ASSESSING THE IMPLICATIONS OF LOW CARBON EMISSIONS ON FUTURE OIL PRODUCTION IN NIGERIA

A Thesis Presented to the Department of Petroleum Engineering,

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Master of Science in Petroleum Engineering

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CERTIFICATION

This is to certify that the thesis titled "**ASSESSING THE IMPLICATIONS OF LOW CARBON EMISSIONS ON FUTURE OIL PRODUCTION IN NIGERIA**" submitted to the school of postgraduate studies, African University of Science and Technology (AUST), Abuja, Nigeria for the award of the Master's degree is recorded of original research carried out by Chiamaka Chiagoziem Chukwujama in the Department of Petroleum Engineering.

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ABSTRACT

Nigeria economy solidly depends on fossil fuels, which serve as the major source of energy and revenue. Fossil fuels, especially petroleum, are readily available to meet the increasing energy demand of a growing population. The aftermath of consuming fossil fuels has globally become a concern, therefore long-term projections of energy demand and supply for proper energy management have become a necessity. Hence, this research focus on forecasting energy demand, predict oil production, projecting GHG emissions from energy demand and supply, and perform cumulative cost-benefit analysis from 2018 to 2060 of demand and supply of energy, under two energy scenarios; Low carbon (LOW) and Reference (REF). The LEAP modelling results show that the demand of energy would continue to increase under the REF scenario, reaching 24.68 billion BOE in 2060 from a base year value of 2.85 billion BOE. While under the LOW scenario, there would be instability in energy demand growth, but from 2031 there would be continuous growth attaining 10.91 billion BOE by 2060. Also from the results obtained, if Nigeria would employ the low carbon scenario policies, the cumulative oil production by 2060 would reduce to one-fifth of the REF, and the cumulative GHG emission from demand and supply is expected to be one-fifth of the REF, resulting to GHGs saving of 30.41 billion $MtCO_2e$ in the LOW scenario. Also, LOW scenario relative to REF scenario shows cost of avoided GHGs of 7963.83USD pre $MtCO_2e$, which implies that over 7000USD would be saved for every one $MtCO_2e$ that was supposed to be emitted in the LOW scenario. However, if the low carbon scenario will be implemented, there would be urgent need for more technical knowledge and skills to aid effective management of these low carbon energy systems.

DEDICATION

This research work is dedicated to YESHUA, the GOD ALMIGHTY.

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To the head of my department, Dr. Alpheus Igbokoyi, thank you for your fatherly love and concern. Also, to all the lecturers and staff of the great citadel of learning, the African University of Science and Technology, your effort towards me will definitely yield positive results.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BOE – Barrel of Oil Equivalent

Bpd/mbpd – barrel per day/million barrel per day

CBN - Central Bank of Nigeria

CBPN - Carbon Brief Profile of Nigeria

COVID-19 – Corona virus disease

DPR – Department of Petroleum Resources

EIA - Energy Information Administration

ESG - Environment Social Governance

FGN – Federal Government of Nigeria

GDP – gross domestic profit

GHG – Greenhouse gases

GJ – Gigajoules

GTL - gas-to-liquid

GWh – Gigawatt-hour

IEA – International Energy Agency

LEAP – Long-range Energy Alternative Planning

LPG - Liquefied Natural Gas

MtCO2e – Metric tonnes carbon dioxide equivalent

MWh – Megawatt-hour

MW – Megawatts

NBS – National Bureau of Statistics

NCDC - Nigeria Center for Disease Control

NEITI - Nigeria Extractive Industries Transparency Initiative

NESCO - Nigerian Electricity Supply Company

NGN – Naira

NLM – Nigeria LEAP Model

NNPC - Nigeria National Petroleum Corporation

NOC – National Oil Company

NPV – Net present value

NREAP - National Renewable Energy Action Plans

NREEP - National Renewable Energy and Energy efficiency Policy

OPEC - Organization of Petroleum Exporting Countries

PV - photo-voltaic

RAMSES - Research Aids for Modelling and Simulation of Environmental Systems

REF/LOW– Reference scenario/Low carbon scenario

SHP/LHP - small hydropower/large hydropower

SNG - Shell Nigeria Gas

SPDC - Shell Petroleum Development Company

Tcm /tcf– trillion cubic meters/ trillion cubic feet

toe/Ktoe – tonnes of oil equivalent/ kilotonnes of oil equivalent

UNEP - United Nations Environment Programme

USD – United State of America Dollar

VOCs - volatile organic compounds

WASP - Water quality Simulation Program

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Nigeria, a country located in the western coast of Africa, is bounded by French speaking countries, with Niger to the north, Republic of Benin to the west, Cameroon to the east, Chad Republic in the North-East and bordering Gulf of Guinea between Benin and Cameroon along its southern coast. The country shares maritime borders with Equatorial Guinea, Ghana, and Sao Tomé and Principe. Nigeria seems the largest in terms of politic, economy, and even population-wise. With over 200 million people and at an annual growth rate of 2.7%, as indicated by the World Bank (Igbokoyi and Iledare, 2016), Nigeria ranked the 7th in the world's population. The area of the Nigeria's Federation is 923,768 square kilometers, more than three times the size of the United Kingdom or slightly more than twice that of California (Toyin, 2021).

