	9	voltage angle (degrees)
BASE KV	10	base voltage (kV)
ZONE	11	loss zone (positive integer)
VMAX	12	maximum voltage magnitude
VMIN	13	minimum voltage magnitude
LAM P†	14	Lagrange multiplier on real power mismatch (u/MW)
LAM Q†	15	Lagrange multiplier on reactive power mismatch (u/MVAr)
MU VMAX†	16	Kuhn-Tucker multiplier on upper voltage limit
MU VMIN†	17	Kuhn-Tucker multiplier on lower voltage limit

Source: (Zimmerman and Murillo-Sánchez, 2020)

While the tool was being constructed, additional nodes were developed to simulate improving the system's performance. The tool was developed to give policymakers the ability to simulate a variety of different scenarios and improvement choices. Alterations to the scenario may involve an expansion of the existing network's load or capacity, as well as the installation of new generators. Alterations classified as enhancements, on the other hand, include installing new transmission lines within the system. These lines are aimed at minimising power losses and maximising the flow of generated electricity to end users. The IEEE 30 bus network shown in Figure 4.12 was modified to create a 33-bus network, depicted in Figure 4.13. This modification involved the addition of three nodes.

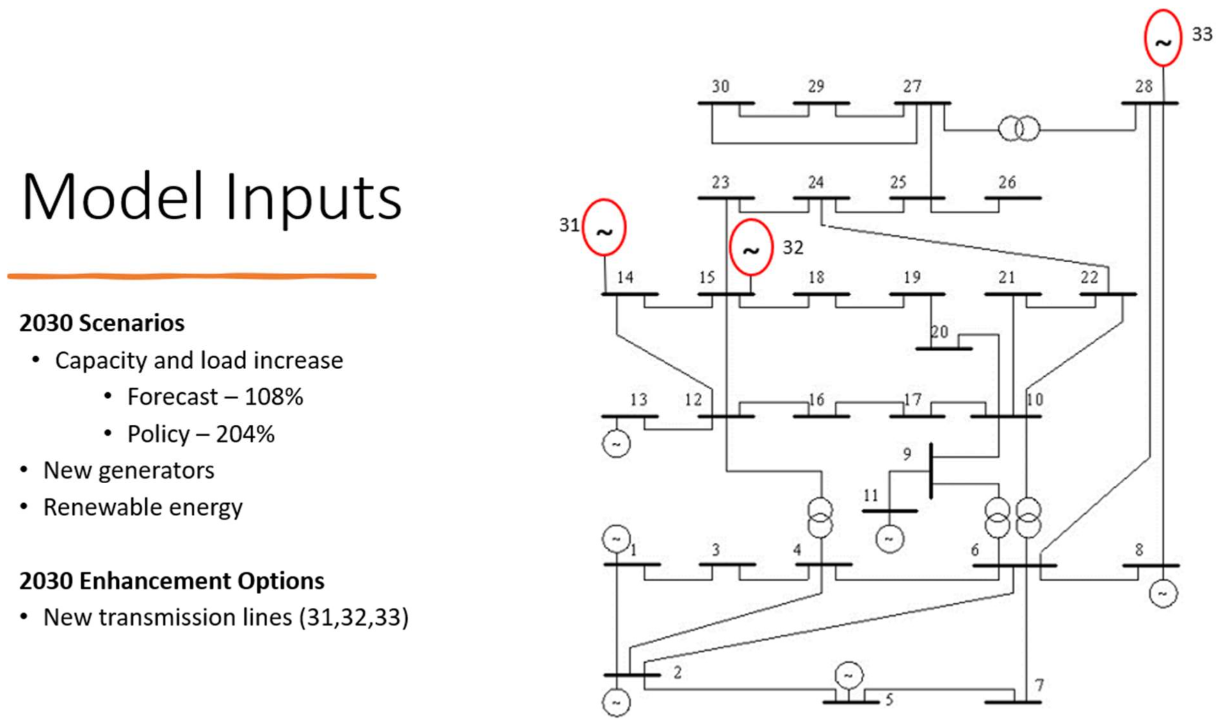


Figure 4.13 Modified IEEE 30 bus network with three additional nodes.

The users can specify the system characteristics using an input file created in Microsoft Excel. These characteristics include the amount by which the capacity and the load are to be increased, the amount of new generation that will be provided by renewable energy, which new transmission lines will be added to the model, and the specifics of any new buses, generators, or branches that are added to the system. The results of the input file are displayed in Figure 4.14, Figure 4.15, Figure 4.16, Figure 4.17, Figure 4.18, Figure 4.19 and Figure 4.20.

A
Increase in Load and Capacity
1.08
2.04

Figure 4.14 Model Input file – scenario tab

A	B
Renewable Energy percentage (0 to 1)	0 = 0% RE 1 = 100% RE
25%	

Figure 4.15 Model Input file – Renewable energy tab

F BUS	T BUS	R	X	B	RATE A	RATE B	RATE C	RATIO	Angle	STATUS	ANGMIN	ANGMAX
31	14	0.221	0.1997	0	5	5	5	0	0	1	-360	360
32	15	0.1073	0.2185	0	5	5	5	0	0	1	-360	360
33	28	0.3202	0.6027	0	5	5	5	0	0	1	-360	360

Figure 4.16 Model Input file – new transmission lines data

bus_i	type	Pd	Qd	Gs	Bs	area	Vm	Va	baseKV	zone	Vmax	Vmin
31	2	3.2	1.6	0	0	2	1	0	135	1	1.1	0.95
32	2	3.2	1.6	0	0	2	1	0	135	1	1.1	0.95
33	2	3.2	1.6	0	0	2	1	0	135	1	1.1	0.95

Figure 4.17 Model Input file – new buses data

bus	Pg	Qg	Qmax	Qmin	Vg	mBase	status	Pmax	Pmin	Pc1	Pc2	Qc1min	Qc1max	Qc2min	Qc2max
31	20	0	40	-10	1	100	1	30	0	0	0	0	0	0	0
32	20	0	40	-10	1	100	1	30	0	0	0	0	0	0	0
33	20	0	40	-10	1	100	1	30	0	0	0	0	0	0	0

Figure 4.18 Model Input file – new generators data

F BUS	T BUS	R	X	B	RATE A	RATE B	RATE C	RATIO	Angle	STATUS	ANGMIN	ANGMAX
31	14	0.221	0.1997	0	5	5	5	0	0	1	-360	360
32	15	0.1073	0.2185	0	5	5	5	0	0	1	-360	360
33	28	0.3202	0.6027	0	5	5	5	0	0	1	-360	360

Figure 4.19 Model Input file – new branch data

Type	startup	shutdown	n	c(n-1)	...	c0
2	0	0	3	0.025	0	0
2	0	0	3	0.025	0	0
2	0	0	3	0.025	0	0

Scenarios | RE | lines | bus | gen | branch | gencost | Definition ...

Figure 4.20 Model Input file – new generator costs data

Upon completing analyses using the deterministic model developed in this study, the user can export the results from MATLAB to a Microsoft Excel file. Figure 4.21 shows the model output file with the results of a power flow analysis completed using the model developed with the MATPOWER tool in MATLAB.

Renewable energy proportion	0.25	
Base case operating cost	574.517	USD/hr
Basecase Total Capacity	335	MW
Basecase Total Demand	189.2	MW

		Operating costs in USD/hr					
Scenario	Load_Increase	Scenario_costs	Enhancement_costs_1	Enhancement_costs_2	Enhancement_costs_3	Total_Capacity_MW	Total_Demand_MW
1	1.08	307	249	236	223	452	214
2	2.04	753	656	635	615	773	396

Sheet1

Figure 4.21 Model output file – optimal power flow analyses results

5. Results and Discussion

The results of the study, which can be found in Table 5-1, illustrate the findings from all the investigated cases. According to the findings, the system's operating costs decreased as more renewable generators were added to the system and more transmission lines were added to the network.