Figure 1.1: Map of Nigeria (source: www.annamap.com/nigeria/nigeria-map)

Being naturally endowed with vast quantities of both fossil and renewable energy resources, Nigeria has an estimated oil reserves of about 37 billion barrels and gas reserve of 193.3 trillion cubic feet (tcf) at end of 2020, ranking the 10th largest oil producing country in the world (BP statistical review, 2021). The Niger Delta region has been known to be the oil storehouse of the country due to its huge availability of oil and gas reserves (Adekola et al., 2017). This delta is the largest in Africa and is located within nine coastal southern states in Nigeria, which include all six states from the South-South geopolitical zones, one state (Ondo) from the South-west geopolitical zone and two states (Abia and Imo) from the South-East geopolitical zone. Cross River State is the only non-producing oil state in the Niger delta region. However, as obviously seen in figure 1.2, the growing trend of Nigerian oil and gas reserves over the years seems unstable. Owing to her growing population and standard of living, the demand and consumption of energy resources of both renewable and non-renewables continue to increase on daily basis. This has been challenging over the years, especially due to the fact that the energy systems in Nigeria are underdeveloped and unable to meet the demand of such huge population, as there is limited access to modern energy services despite the sufficient energy resources available.

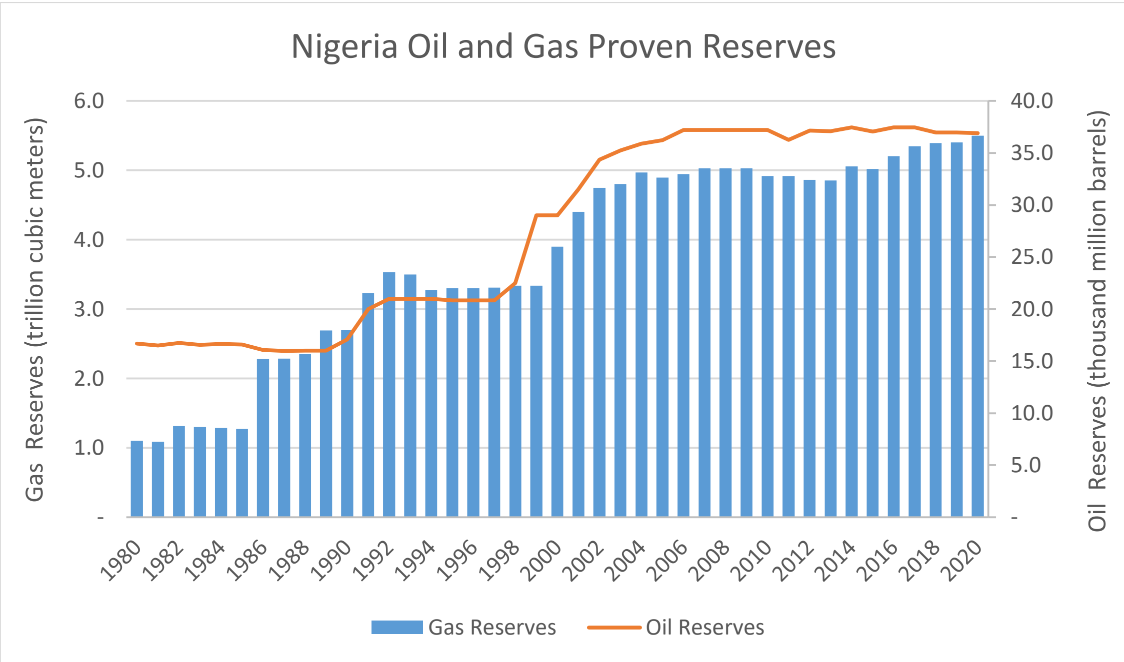

Figure 1.2: Nigerian Proven Oil and Gas Reserves from 1980 to 2020 (source: BP Statistical Review 2021)

Nigeria economy basically have four keys sectors: agriculture, industry, service and residential. The industrial sectors comprise of manufacturing (oil refining, cement, textile, chemical and pharmaceutical production, etc.) and mining (crude oil and gas, coal mining, metal ores, quarrying and other minerals). These sectors have each contributed to the gross domestic profit of the country, with mining of oil and gas contributing hugely to the growth and development of the Nigeria economy due to its high revenue. The sector generated about 10.20 trillion NGN in 2020 (NBS, 2020). However, this sector of the economy seems to be the major source of greenhouse gases emissions (Raffaello et al., 2013). The production and consumption of oil and gas (fossil fuels and its equivalent) have brought about health and environmental challenges since the beginning of industrialization in the 19th century. During production or usage of fossil fuels, numerous amounts of chemicals/gases are being released to the atmosphere, resulting to the building up of emitted greenhouse gases (carbon dioxide and its equivalent). These emitted greenhouse gases have in turn, cause climate change across the globe (Sengul, 2006).

With rising energy demand and consumption, declining production from existing oil fields in the world, many energy economic experts believe that maintaining the increasing trend of energy supply to satisfy the growing energy demand will be quite difficult, especially when considering both the environmental and socio-economic impacts associated with oil and gas exploration and production in the country (Art and Emil, 2002; Baptiste and Nordenstam, 2009). Therefore, to meet the increasing energy demand and at the same time reducing these environmental impacts, the sustainability of Nigerian oil and gas resources would require some firm policies, principles and practices that support their usage in such a way that will benefit both now and future generations, preventing run-out of these resources and high emissions of greenhouse gases. To this end, effective energy management strategies is of great importance.

Energy management deals with adequate planning and operation of energy production and consumption as well as energy distribution and storage. According to Ouedraogo N. S. (2017), energy management strategies ensure that energy supply-demand related policies and investment decisions considers all feasible demand-side and supply-side options and are also consistent with global goals of sustainability are vital. One crucial component of energy management is the utilization of energy demand modelling for predicting the future energy demand, likewise its trend. Energy models have been widely used as far as 1970 after the first oil crisis, to forecast how energy systems can evolve over a very long period of time. This is very vital for developing African countries like Nigeria, where there is increasing energy demand and high dependency on fossil fuel to meet energy requirements, and likewise the global concern over environmental impacts of non-renewables. Presently, many energy companies, policy makers and research institutions have use energy models to increase insights energy markets, future energy system development and implications of energy policies (Wiese, et al., 2018). Examples of energy modelling framework includes RAMSES (Research Aids for Modelling and Simulation of Environmental Systems), BALMOREL, LEAP (Long-range Energy Alternative Planning), WASP (Water quality Simulation Program), etc. LEAP modelling framework was employed in this research work for Nigeria energy systems.

1.2 Problem Statement

Nigeria is naturally endowed with both renewables and non-renewable energy resources, of which one of the most utilized energy resources is the fossil fuel. The exploration and production of fossil fuels have contributed hugely to the growth and development of the country, however, there are shortcomings of both the production and consumption of these fossil fuels.

Oil and gas production in the Niger Delta has caused pollution through oil spills, with environmental and public health implications. This has made these regions one of the most polluted places in Nigeria. According to Stake Holder Democracy, oil spills have been big issues over the years. Since 2011, Shell has reported over 17.5 million liters of oil spilled, and Eni has also report over 4.1 million liters of oil lost since 2014 in the Niger Delta. This incidence has damaged many traditional agricultural and fishing livelihoods, which in turn had affected local populations dependent on agriculture and fishing for their livelihoods (www.stakeholderdemocracy.org). According to Shell and Eni, the major and most common cause of oil spill is sabotage and theft, and these has brought about damage of the environment and devastation of lives in this part of Nigeria (www.amnesty.org).

Historically proven, the oil and gas sector has been the main source of greenhouse gases (GHG) emissions in Nigeria, and virtually in other countries. These emission as resulted to climate changes, which have brought about acidic rain in most Niger delta regions. As reviewed by Raffaello et al. (2013), the annual emissions of GHG in 2010 were approximately 90 million metric tons carbon dioxide equivalent ($MtCO_2e$), with dominate source from gas flaring. Other sources of GHG emissions include on-site use of gas for operating oil and gas production, transportation, and processing facilities; emission of gas through leakages and other losses; and venting of gas from oil storage tanks. In August 2020, the Carbon Brief Profile of Nigeria (CBPN) reported that the annual emissions of GHG in 2015 were approximately 506 million metric tons carbon dioxide equivalent ($MtCO_2e$), which was roughly the same as the UK's total emission same year (Daisy, 2020). This increment of GHG emission between 2010 and 2015 is over 100%, with higher tendency of increment as the year goes, except for remedies.

One of the remedies of these high GHG emissions is to utilize more of Nigeria renewable energy resources such as solar, wind, hydro, biomass, etc., therefore switching from fossil fuel dominated to low-carbon sources, to meet the energy demand of a growing population. However, this doesn't connote a total back off from fossil fuels production and consumption, but to reduce its production and usage to an extent. Notwithstanding, there seems to be lot of challenges and implications of these transition into cleaner energy future with more variable renewable energy resources. Some of such challenges include expensive investment cost of renewable energy resources, converting some of the oil refineries into renewable refineries, etc. To this effect, energy models are required to deal with these challenges, and for efficient energy management systems. Energy modelling framework do not prevent the environmental impacts of oil and gas industries, but based on different energy policies, they help provide insights into how energy systems can evolve in the future and the GHG emissions, thereby generating energy options for better Nigeria; hence effective energy management strategies.

1.3 Aim and Objectives of the Research

The main aim of this research is to assess the implications of alternative energy scenario on carbon emissions in Nigeria, while the objectives are:

- Review the demand and supply of energy, sources and effects of GHG emissions in Nigeria.
- Assess the implications of low-carbon energy production options in Nigeria;

- Applied Long-range Energy Alternative Planning (LEAP) computer model to evaluate current Nigeria energy patterns, energy demand projections, oil production projections, and the associated GHG emissions from 2018 – 2060;
- Perform cumulative cost-benefit analysis between the period of analysis, of various demand and supply-side technologies, under the two different carbon-emissions scenarios (Reference and Low Carbon scenarios).

1.4 Scope of the Research

This research covers and is limited to the utilization of LEAP energy model using Nigeria 2018 data available under the Reference and Low carbon scenarios, for

- Forecasting Nigeria energy demand in all sectors of the economy (agriculture, industry, service and residential), crude oil production/output, and the corresponding GHG emissions for a long-term period (2018 – 2060) under a range of user-defined assumptions.
- Cumulative cost-benefit analysis for the Reference and Low Carbon scenarios with respect to energy demand, oil production and import/export of resources.

1.5 Organization of the Research

This research work is organized into five chapters including Chapter one (Introduction), which comprises of background, study area (Niger Delta), problem statement, aims and objectives of the research, scope of the research, and how the thesis is organized. The Chapter two focused on the reviewed relevant literature on the subject matter. The Chapter three describes the methodology carried out at the cause of the research in achieving its aims and objectives, as well as the sources of data and information used in the course of this research work. The Chapter four reveals and discussed on the results obtained after carrying out the methodology. Finally, the Chapter five states the conclusions, policy implications as well as the recommendations, based on the results outcome.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 The Sectors of Nigerian Economy

The Nigerian economic model is considered as a dual economy with a modern segment solidly dependent on oil and gas revenue, and the traditional agriculture and trading economy. These sectors have doubtlessly contributed to the growth and development of the country's economy. As revealed from the World Bank official data, likewise projections from Trading Economics, the GDP in Nigeria was worth 448.10 billion US dollars in 2019, representing 0.37 percent of the 2019 world economy. Out of this 2019 GDP value, the agricultural sector contributed 25.16%, while the service and industrial sectors contributed 52.60% and 22.25%, respectively (see Figure 2.1). In the third quarter of 2019, the National Bureau of Statistics (NBS) reviewed that the Nigeria's GDP grew by 2.28% (year-on-year) in real terms. Comparing this growth to that of the third quarter of 2018 (1.81%), the real GDP growth rate observed in the third quarter of 2019 indicates an increase of 0.47% points.