Table 5-1–Results of the load modelling tool

Case Num	Renewable energy %	Scenario	Load_ Increase	Scenario costs	Enhancement costs_1	Enhancement costs_2	Enhancement costs_3
1	0%	1	1.08	634	565	548	532
2	0%	2	2.04	1563	1434	1405	1379
3	5%	1	1.08	565	497	482	466
4	5%	2	2.04	1382	1260	1233	1208
5	10%	1	1.08	497	432	417	402
6	10%	2	2.04	1211	1095	1070	1046
7	15%	1	1.08	432	369	354	340
8	15%	2	2.04	1049	940	916	894
9	20%	1	1.08	369	308	294	280
10	20%	2	2.04	897	793	771	750
11	25%	1	1.08	307	249	236	223
12	25%	2	2.04	753	656	635	615
13	30%	1	1.08	248	193	180	168
14	30%	2	2.04	618	526	507	488
15	35%	1	1.08	191	140	129	119
16	35%	2	2.04	492	405	387	370
17	40%	1	1.08	138	93	83	75
18	40%	2	2.04	376	293	276	260
19	45%	1	1.08	90	51	43	36
20	45%	2	2.04	284	195	179	165
21	50%	1	1.08	48	16	11	10
22	50%	2	2.04	207	122	107	95
23	55%	1	1.08	11	3	3	3
24	55%	2	2.04	143	67	53	42
25	60%	1	1.08	0	0	0	0
26	60%	2	2.04	92	26	15	7
27	65%	1	1.08	0	0	0	0
28	65%	2	2.04	50	2	1	1
29	70%	1	1.08	0	0	0	0
30	70%	2	2.04	15	0	0	0
31	75%	1	1.08	0	0	0	0
32	75%	2	2.04	0	0	0	0

33	80%	1	1.08	0	0	0	0
34	80%	2	2.04	0	0	0	0
35	85%	1	1.08	0	0	0	0
36	85%	2	2.04	0	0	0	0
37	90%	1	1.08	0	0	0	0
38	90%	2	2.04	0	0	0	0
39	95%	1	1.08	0	0	0	0
40	95%	2	2.04	0	0	0	0
41	100%	1	1.08	0	0	0	0
42	100%	2	2.04	0	0	0	0

Two main scenarios were examined using the deterministic tool developed in this study. The first scenario depicts Nigeria's situation in 2030 (Forecast Scenario). In this scenario, multiple cases were run in which the electricity capacity and load were increased by a factor of 1.08 to match the forecast increase in demand, as determined by the outcomes of the ARIMA modelling performed earlier on in this study. In this scenario, the tool was used to model the system's performance after adding new power-generating stations to the network. The tool was executed numerous times, and each time, the proportion of renewable energy contributing to the generation was increased by increments of 5%, with the total percentage ranging from 0 to 100 percent. In addition, the network received new transmission lines to support the evacuation of the additional power generated from the new power station. The tool calculated the system's operating cost as each scenario was run through it. The scenario cost represents the system's operating cost, which includes the cost of operating the network with electricity generated from renewable and non-renewable sources of energy. The operating cost of the system with one new transmission line is represented by the enhancement cost one, the operating cost of the system with two new transmission lines is represented by the enhancement cost two, and the operating cost of the system with three new transmission lines is represented by the enhancement cost three. The results of the analyses run only for scenario one (Forecast cases) are displayed in Figure 5.1.

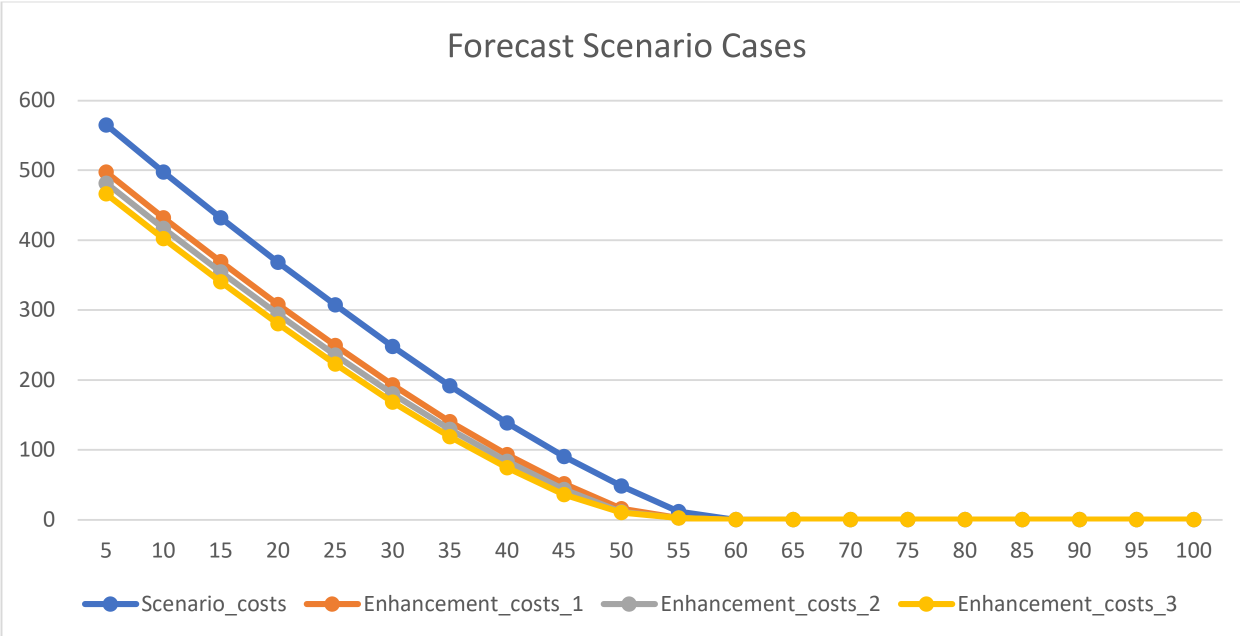


Figure 5.1 Forecast Scenario case results.

In the Forecast scenario, the system's operating costs decreased due to the introduction of additional power generation from renewable energy sources and the addition of each new transmission line. However, it should also be noted that increasing the proportion of renewable energy in the electricity mix beyond 60% does not result in any additional benefits because the system's operating cost does not change after reaching this point.

The second scenario run in the tool depicts the situation in Nigeria in the year 2030 based on the plans stipulated in the Nigerian policies (Policy scenario). In this scenario, multiple cases were run in which the electricity capacity and load were increased by a factor of 2.04 to match the forecast increase in demand, as determined by the policies.
It was observed that the existing infrastructure could not support this load and capacity increase in the Policy Scenario. This is because the optimal power flow analyses (OPF) for these cases did not converge. Therefore, some alterations were made to the line characteristics to accommodate the new load and capacity increase depicted in the Policies. This indicates that extra transmission lines need to be added to the existing system in addition to the ones that are required to connect the new generating stations to the existing grid to avoid overloading the lines and causing damage to the infrastructure in the 2030 Policy scenario.

The tool was used to run multiple simulations on the policy scenario. Each time, the proportion of renewable energy contributing to the generation was increased by increments of 5%, with the total percentage ranging from 0 to 100 percent, as was done in the Forecast scenario. The results of the analyses run only for scenario two (Policy cases) are displayed in Figure 5.1.

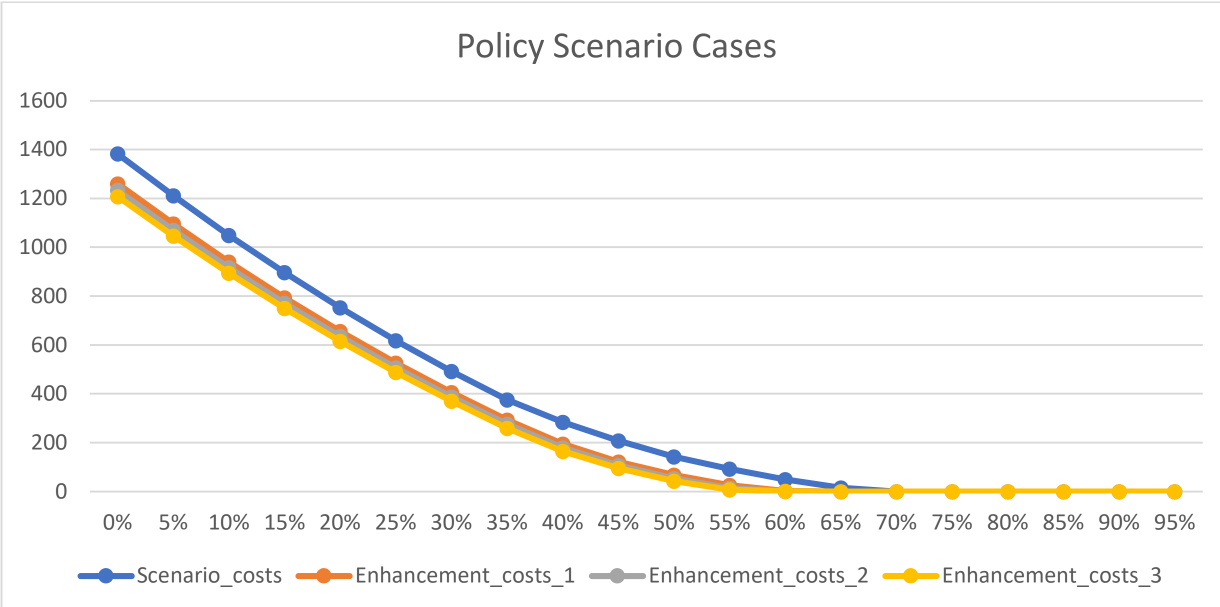


Figure 5.2 Policy Scenario Case results

In addition, the network received new transmission lines to support the evacuation of the additional power generated from the new power station. The tool calculated the system's operating cost as each scenario was run through it. The scenario cost represents the system's operating cost, which includes the cost of operating the network with electricity generated from renewable and non-renewable sources of energy. For example, the operating cost of the system with one new transmission line is represented by the enhancement cost one, the operating cost of the system with two new transmission lines is represented by the enhancement cost two, and the operating cost of the system with three new transmission lines is represented by the enhancement cost three.