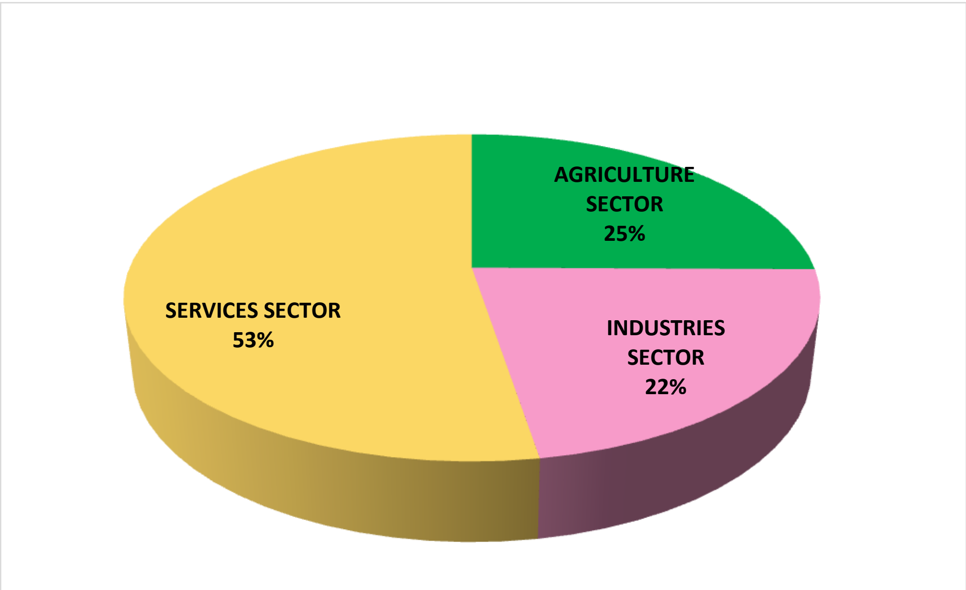

Figure 2.1: Nigeria GDP by Sector 2019 (*Source: National Bureau of Statistics, 2019*)

In the second and third quarter of 2020, NBS reported a year-on-year growth rate of -6.10% and -3.62%, respectively, in real times (see Figure 2.2). This growth rate seems very lower than that of 2019, with growth rate of 2.10%, 2.12%, 2.28%, and 2.55%, in the first, second, third, and fourth quarters, respectively. This poor economy performance in the second quarter of 2020 reflected residual effects of the restrictions to movement and economic activities implemented across the country to aid prevent the spread of COVID-19. When the restrictions were lifted and movement were restored to an extent, a total of 18 economic activities recorded positive growth in the third quarter of 2020 (NBS, 2020).

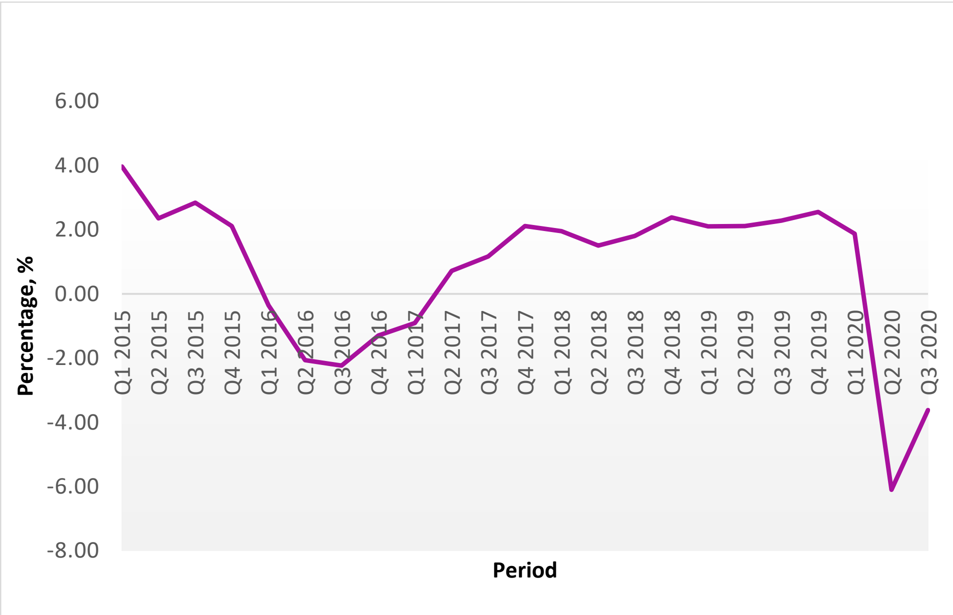

Figure 2.2: Nigeria GDP *(Source: National Bureau of Statistics, 2020)*

2.1.1 Agricultural and Land Use Sector

Especially in the developing countries, agriculture has been the bedrock of economic growth, development, and poverty eradication. Nigerian economy strives on the agricultural sector since past decades, maybe because of the blessings of over 91 million hectares of land, with 81 hectares arable. Most part of the country experience-rich soil and well-distributed rainfall with warm year-round temperatures, hence encouraging agricultural activities dates far back to the per-colonial era (Alahira, 2013).

Agricultural sector comprises Crop Production, Livestock, Forestry and Fishing sub-sectors. Each subsector has played major role in the livelihood of the Nigerians, as over 35% of the population depend on it. According to the Agricultural policy for Nigeria, the roles conventionally ascribed to the agricultural sector in a growing economy include: providing adequate food for an increasing population, supplying adequate raw materials to a growing industrial sector, constituting the major source of employment, constituting a major source of foreign exchange earnings, and providing a market for the products of the industrial sector. Agricultural sector has provided several job opportunities and raw materials for many agro-allied industries; and about 88% of non-oil exports earning comes from this sector of the economy (Sertoğlu et al., 2017). This sector has also provided the needed foreign exchange earnings for other capital development projects; contributing about 75% of the total annual merchandise exports of commodities such as cocoa, palm kernel, beans, etc., since 1960 (Oji-Okoro, 2011).

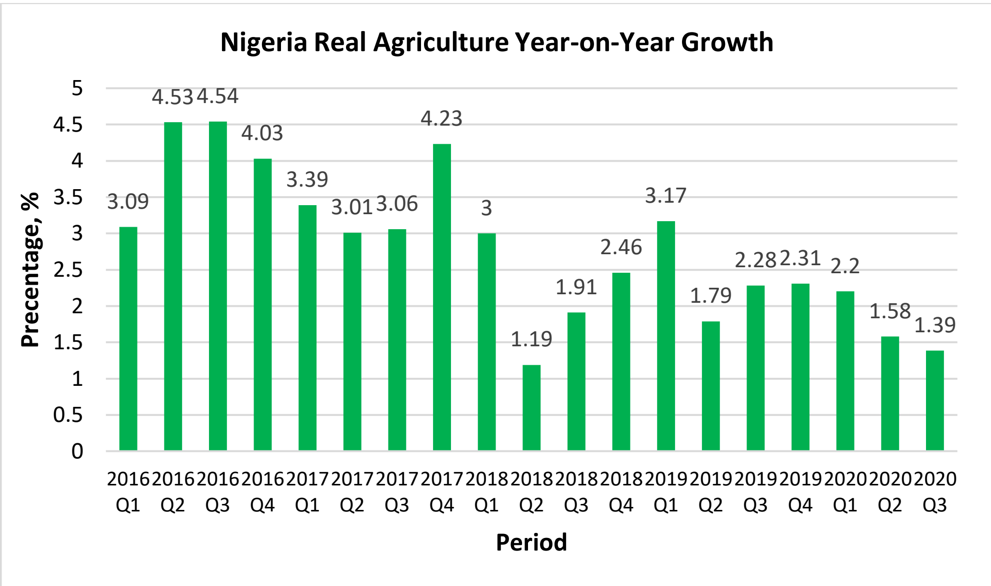

Figure 2.3: Agriculture Real Growth *(Source: National Bureau of Statistics, 2020)*

Clearly seen in figure 2.1, the agricultural sector contributes about 25% of the Nigeria's GDP. As revealed by NBS, this sector of the economy grew year-on- year in real terms by 1.39% in 2020, which was a drop of 0.89% points from the corresponding period of 2019 and a decrease of -0.19% points from the preceding quarter (see Figure 2.3). In real terms, the sector contributed 30.77% to the overall GDP in the third quarter of 2020, higher than 24.65% and 24.65% in the second and third quarter of 2019. Obviously, the contribution of agricultural sector to the Nigeria's GDP will continue to increase.

2.1.2 The Service Sector

Another important sector of the Nigerian Economy to consider is the service sector, also known as the tertiary sector. They provide services maintenance and repairs, training, or consulting to the public rather than producing raw materials. They include retail and wholesale trade, banks, hotels, real estate, education, health, social work, computer services, recreation, media, communications, motion pictures ("Nollywood"), electricity, gas and water supply. The service sector contributes the largest sector of the economy, especially in many Africa countries. Even though the Nigeria economy has poor ranking in terms of infrastructure and ease of doing businesses, the World Bank published that the country is one of the most open service markets in Africa, receiving an overall score of 27.1 on Service Trade Restrictions Index (Oh, 2017).

The service sector has contributed massively to the growth and development of Nigeria, which has been seen through the increasing share to GDP, trade, and employment between year2000 to year 2012. Meanwhile, between year 2009 to 2012, Africa's services sector grew rapidly at 4.6% in real terms, being the biggest among exporters of manufactured goods, then it was followed by countries that export service (such as Djibouti), but fuel exporter like Nigeria was the lowest (Ehigiator, 2017). As reviewed by the National Bureau of Statistics Nigeria, service sector contributed the highest of about 53% to the Nigeria's 2019 GDP (see Figure 2.1). In the first, second and third quarters of 2020, this sector accounted for 53.39%, 53.49% and 47.64% of the Nigeria's GDP, respectively.

2.1.3 The Industrial Sector

Nigeria remains a major industrialized country in the West African sub-region and Africa south of the Sahara. Also, during the pre-colonial era, the country was known for its high industrial activities even when modern factory activities were barely known, as craft industries were featured in the various clans and kingdoms (Ajayi, 2011).