It was observed that in the Policy scenario, the system's operating costs decreased due to the introduction of additional power generation from renewable energy sources and the addition of each new transmission line. However, it should also be noted that increasing the proportion of renewable energy in the electricity mix beyond 70% does not result in any additional benefits because the system's operating cost does not change after reaching this point. Figure 5.3 depicts the combined results for the Forecast and Policy scenario cases.

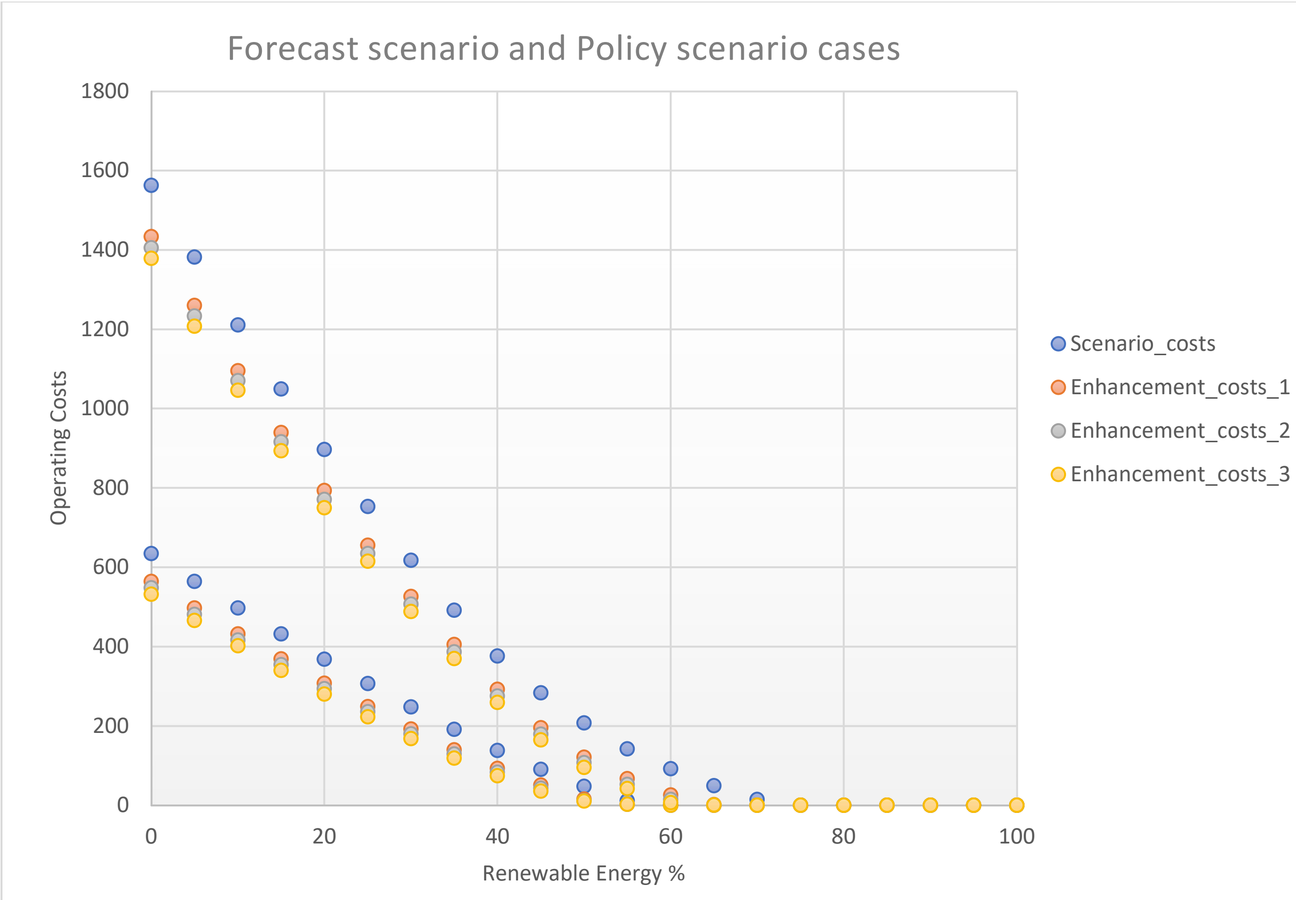


Figure 5.3 Combined results for Forecast scenario and Policy scenario cases

Additional transmission lines and generation stations must be constructed and added to the existing network for the Nigerian power system to meet the requirements of the forecast or policy scenarios. The analyses indicate that adding more than 60 percent renewable energy to the network in the 2030 forecast scenario and adding more than 70 percent renewable energy in the 2030 Policy scenario provides no additional benefit.

Without the need for in-depth technical knowledge, policymakers and planners can design and test their assumptions before launching a policy with the tool developed in this study, which is accessible and can be operated by policymakers with less technical skills.

5.1 Validation of research findings

Findings from this study show that the Nigerian government needs to create a long-term strategy for the electricity sector that considers renewable energy, energy efficiency, and the correction of institutional weaknesses. It is recommended that for the government to meet the rising demand for electricity, it will have to prioritise investments in the

transmission and distribution infrastructure as demonstrated successfully by countries like India.
India achieved 100% electrification in 2019 via an ambitious rural electrification program, which provided financial support to state electricity distribution companies to set up infrastructure in rural areas, electricity connections to households and promote the use of renewable energy sources such as solar power. The government's efforts were also complemented by the private sector's investments in the power sector and the growth of decentralised renewable energy solutions such as microgrids, which provide power to remote areas that are not connected to the main grid (Palit and Kumar, 2022).

The combination of government policies, public-private partnerships, and the adoption of innovative technologies helped India achieve 100% electrification, which has had a significant impact on improving the quality of life of people, promoting economic growth, and reducing carbon emissions. This can be replicated in Nigeria and already steps have been taken by the Nigerian government to achieve this like the creation of the REA and the passing of the bill in March 2023 which allows individual states to generate and supply electricity to consumers and the grid (Bloomberg, 2023), and the Electricity Act that was signed by the president of Nigeria in June 2023 to establish a comprehensive legal and institutional framework for a fully privatised, competitive electricity market in Nigeria (KPMG, 2023).

6. Conclusion and recommendation for future work

Around 60% of Nigeria's population has access to electricity, but it is unreliable and insufficient. As a result, most Nigerian homes rely on generators or solar panels for power. Like most developing countries, Nigeria requires sufficient electricity to grow its economy and meet the needs of its expanding population. In addition, as demonstrated by the recent COVID-19 pandemic, hospitals treating patients, communities obtaining clean water, the dissemination of critical information, and the education of children who are not in school all rely on reliable and affordable electricity.

A deterministic modelling tool was developed in this study. It was used to examine the Nigerian electricity policies from 2001 to 2020 to identify the least-cost electrification generation and supply option required to provide electricity to all areas of Nigeria by 2030. According to the study, because Nigeria's economy is still in its early stages, it would be prudent to promote a mix of non-renewable and renewable energy to help the economy, reduce energy poverty, and protect the environment. This could be accomplished by diversifying the country's energy mix and constructing renewable power plants.

Future policymakers will be able to use this tool to model or extrapolate the potential effects of their ideas before committing to specific courses of action. Moreover, the software is accessible and can be used by policymakers with no technical background.
At the end of the planning period, in 2030, the model predicted that a network of power stations that use renewable and non-renewable energy sources would be the best option for Nigeria's future network. However, falling oil prices, support chain issues, lower incomes, and higher living costs will likely slow the adoption of renewable energy in Nigeria.