Nigeria industrial sector represents group of firms that involves in transforming factors of productions to consumer goods and services. This sector of the economy serves as an effective tool of promoting economic growth and development by increasing productive capacity, enhancing revenue, creating employment opportunities, ensuring effective income distribution, poverty reduction, contribution to export and gross domestic product (Akinwale and Oludayo, 2019). They include:

i. Mining and Quarrying: Crude Petroleum and Natural Gas, Coal Mining, Metal Ores, Quarrying and Other Minerals
ii. Manufacturing: Oil Refining, Cement; Food, Beverage and Tobacco; Textile, Apparel and Footwear; Wood and Wood Products; Pulp, Paper and Paper Products; Chemical and Pharmaceutical Products; Non-Metallic Products; Plastic and Rubber products; Electrical and Electronics; Basic metal, Iron and Steel; Motor vehicles & assemble; Other Manufacturing.
iii. Electricity, Gas, Steam & Air conditioner
iv. Water supply, sewage, waste managements.
v. Construction

The Nigerian industrial sector, especially the oil and gas sub-sector, has massively contributed to the economic growth and development over the years. As revealed by the Central Bank of Nigeria Statistical Bulletin and the National Bureau of Statistics, this sector contributed 48.59% and 47.64% of the overall Nigeria’s GDP in the third quarter of 2019 and 2020, respectively, hence a decline. The decline was also seen in other sub-sectors of the industrial sector and were as a result of the effect of the COVID-19 pandemic that busted out in 2020 December period at China (NBS, 2020).

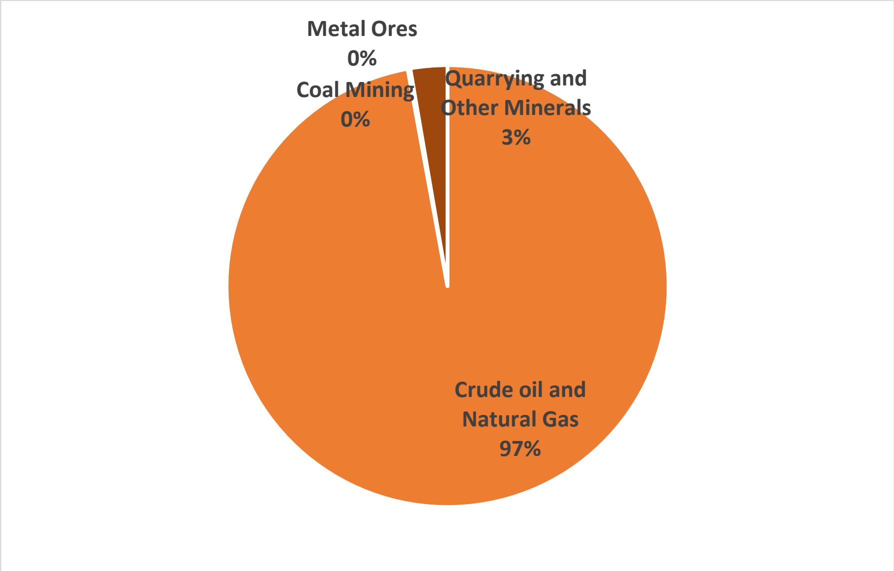

Figure 2.4: 2019 GDP Contribution from Mining and Quarrying Sub-sector of Nigeria Economy (source, *National Bureau of Statistics*, 2020)

Also, as revealed by the National Bureau of Statistics, the mining and quarrying sub sector of the industry sectors contributed over 12 trillion NGN to the Nigerian economy in 2019, with leading GDP contribution from crude oil and natural gas of about 2.6 trillion NGN (see figure 2.4).

2.2 Overview of the Nigerian Oil and Gas

2.2.1 The Nigerian Oil

Oil was first discovered in the year 1956, at Oloibiri in the Niger Delta region of Nigeria by Shell-BP. After producing oil of about 5000 bpd from her reserve in 1958, she then joined the ranks of other oil-producing countries. The oil produced is light and has less sulfur content (sweet crude oil), therefore called Bonny Light. In 1971, Nigeria became a member of OPEC, and have produced her past leaders from OPEC, in the likes of late Chief M.A. Feyide and Dr. Rilwanu Lukman (Orukpe and Omoruyi, 2017).

Nigeria remains the giant of Africa in terms of economy, politics, population, and land mass, availability of resources, etc., however still suffers insecurity, poverty and backwardness even in terms of technology (Orukpe and Omoruyi, 2017). The country is endowed with both renewable and nonrenewable energy resources – large oil, gas, hydro and solar – of which likes of solar resources have been underutilized for years.

Despite all the available energy resources, the dominated resources produced and utilized is the liquid fuel (oil and natural gas), accounting for over 90% of the country's total export and 70% of the foreign exchange earnings and revenue (Babatope and Audu, 2020). According to National Petroleum Investment Management Services (NAPIMS, 2021) under NNPC, Nigeria have over 50 oil and gas companies; with Shell, Chevron, Mobil, Agip, Elf and Texaco, as the major oil and gas companies. These companies operate on different geographic spread across the country. With over 500 oil fields in the Niger Delta, of which some are being closed-down, 55% is onshore while the remaining are swallow waters with depth less than 500 meters.

Nigeria oil and gas sector are structured into upstream, midstream and downstream, working together for the development of the oil industry (Odupitan, 2017). From the 2018 energy data of the U.S. Energy Information Administration (EIA), the total energy produced in Nigeria was 5.929 quadrillion Btu, ranking her 19th in the world with China (115.93 quadrillion Btu) and the United States (95.75 quadrillion Btu) taking the top lead. Out of this total energy production, 1.656 quadrillion Btu of energy was consumed by the Nigeria dwellers. The least produced and consumed energy resources was coal, with total consumption greater than the amount produced. The highest produced and consumed energy resources was petroleum and other liquids (see Table 2.1).