The power flow of the distribution network was calculated using the Newton-Raphson technique. The distribution network's optimum power flow model was then constructed using the network's most negligible loss as the objective function. The enhanced technique was then used to solve the optimisation issue. The simulation is examined and validated using the IEEE 30 bus system in the MATLAB programme. The test findings demonstrate that to lower network losses and boost system efficiency in both the 2030 forecast and the 2030 policy scenario, and the current network needs to be modified to include more generators and transmission lines. Including renewable energy generators in the electricity mix also lowers the system's operating cost. For the Forecast scenario, the optimal power flow analysis showed no additional benefit of introducing over 60% renewable energy to the mix. For the Policy scenario, the optimal power flow analysis showed no additional benefit of introducing over 70% renewable energy to the mix in 2030.

Furthermore, the policies investigated contributed to the generation and supply of electricity in Nigeria by facilitating the electrification of rural areas and places not connected to the grid, creating competitive investment opportunities, encouraging the use of alternative energy sources, and increasing the involvement of players from the entire electricity value chain. It is hoped that the findings of this paper and the planning tool will assist policymakers and decision-makers in Nigeria's electricity sector in creating appealing investment opportunities to regulate the power sector better and improve national electrification.

This analysis shows that if the proper rules were implemented to encourage investors in renewable energy, Nigeria's power sector problems could be solved. This allows for the construction of more power plants capable of generating and supplying electricity to areas and people not currently connected to the grid. In addition, this calls for the country's untapped natural resources, such as wind, biomass, and tidal, to be used to generate cleaner and more efficient electricity.

Subsequent studies could include examining the impact of the policies on electricity storage in Nigeria, as this study only examined the impacts on electricity generation and supply. Furthermore, this study did not investigate funding availability for the proposed Generation and Transmission expansion projects. In addition, the modelling tool was created using the IEEE 30-bus case as reliable load data from the Nigerian 330kV bus network was unavailable. Future studies can use data from the Nigerian case to build the tool and include the 132kV and 33kV transmission networks. Finally, this study examined the impact of the policies between 2001 and 2020, and future studies can assess the impacts of current policies beyond this period.

Because of climate change and global warming, Nigerian decision-makers and policymakers should consider incorporating additional renewable energy sources into future electricity expansion to make the sector more sustainable and resilient.

References

Adeoti, O., Adewumi, A. O., Oyedele, L. O., & Akinade, O. O (2019) Impact of privatisation on electricity industry performance in Nigeria, Sustainability, 11(4), 1153.,.

Adesanya, A. A. and Schelly, C. (2019) Solar PV-diesel hybrid systems for the Nigerian private sector: An impact assessment, Energy Policy, 132, pp. 196-207. DOI: //doi.org/10.1016/j.enpol.2019.05.038.

Adhekpukoli, E. (2018) The democratization of electricity in Nigeria, The Electricity Journal, 31 (2), pp. 1-6. DOI: 10.1016/j.tej.2018.02.007.

African Development Bank (2019) Nigeria Transmission Expansion Project-phase-1-appraisal-report. Available from: https://www.afdb.org/en/documents/nigeria-nigeria-transmission-expansion-project-phase-1-ntep1-project-appraisal-report [Accessed 25 Feb 2021].

Agbo, E. P., Edet, C. O., Magu, T. O., Njoku, A. O., Ekpo, C. M. and Louis, H. (2021) Solar energy: A panacea for the electricity generation crisis in Nigeria, Heliyon, 7 (5), pp. e07016. DOI: https://doi.org/10.1016/j.heliyon.2021.e07016.

Ahmed, A. and Khalid, M. (2019) A review on the selected applications of forecasting models in renewable power systems, Renewable and Sustainable Energy Reviews, 100, pp. 9-21. DOI: https://doi.org/10.1016/j.rser.2018.09.046.

Ajayi, O. O. and Ajayi, O. O. (2013) Nigeria's energy policy: Inferences, analysis and legal ethics toward RE development, Energy Policy, 60, pp. 61-67. DOI: //doi.org/10.1016/j.enpol.2013.05.095.

Akinlo, A. E. (2009) Electricity consumption and economic growth in Nigeria: Evidence from cointegration and co-feature analysis, Journal of Policy Modelling, 31 (5), pp. 681-693. DOI: https://doi.org/10.1016/j.jpolmod.2009.03.004.

Akpan, U. (2015) Technology options for increasing electricity access in areas with low electricity access rate in Nigeria, Socio-Economic Planning Sciences, 51, pp. 1-12. DOI: //doi.org/10.1016/j.seps.2015.05.001.

Akuru, U. B., Onukwube, I. E., Okoro, O. I. and Obe, E. S. (2017) Towards 100% renewable energy in Nigeria, Renewable and Sustainable Energy Reviews, 71, pp. 943-953. DOI: //doi.org/10.1016/j.rser.2016.12.123.

Anderson, J. A. (2009) Electricity restructuring: A review of efforts around the world and the consumer response, The Electricity Journal, 22 (3), pp. 70-86. DOI: 10.1016/j.tej.2009.02.017.

Anwar, A. and Pota, H. R. (2014) Optimal capacity planning of distributed generators. 1st ed. LAP LAMBERT Academic Publishing.

Ariyo, A. and Jerome, A. (1999) Privatization in Africa: An appraisal, World Development, -01st, 27 (1), pp. 201. DOI: 10.1016/s0305-750x (98)00124-7.

Auty, R. M. (2007) Natural resources, capital accumulation and the resource curse, Ecological Economics, 61 (4), pp. 627-634. DOI: //doi.org/10.1016/j.ecolecon.2006.09.006.

Badeeb, R. A., Lean, H. H. and Clark, J. (2017) The evolution of the natural resource curse thesis: A critical literature survey, Resources Policy, 51, pp. 123-134. DOI: //doi.org/10.1016/j.resourpol.2016.10.015.

BBC News (2022) Ukraine conflict: How reliant is Europe on Russia for oil and gas? United Kingdom: Available from: https://www.bbc.co.uk/news/58888451 [Accessed 4 Mar 2022].

Bent, R. and Toole, G. L. (2012) Grid expansion planning for carbon emissions reduction, in: - 2012 IEEE Power and Energy Society General Meeting, pp. 1-8. DOI: 10.1109/PESGM.2012.6345362.

Best, R. and Burke, P. J. (2018) Electricity availability: A precondition for faster economic growth? Energy Economics, 74, pp. 321-329. DOI: https://doi.org/10.1016/j.eneco.2018.06.018.

Bloomberg (2023), Nigerian States Enabled by Law Reform to Supply Electricity. Available from: https://www.bloomberg.com/news/articles/2022-03-01/nigeria-law-reforms-allow-states-to-supply-their-own-electricity?leadSource=uverify%20wall

Brower, M. (1994) Cool energy renewable solutions to environmental problems. MIT Press.

Chanchangi, Y. N., Adu, F., Ghosh, A., Sundaram, S. and Mallick, T. K. (2022) Nigeria's energy review: Focusing on solar energy potential and penetration, Environment, Development and Sustainability, pp. 1-42. DOI: 10.1007/s10668-022-02308-4.

Covarrubias, A. J. (1979) Expansion planning for electric power systems, IAEA Bulletin, 21 (2), pp. 55-64. Available from: http://www.iaea.org/Publications/Magazines/Bulletin/Bull212_3/212_304985564.pdf http://inis.iaea.org/search/search.aspx?orig_q=RN:39027752.

Creswell, J. W. (2014) Research design: Qualitative, quantitative, and mixed methods approaches / john W. Creswell. Fourth ed. Los Angeles, California: SAGE.

Dada, J. O. and Moser, A. (2019) REPLAN: Multi-Region Power System Planning Approach for Nigeria, in: - 2019 IEEE PES/IAS Power Africa, pp. 87-92.

Das, J. (2017) Load flow optimization and optimal power flow. 1st ed. CRC Press.

Dawson, C. (2019) Introduction to research methods: A practical guide for anyone undertaking a research project / Catherine Dawson. fifth ed. London: Robinson.

ECN (2018), National Energy Policy.

Edomah, N. (2021) The governance of energy transition: Lessons from the Nigerian electricity sector, Energy, Sustainability and Society, 11 (1), pp. 40. DOI: 10.1186/s13705-021-00317-1.

Emodi, N. V. and Boo, K. (2015) Sustainable energy development in Nigeria: Current status and policy options, Renewable and Sustainable Energy Reviews, 51, pp. 356-381. DOI: //doi.org/10.1016/j.rser.2015.06.016.

Emodi, N. V., Haruna, E. U., Abdu, N., Aldana Morataya, S. D., Dioha, M. O. and Abraham-Dukuma, M. C. (2022) Urban and rural household energy transition in sub-saharan Africa: Does spatial heterogeneity reveal the direction of the transition? Energy Policy, 168, pp. 113118. DOI: https://doi.org/10.1016/j.enpol.2022.113118.

Emodi, N. and Ebele, N. (2016) Policies promoting renewable energy development and implications for Nigeria, British Journal of Environment and Climate Change, 6 (1), pp. 1-17. DOI: 10.9734/BJECC/2016/24628.

Estache, A., Goicoechea, A. and Trujillo, L. (2009) Utilities reforms and corruption in developing countries, Utilities Policy, 17 (2), pp. 191-202. DOI: 10.1016/j.jup.2008.07.002.

Estache, A., Tovar, B. and Trujillo, L. (2008) How efficient are African electricity companies? evidence from the southern African countries, Energy Policy, 36 (6), pp. 1969-1979. DOI: 10.1016/j.enpol.2008.02.011.

Estebsari, A. and Rajabi, R. (2020) Single residential load forecasting using deep learning and image encoding techniques, Electronics (Basel), 9 (1), pp. 68. DOI: 10.3390/electronics9010068.

Faminu, G. (2021, May 24). Nigerian Breweries commissions 663.6kWp solar plant to boost energy capacity. Business day NG. Available from: https://businessday.ng/real-sector/article/nigerian-breweries-commissions-663-6kwp-solar-plant-to-boost-energy-capacity

Financial Nigeria (2021, February 18). Nigeria to host West Africa’s largest solar farm with 200MW capacity. Financial Nigeria International Limited. Available from: https://www.financialnigeria.com/nigeria-to-host-west-africa-s-largest-solar-farm-with-200mw-capacity-news-2317.html

Gacitua, L., Gallegos, P., Henriquez-Auba, R., Lorca, Á, Negrete-Pincetic, M., Olivares, D., Valenzuela, A. and Wenzel, G. (2018) A comprehensive review on expansion planning: Models and tools for energy policy analysis, Renewable and Sustainable Energy Reviews, 98, pp. 346-360. DOI: https://doi.org/10.1016/j.rser.2018.08.043.

Gatugel Usman, Z., Abbasoglu, S., Tekbiyik Ersoy, N. and Fahrioglu, M. (2015) Transforming the Nigerian power sector for sustainable development, Energy Policy, 87, pp. 429-437. DOI: https://doi.org/10.1016/j.enpol.2015.09.004.

GIZ (2015) The Nigerian Energy Sector. London: Available from: https://www.giz.de [Accessed 01 May 2018].

Gungah, A., Emodi, N. V. and Dioha, M. O. (2019) Improving Nigeria's renewable energy policy design: A case study approach, Energy Policy, 130, pp. 89-100. DOI: //doi.org/10.1016/j.enpol.2019.03.059.

Halff, A. Sovacool, B. K. Rozhon, J. (2015) Energy poverty: Global challenges and local

solutions, Oxford Scholarship Online.

Haque, M. H. (1996) Load flow solution of distribution systems with voltage dependent load models, Electric Power Systems Research, 36 (3), pp. 151-156. DOI: https://doi.org/10.1016/0378-7796(95)01025-4.

Harish, V. S. K. V. and Kumar, A. (2016) A review on modelling and simulation of building energy systems, Renewable and Sustainable Energy Reviews, 56, pp. 1272-1292. DOI: https://doi.org/10.1016/j.rser.2015.12.040.

Hemmati, R., Hooshmand, R. and Khodabakhshian, A. (2013) State-of-the-art of transmission expansion planning: Comprehensive review, Renewable and Sustainable Energy Reviews, 23, pp. 312-319. DOI: https://doi.org/10.1016/j.rser.2013.03.015.

IEA (2017) Nigeria Energy Policies and Measures, Https://Www.Iea.Org/Policiesandmeasures/Pams/Nigeria/,

IEA (2018) Population without access to electricity falls below 1 billion. [Accessed 29 Oct 2019].

IEA (2019a) IEA Electricity Information 2019 Overview.

IEA (2019b) Nigeria Energy Outlook, 8 November.

IEA (2019c) World Energy Balances 2019 Overview.

IEA (2020) IEA Country Information, Https://Www.Iea.Org/Countries/Nigeria

Ikeme, J. and Ebohon, O. J. (2005) Nigeria's electric power sector reform: What should form the key objectives? Energy Policy, 33 (9), pp. 1213-1221. DOI: //doi.org/10.1016/j.enpol.2003.11.018.

Iwayemi, A. (1994) Deregulating public utilities: An analysis of the electricity industry in nigeria, Utilities Policy, 4 (1), pp. 55-64. DOI: //doi.org/10.1016/0957-1787 (94)90036-1.

Iwayemi, A. and Fowowe, B. (2011) Impact of oil price shocks on selected macroeconomic variables in nigeria, Energy Policy, 39 (2), pp. 603-612. DOI: 10.1016/j.enpol.2010.10.033.

Iyke, B. N. (2015) Electricity consumption and economic growth in Nigeria: A revisit of the energy-growth debate, Energy Economics, 51, pp. 166-176. DOI: //doi.org/10.1016/j.eneco.2015.05.024.

Jacob, M., Neves, C. and Vukadinovic Greetham, D. (2020) Forecasting and assessing risk of individual electricity peaks. DOI: 10.1007/978-3-030-28669-9.

Khan, S., Peng, Z. and Li, Y. (2019) Energy consumption, environmental degradation, economic growth, and financial development in globe: Dynamic simultaneous equations panel analysis, Energy Reports, 5, pp. 1089-1102. DOI: https://doi.org/10.1016/j.egyr.2019.08.004.

Khwaja, A. S., Anpalagan, A., Naeem, M. and Venkatesh, B. (2020) Joint bagged-boosted artificial neural networks: Using ensemble machine learning to improve short-term electricity load forecasting, Electric Power Systems Research, 179, pp. 106080. DOI: https://doi.org/10.1016/j.epsr.2019.106080.

KPMG (2023), Commentaries on the Electricity Act, 2023. Available from: https://kpmg.com/ng/en/home/insights/2023/06/commentaries-on-the-electricity-act--2023.html

Kumar, A., L and Sundaram, M., K (2020) Optimal power flow using FACTS devices. 1st ed. CRC Press.

Kumar, S. D. (2012) Load Modeling in Optimal Power Flow Studies. http://ethesis.nitrkl.ac.in/3503/

Kumari, A. and Sharma, A. K. (2018) Causal relationships among electricity consumption, foreign direct investment and economic growth in India, The Electricity Journal, 31 (7), pp. 33-38. DOI: https://doi.org/10.1016/j.tej.2018.08.004.

Lee, C. (2005) Energy consumption and GDP in developing countries: A cointegrated panel analysis, Energy Economics, 27 (3), pp. 415-427. DOI: https://doi.org/10.1016/j.eneco.2005.03.003.

Lin, B. and Ankrah, I. (2019) On Nigeria’s renewable energy program: Examining the effectiveness, substitution potential, and the impact on national output, Energy Policy, 167, pp. 1181-1193. DOI: //doi.org/10.1016/j.energy.2018.11.031.

Martínez, D. M., Ebenhack, B. W. and Wagner, T. P. (2019) Chapter 2 - Dealing with energy units, measures, and statistics, in: Martínez, D. M., Ebenhack, B. W. and Wagner, T. P. (eds.) Energy Efficiency, Elsevier, pp. 35-66. DOI: https://doi.org/10.1016/B978-0-12-812111-5.00002-0.

Mbuli, N., Mathonsi, M., Seitshiro, M. and Pretorius, J. C. (2020) Decomposition forecasting methods: A review of applications in power systems, Energy Reports, 6, pp. 298-306. DOI: https://doi.org/10.1016/j.egyr.2020.11.238.

Monyei, C. G., Adewumi, A. O., Obolo, M. O. and Sajou, B. (2018) Nigeria's energy poverty: Insights and implications for smart policies and framework towards a smart Nigeria electricity network, Renewable and Sustainable Energy Reviews, 81, pp. 1582-1601. DOI: //doi.org/10.1016/j.rser.2017.05.237.

NERC (2019) Nigerian Electricity Supply Industry (NESI), Www.Nercng.org.

OECD (2016) Productivity gains from privatisation in OECD countries. Available from: https://www.oecd-ilibrary.org/governance/productivity-gains-from-privatisation-in-oecd-countries_5jm2fjlkps0n-en.