Table 2.1: Nigeria 2018 Primary Energy data (source: EIA 2020)

S/N	**Energy Resources**	**Production (quadrillion Btu)**	**Consumption (quadrillion Btu)**
1.	Coal	0.001	0.004
2.	Dry natural gas	1.685	0.685
3.	Petroleum & other liquids	4.184	0.908
4.	Nuclear, renewables, & other	0.059	0.059

As of 2016, Nigeria has proven oil reserves of 37.07 billion barrels of oil, accounting for about 2.2% of the total world oil reserves of 1.65 trillion barrels, and was ranked 10th in the world. This oil reserve has been known to gradually increase over the years.

In the third quarter of 2019, NBS reviewed that Nigeria recorded oil production of over 2.04 million barrels per day. The output was 0.1mbpd higher than the daily average production of 1.94mbpd recorded same quarter of 2018. In 2020, there was a cut in exploration and production because of low oil demand due to the Covid-19 pandemic likewise the OPEC+ nation's agreement to cut oil production by 9.07million bpd (Klynyeld et al., 2020). The third quarter of 2020 had an average daily production of 1.67mbpd, which was 0.14mbpd lower than the production volume recorded in the second quarter same year, resulting to a decline of -7.26% points as compared with the oil sector growth recorded in Q2 2020.

2.2.2 The Nigerian Natural Gas

As reviewed by EIA 2020, Nigeria holds the largest natural gas reserve on the continent of Africa and was ranked the 5th largest exporter of LNG in 2018. According to the 69thversion of bp Statistical Review of World Energy (2020), Nigeria proven gas reserves at the end of 2018 was 5.4 tcm out of the 197.1 tcm produced in the world. These gases are transformed into liquid before they can be delivered to the customers, through liquefaction process. During this process, the pressure on the gas is increased to bring its molecules closer together, and the temperature is reduced below its boiling point. Therefore, removing enough energy to make it transform from gaseous to liquid state in gas plants, one of which is the Shell Nigeria Gas (SNG). The Shell Nigeria Gas supply natural gas through pipelines to industries customers within the Agbara/Ota axis, including the Ogun-Guangdng Free Trade Zone (Ogun state), Aba industrials areas (Abia State) and Port Harcourt (Rivers State). Another gas plant is the Escravos GTL. This gas plant started in 2014 with a name-plate capacity of 33000 b/d, and it is 75% operated by Chevron and 25% partnership with NNPC.

In June 2020, the DPR Director announced the Nigeria's proven gas reserve to be 203.16 tcf, with difference of about 6.84 tcf to the 2025 target. Meanwhile, the demand and consumption of natural gas has been increasing, except for few occasions where there was occurrence of instability (see Figure 2.5). In 2020, reports came in that Nigeria had over 50 stranded cargoes of crude oil and 12 of LNG that were unable to find buyers due to low demand as a result of the COVID-19 pandemic, which have also affected the revenue profile of Nigerian Government (Klynyeld, 2020).

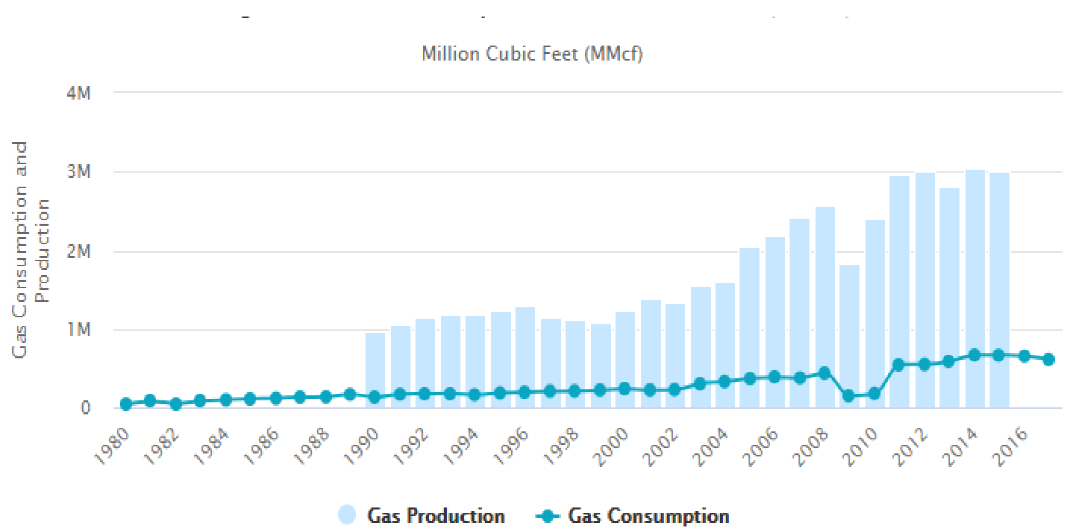

Figure 2.5: Nigeria Natural Gas Production and Consumption till 2016(source: worldometer)

2.2.3 Challenges of Nigerian Oil and Gas Sector

The Nigerian oil and gas industry have faced challenges, which have limited the growth and development of the economy, directly or indirectly. Most of these challenges might be difficult to resolve without amending the Nigeria's 1999 constitution. Iledare (2007) outlined and elaborated on the key elements of the challenges faced by the Nigeria oil and gas industry, proffering, as well, the possible solutions. The challenges include:

- Resource ownership and the exclusive rights of the national government to grant the permission to explore and develop petroleum resources in Nigeria
- Effective, progressive petroleum fiscal systems
- Funding options for joint venture operations and the NOC
- Authentic indigenous participation in the domestic oil and gas industry.
- The rules of law and institutional empowerment; and
- Continual membership of Nigeria in OPEC.