Ogunmodimu, O. and Okoroigwe, E. C. (2019) Solar thermal electricity in Nigeria: Prospects and challenges, Energy Policy, 128, pp. 440-448. DOI: //doi.org/10.1016/j.enpol.2019.01.013.

Ohiare, S. (2015) Expanding electricity access to all in Nigeria: A spatial planning and cost analysis, Energy, Sustainability and Society, 5. DOI: 10.1186/s13705-015-0037-9.

Otobo, J. C. (2022) Sustainability and Resilience in the Nigerian Power sector, in: Industrial Engineering and Operations Management (IEOM), July 26-28, 2022.

Palit, D. and Kumar, A. (2022) Drivers and barriers to rural electrification in India – A multi-stakeholder analysis, Renewable and Sustainable Energy Reviews, 166, pp. 112663. DOI: 10.1016/j.rser.2022.112663.

Power Africa (2015) Nigeria Power Baseline Report.

REA (2021) REA Covid 19 programme.

Saunders, M. N. K., Thornhill, A. and Lewis, P. (2019) Research methods for business students. Harlow, United Kingdom: Pearson Education Limited. Available from: http://ebookcentral.proquest.com/lib/lsbuuk/detail.action?docID=5774742.

Siemens (2019) Electrification Roadmap for Nigeria. Available from: https://press.siemens.com/global/en/pressrelease/siemens-and-nigerian-government-signed-implementation-agreement-electrification

Singh, A. K., Khatoon, S., Muazzam and Chaturvedi, D. K. (2013) An overview of electricity demand forecasting techniques.

Smil, V. (2004) World history and energy, Encyclopaedia of Energy, 6, pp. 549-561. Available from: https://search.credoreference.com/content/entry/estenergy/world_history_and_energy/0

Squalli, J. (2007) Electricity consumption and economic growth: Bounds and causality analyses of OPEC members, Energy Economics, 29 (6), pp. 1192-1205. DOI: https://doi.org/10.1016/j.eneco.2006.10.001.

The Guardian (2022), The Nigerian Guardian. Available from: https://guardian.ng/news

Trotter, P. A., McManus, M. C. and Maconachie, R. (2017) Electricity planning and implementation in sub-Saharan Africa: A systematic review, Renewable and Sustainable Energy Reviews, 74, pp. 1189-1209. DOI: //doi.org/10.1016/j.rser.2017.03.001.

Ugwoke, B., Gershon, O., Becchio, C., Corgnati, S. P. and Leone, P. (2020) A review of Nigerian energy access studies: The story told so far, Renewable and Sustainable Energy Reviews, 120, pp. 109646. DOI: https://doi.org/10.1016/j.rser.2019.109646.

United Nations (2022) UN Sustainable Development Goals. Available from: https://sdgs.un.org

Warner, K. J. and Jones, G. A. (2017) A population-induced renewable energy timeline in nine world regions, Energy Policy, 101, pp. 65-76. DOI: https://doi.org/10.1016/j.enpol.2016.11.031.

Weinberg, D. (2002) Qualitative research methods. Malden, MA: Blackwell Publishers.

World Bank (2017) Nigeria's Flaring Reduction Target: 2020. Available from: http://www.worldbank.org/en/news/feature/2017/03/10/nigerias-flaring-reduction-target-2020 [Accessed 18 May 2019].

World Bank (2019a) Privatisation of power utilities. Available from: https://openknowledge.worldbank.org/bitstream/handle/10986/31634/9781464814402.pdf.

World Bank (2019b) World Bank Data. Available from: https://data.worldbank.org

World Bank (2020) World Bank. Available from: https://data.worldbank.org/country/nigeria.

World Bank (2022) World Energy Outlook Special Report Africa Energy Outlook 2022.

Wu, C., Wang, C., Chang, T. and Yuan, C. (2019) The nexus of electricity and economic growth in major economies: The United States-India-China triangle, Energy, 188, pp. 116006. DOI: https://doi.org/10.1016/j.energy.2019.116006.

Zhijian, L., Jun, Y. and Qi, S. (2016) Optimal power flow research on distributed network considering distributed generation, pp. 1-6. DOI: 10.1109/CICED.2016.7576148.

Zimmerman, R. D. and Murillo-Sánchez, C. E. (2020) MATPOWER manual, 7.1. DOI: 10.17487/rfc1196.

Addendum - Constitution Amendment to individual states to generate, transmit, and distribute electricity, and the Electricity Act,2023.

In response to Nigeria's challenges in meeting its electricity demands, frequent power outages and low supply, the Nigerian government has proposed a bill in 2021 to allow individual states in the country to generate their electricity. Stakeholders in the energy sector have widely welcomed this move as it is expected to increase access to electricity in Nigeria, particularly in rural areas where the national grid is unavailable.

In March 2023, the bill, passed by the National Assembly, was signed into law by the President to allow the 36 states to generate, transmit, and distribute electricity in areas covered by the national grid. The passing of the bill supports the findings in Chapter 5 of this thesis and corroborates the recommendations from the subject matter experts that were interviewed during this study. They called for more autonomy in the power system network and involvement from all participants in the electricity value chain. By allowing the individual states to generate their electricity, likely, the adoption of more types of energy sources that are local to the region would be implemented. This would also lead to the development of the human capital required to build and maintain the facilities, and it would support the localisation of the electricity policies to meet the diverse needs of the nation.

The bill is expected to reduce the country's reliance on the national grid, which is often unreliable. The bill is also expected to create jobs and boost economic growth in the states. This is a significant departure from the previous system, where the federal government monopolised electricity generation and distribution.

The bill is expected to have several benefits, including:

- Increased competition in the electricity sector, which could lead to lower prices for consumers.
- Increased investment in electricity generation and distribution, as states, will now be able to attract private sector investment.
- Improved reliability of electricity supply, as states will be able to generate their power and avoid disruptions caused by problems with the national grid.
- New job creation, as the electricity sector is a significant employer.
- Improved economic growth, as businesses will have access to reliable electricity.
- People can use electricity to power their homes and businesses, reducing poverty.

However, there are concerns about the potential challenges arising from the bill's implementation. For example, some experts have raised questions about the capacity of states to effectively manage their own power generation and distribution systems, as well as the potential for conflicts between states and the national government over regulatory and pricing issues (Bloomberg, 2023). One challenge is that the states must invest in infrastructure to generate and transmit electricity. This could be a significant financial burden for some states.

Despite these concerns, the bill represents an important step towards addressing Nigeria's electricity challenges and promoting sustainable development. It is expected that the government will work closely with stakeholders to ensure that the bill is implemented in a way that benefits all Nigerians (Bloomberg, 2023).
In conclusion, the Nigerian bill to allow states to generate electricity presents a promising solution to the country's electricity challenges. Promoting renewable energy sources and decentralising electricity generation and distribution by the bill can increase access to electricity, create jobs, and promote sustainable development in Nigeria. Due to the significance of this change, it will take time for the states to invest in infrastructure and coordinate their efforts. However, the bill is a step in the right direction and is expected to impact Nigeria's power supply in the long run positively.
It is recommended that future studies are conducted on the impact of this bill on electricity generation and supply in Nigeria to improve the performance of future electricity policies. The Decision support tool created in this study can also be used by the network planners to assess the feasibility of the proposed networks for the individual states that intend to build new generation, transmission and distribution infrastructure.

The Nigerian Electricity Act, 2023

On June 8, 2023, the president of Nigeria, signed the Electricity Bill 2023 into law as the Electricity Act, 2023. This Act establishes a comprehensive legal and institutional framework for a fully privatised, competitive electricity market in Nigeria. It replaces several existing Acts and aims to address the sector's problems, such as liquidity issues, profitability challenges, and high debt levels (KPMG, 2023)

The Act also consolidates laws related to the Nigerian Electricity Supply Industry (NESI) to reform the sector, promote renewable energy integration, and attract necessary investments (KPMG 2023).

One of the Act's primary objectives is to introduce new policies and regulations to tackle current challenges and encourage private sector investments across the NESI value chain. Ultimately, the goal is to create a self-sustaining, profitable, and sufficient electricity industry in Nigeria (KPMG 2023). The signing of the Electricity Act, 2023 also supports the findings in Chapter 5 of this thesis.

References

Bloomberg (2023), Nigerian States Enabled by Law Reform to Supply Electricity. Available from: https://www.bloomberg.com/news/articles/2022-03-01/nigeria-law-reforms-allow-states-to-supply-their-own-electricity?leadSource=uverify%20wall

Electricity Act, 2023. Available from: https://placng.org/i/wp-content/uploads/2023/06/Electricity-Act-2023.pdf

KPMG (2023), Commentaries on the Electricity Act, 2023. Available from: https://kpmg.com/ng/en/home/insights/2023/06/commentaries-on-the-electricity-act--2023.html

Appendix – Survey Participant Information Sheet

Participant Information Sheet

Study title: A Critical Examination of Nigeria's Electricity Generation and Supply

You are being invited to take part in a research study. Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

Purpose of the study

Nigeria faces a protracted crisis in the energy sector which has resulted in an inability to sustainably generate and supply sufficient electric power to its ever-growing population of over 200 million (Emodi, Nnaemeka Vincent, Boo 2015).

With the largest economy in Africa, only about 60% of Nigeria's population has access to electricity (IEA 2020).

It is estimated that the Federal Government of Nigeria (FGN) committed an enormous investment of US $16 billion for restoring the electricity sector from 1999 to 2017. (Akuru, Onukwube et al. 2017). The Nigerian government has taken steps to reform the energy sector by deregulating and restructuring the oil and gas sectors and by privatising the power sector to generate revenue to support investments in infrastructure.

Several policies have been developed, including The National Electric Power Policy (NEPP) which marks the first step in the electricity sector reform. The NEPP also provides the framework for achieving the subsequent reformation of the power sector. This study will determine how nine energy and electricity policies have contributed to the increased electricity generation and supply in Nigeria between 2001 and 2020.

Additional Information

You have been chosen to participate in this study due to your knowledge of, and experience in the Nigerian electricity sector.

All personal details collected during this study will remain confidential. Your name will be recorded as P1, P2 etc., to ensure anonymity. All data will be stored in a password-protected computer that only the researchers will have access to. Consent forms will be stored in a locked filing cabinet in the home office of the researcher.

Outputs from this study will contribute to building a model to forecast electricity generation which can inform policy makers on decisions that can help to provide sufficient electricity generation and supply in Nigeria.

All information collected about you will be kept strictly confidential. Data generated by the study will be anonymised and retained in accordance with the University's Code of

Practice. Please note that data generated during this research must be kept securely in paper or electronic form for a period of 10 years after the completion of the research project.

Results from this research will be used in the researcher's thesis to support their PhD degree. This will be available from the university research office. Kindly contact the researcher if you would like a copy of the research.

This study has been reviewed and approved by the School of the Built Environment & Architecture Department ethics committee at London South Bank University.

Please note that this study is conducted by the Justicia Otobo as a PhD student at the London South Bank University.

If you wish to take part in the research, you can do so by completing the attached consent form.

Thank you for taking time to read the information sheet.

Researcher: Justicia Otobo
PhD Researcher
The School of the Built Environment & Architecture
London South Bank University
Otoboj@lasbu.ac.uk

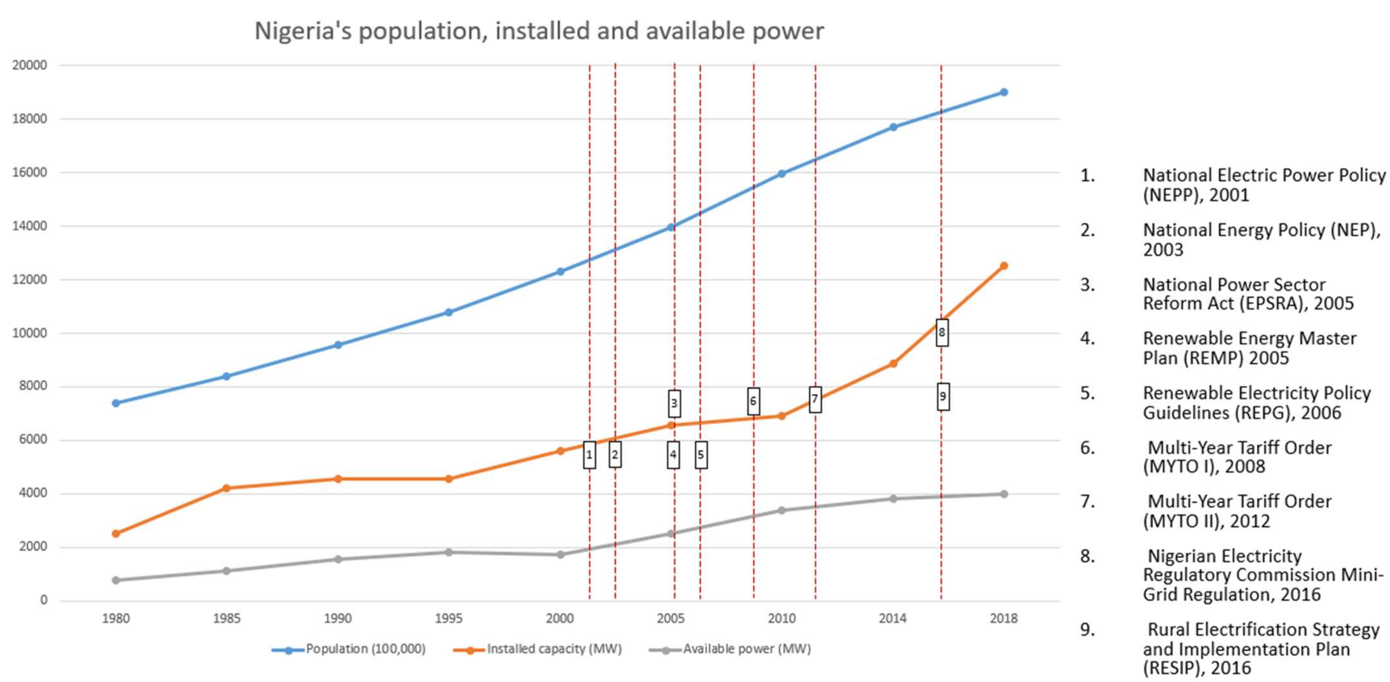
Date: 11/03/2021

Appendix – Survey Questions

Please answer all questions and follow the instructions relating to each question. All responses will be treated as strictly confidential and will only be used for the purposes of this research.

This questionnaire will be used as a tool to generate information to evaluate how the following electricity and energy policies have contributed to the increase of electricity generation and supply in the Nigerian electricity sector:

1. National Electric Power Policy (NEPP), 2001
2. National Energy Policy (NEP), 2003
3. National Power Sector Reform Act (EPSRA), 2005
4. Renewable Energy Master Plan (REMP) 2005
5. Renewable Electricity Policy Guidelines (REPG), 2006
6. Multi-Year Tariff Order (MYTO I), 2008
7. Multi-Year Tariff Order (MYTO II), 2012
8. Nigerian Electricity Regulatory Commission Mini-Grid Regulation, 2016
9. Rural Electrification Strategy and Implementation Plan (RESIP), 2016



Source: (Gatugel Usman, Abbasoglu et al. 2015) and (IEA 2019)

The questionnaire will take about ten minutes to complete.

SECTION 1: Please tick the appropriate box □

A: Basic information

1. Years of practice? 5 or below □ 6-10 □ 11-15□ 16-20□ 21-25□ 26-30□ 30+ □
2. Sector: Regulatory □ Generation □ Transmission □ Distribution □ N/A □
3. Organisation type: Practice? Private □ Public □

1. Please indicate to what degree you agree that the following policies have contributed to an increased electricity generation or supply in Nigeria by ranking the policies from 1 to 9 with1 being the highest score to 9 being the lowest score.

Unique ID	Policies	Increased Generation	Increased Supply
1	National Electric Power Policy (NEPP), 2001		
2	National Energy Policy (NEP), 2003		
3	National Power Sector Reform Act (EPSRA), 2005		
4	Renewable Energy Master Plan (REMP) 2005		
5	Renewable Electricity Policy Guidelines (REPG), 2006		
6	Multi-Year Tariff Order (MYTO I), 2008		
7	Multi-Year Tariff Order (MYTO II), 2012		
8	Nigerian Electricity Regulatory Commission Mini-Grid Regulation, 2016		
9	Rural Electrification Strategy and Implementation Plan (RESIP), 2016		

2. Briefly describe how the policy ranked as 1 in generation contributed to the increased electricity generation from 2001 to 2020

____

____

3. Describe how the policy ranked as 1 in supply contributed to the increased electricity supply from 2001 to 2020

____

____

4. In your opinion indicate to what degree you agree that the electricity policies have improved the following factors (investment, Infrastructure, Energy resources and Human resource) in increasing electricity generation or supply.

Rate them from 1 to 4 with 1 being the highest and 4 being the lowest.

Unique ID	Policies	Investment	Infrastructure	Energy Resources / mix	Expertise / technical manpower
1	National Electric Power Policy (NEPP), 2001				
2	National Energy Policy (NEP), 2003				
3	National Power Sector Reform Act (EPSRA), 2005				
4	Renewable Energy Master Plan (REMP) 2005				
5	Renewable Electricity Policy Guidelines (REPG), 2006				
6	Multi-Year Tariff Order (MYTO I), 2008				
7	Multi-Year Tariff Order (MYTO II), 2012				
8	Nigerian Electricity Regulatory Commission Mini-Grid Regulation, 2016				

9	Rural Electrification Strategy and Implementation Plan (RESIP), 2016				

Appendix – Survey Participant Consent Form

Consent Form

Full title of Project: A Critical Examination of Nigeria's Electricity Generation and Supply

Name, position and contact details of Researcher:
Justicia Otobo
PhD Researcher
The School of the Built Environment & Architecture, London South Bank University
Otoboj@lasbu.ac.uk

Taking part (please tick the box that applies)	Yes	No
I confirm that I have read and understand the information sheet/project brief and/or the student has explained the above study. I have had the opportunity to ask questions.	☐	☐
I understand that my participation is voluntary and that I am free to withdraw as explained in the information sheet, without providing a reason.	☐	☐
I agree to take part in the above study.	☐	☐
Use of my information (please tick the box that applies)	**Yes**	**No**
I agree to the use of anonymised quotes in potential publications and presentations	☐	☐
I agree for the data I provide to be stored (after it has been anonymised) in a specialist data centre and I understand it may be used for future research.	☐	☐
I agree to the interview being audio recorded.	☐	☐
I agree to the interview being video recorded.	☐	☐
I agree to the use of anonymised quotes in publications.	☐	☐

By clicking ‘Yes’ below, I confirm that I agree to take part in the study.

Project contact details for further information:
Name: Dr Rusdy Hartungi

Address: School of the Built Environment and Architecture. London South Bank University. 103 Borough Road, London - SE1 0AA, United Kingdom
Email: hartungr@lsbu.ac.uk

Appendix – Deterministic Model MATLAB script

```
close all
clear all
clc

%% Load Case file
mpc = loadcase('case_33');
result=runopf(mpc);
Basecase_cost=result.f;
Pmax_gen_base = sum(mpc.gen(:,9));
Pd_bus_base = sum(mpc.bus(:,3));
exceldata = readmatrix('input.xlsx');
RE= xlsread('input.xlsx',"RE"); % Get a file from the folder


%% Step 1 - Get Scenario 1 … n
%Number of new renewable nodes = n
 n=length(exceldata);  %enter the number of desired new nodes

%% add new nodes (gen and branch)
% Add new generators

b= mpc.gen;
d= mpc.gen;
d(:[2,4,9])= RE*d(:[2,4,9]);
e= mpc.gen;
e(:,[2,4,9])=(1-RE)*e(:,[2,4,9]);
m=[e;d];
mpc.gen = [m];       %create new gen matrix
gens = xlsread('input.xlsx',"gen");
mpc.gen = [m; gens];


% add new gen costs
c = mpc.gencost;   % add the first 'n' number of rows to gen cost matrix
h= mpc.gencost;
h(:,[5,6])= 0*h(:,[5,6]);
g=[c;h];

mpc.gencost = [g];  %create new gen cost matrix with new gen nodes
genc = xlsread('input.xlsx',"gencost");
```

```
y= genc;
mpc.gencost = [g; y];



   %add new buses
     buses = xlsread('input.xlsx',"bus");
     u= buses;
     v= mpc.bus;
    mpc.bus = [v; u];


%add new branches
    branches = xlsread('input.xlsx',"branch");
    x= branches;
    mpc.branch = [mpc.branch; x];

Pmax_gen_base2 = sum(mpc.gen(:,9));
Pd_bus_base2 = sum(mpc.bus(:,3))


for i = 1: length(exceldata)
mpc = loadcase('case_33');
mpc.bus(:,[3,4])=exceldata(i)*mpc.bus(:,[3,4]);
mpc.gen(:,[2,4,9])=exceldata(i)*mpc.gen(:,[2,4,9]);
lines = xlsread('input.xlsx',"lines");


 %% Step x add new nodes (gen and branch)

b= mpc.gen;
d= mpc.gen;
d(:,[2,4,9])=RE*d(:,[2,4,9]);
e= mpc.gen;
e(:,[2,4,9])=(1-RE)*e(:,[2,4,9]);
m=[e;d];
m(:,[2,4,9])=m(:,[2,4,9]);

mpc.gen = [m];   %create new gen matrix
c = mpc.gencost;   % add the first 'n' number of rows to gen cost matrix
h= mpc.gencost;
```

```
h(:,[5,6])= 0*h(:,[5,6]);
g=[c;h];
mpc.gencost = [g]; %create new gen cost matrix with new gen nodes
result1=runopf(mpc);
cost1(i) = result1.f;



%% Step 2 - Get Scenario 1 … n
for j= 1:1:height(lines)

Scenario = i
option = j
mpc = loadcase('case_33');
exceldata = readmatrix('input.xlsx');
RE= xlsread('input.xlsx',"RE");
%% Increase Load in bus and gen matrices

S4 = exceldata(i);
mpc.bus(:,[3,4])=exceldata(i)*mpc.bus(:,[3,4]);
mpc.gen(:,[2,4,9])=exceldata(i)*mpc.gen(:,[2,4,9]);


%% Add new nodes (gen and branch)
b= mpc.gen;
d= mpc.gen;
d(:,[2,4,9])=RE*d(:,[2,4,9]);
e= mpc.gen;
e(:,[2,4,9])=(1-RE)*e(:,[2,4,9]);
m=[e;d];
m(:,[2,4,9])=m(:,[2,4,9]);
mpc.gen = [m]; %create new gen matrix



c = mpc.gencost;   % add the first 'n' number of rows to gen cost matrix
h= mpc.gencost;
h(:,[5,6])= 0*h(:,[5,6]);
g=[c;h];
mpc.gencost = [g]; %create new gen cost matrix with new gen nodes
%create new gen matrix with additional branches
   m2 = lines(1:j,:);
```

```
    mpc.branch = [mpc.branch ; m2];




% add new generator
    gens = xlsread('input.xlsx',"gen");
    mpc.gen = [m; gens];

% add new gen costs
 genc = xlsread('input.xlsx',"gencost")
     y= genc;
    mpc.gencost = [g; y];


%add new buses
     buses = xlsread('input.xlsx',"bus");
     u= buses;

     v= mpc.bus;

    mpc.bus = [v; u];

%add new branches
    branches = xlsread('input.xlsx',"branch");
    x= branche
    mpc.branch = [mpc.branch; x];
Total_Capacity_MW(i,1) = sum(mpc.gen(:,9));
Total_Demand_MW(i,1) = sum(mpc.bus(:,3));


 %% Step 3 - Run OPF
resultopf=runopf(mpc);


%% Step 4 - Log the overall cost

Enhancement_costs(i, j,1) = resultopf.f;
Load_Increase = exceldata;
```

```
value= 1: height(exceldata);
Scenario = transpose(value);


end
end


%%
disp("*-----------------------------------------------------------------")
disp(" ")
fprintf('<strong> Base case operating cost value is USD/hr</strong>');disp(Basecase_cost)
fprintf('<strong> Renewable energy proportion is</strong>');disp(RE)
fprintf('<strong> Basecase Gen Pmax is</strong>');disp(Pmax_gen_base)
fprintf('<strong> Basecase Bus Pd is</strong>');disp(Pd_bus_base)

disp(" ")
disp("*-----------------------------------------------------------------")
disp(" ")
Scenario_costs = transpose(cost1);
CostData1 = table(Scenario,Load_Increase,Scenario_costs,Enhancement_costs,Total_Capacity_MW,Total_Demand_MW);
disp(CostData1)

%% Write to Report to Excel file

filename = 'Report.xlsx';
q= ["Renewable energy proportion" RE];
writematrix(q, filename,'Sheet',1,'Range','A1');
z= ["Base case operating cost" Basecase_cost; "Basecase Total Capacity" Pmax_gen_base; "Basecase Total Demand" Pd_bus_base];
writematrix(z, filename,'Sheet',1,'Range','A3');
writetable(CostData1, filename,'Sheet',1,'Range','B8');
```