Aside from the outlined challenges, the effect of the Covid-19 has negatively affected the Nigeria oil and gas sector, since the country solidly depend on the revenue that comes from it. The Nigeria Center for Disease Control (NCDC) stated, as at 22nd January 2021, that the numbers of COVID-19 confirmed cases in Nigeria was 118,969 with 1490 deaths, and still counting (NCDC, 2021).

As an effect of this global pandemic, top importers of Nigerian's oil, accounting for over 70% of the Nigeria's oil export's destination for April 2020, experienced decline in both their internal consumption and external demand for oil. This had huge effect on Nigeria directly and indirectly, as it also affected the price of Bonny Light, whose price have not really been stable over the years. The Central Bank of Nigeria (CBN, 2020) reviewed that the Nigerian's oil price at the end of the first quarter in 2020 was US$32.29 per barrel, and US$40.3 per barrel at the end of the second quarter the same year. To be able to address this instability, the President of Federal republic of Nigeria, Muhammadu Buhari, inaugurated the National Oil and Gas Excellence Centre (NOGEC) Lagos, on 21st January 2021, to enhance safety, value and cost efficiency in Nigeria's petroleum sector (DPR, 2021).

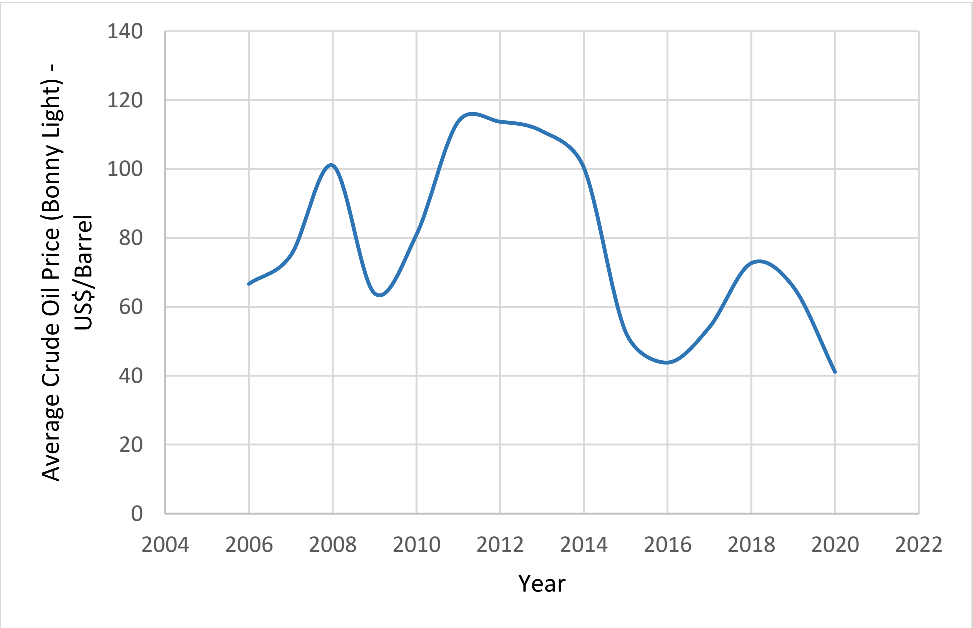

Figure 2.6: Average Nigeria Oil Price from January 2006 to August 2020*(Source: CBN, 2020)*

2.3 Environmental Impact of Nigerian Oil and Gas Industries

Asides from the ongoing threat faced by the oil and gas industries; corruption, terrorism and theft from criminal organizations that steal crude directly from pipelines; exploration and production activities have caused severe social and environmental impacts in the country, especially in the Niger Delta regions. Some of these environmental hazards caused include oil spillage, emission of greenhouse gases, environmental disaster and explosion, loss of mangrove forests, depletion of fish populations, water hyacinth invasion, biological remediation, etc. These environmental impacts have not only caused degradation and destruction of the traditional livelihood of the Niger Delta region, but have also resulted to environmental pollution with long impacts on the weather conditions, soil fertility, waterways, aquatic habitats and wildlife (Ukwayi et al., 2012).

However, this section focuses on oil spillage and greenhouse gases emission environmental impacts from oil and gas industries in Nigeria.

2.3.1 Oil Spillage

Oil spills are discharge crude oil or oil distilled products like gasoline, diesel, fuels, etc. that can pollute the surface of the land, air, and water environments. Oil spill be as a result of mechanical failure, operational error natural hazard, corrosion of pipelines, third party activity and sabotage (Aroh et al., 2010). An estimate of over 1.5 million tons of oil has been spilled over the past 50 years. This estimate is over 50 times the estimated volume spilled in ExxonValdez oil spill in Alaska 1989. The most common form of oil spills is through sabotage; common in the Niger Delta region, especially in the Ogoniland region of the Delta state (Agoi, 2020).

The Niger Delta regions have experienced millions volume of spilled oil, which have been challenging over the years. No doubt that spills of oil cannot be totally avoided, but its magnitude and frequent occurrence with little/no effort of controlling it at the appropriate period, is where the big challenge lies (Enyoghasim et al., 2019). According to Pitkin (2013), the result from the comprehensive study of the environmental impact of oil extraction in the Ogoniland region of the Rivers State by UNEP in 2011, shows the level of severity of oil spills in the area over time. These oil spills would take approximately 30 years to clean up the mess with an average cost of one billion USD (Daisy, 2020). Meanwhile, the government launched a clean-up program of the affected areas after the report from the UNEP in 2011 (Agoi, 2020).

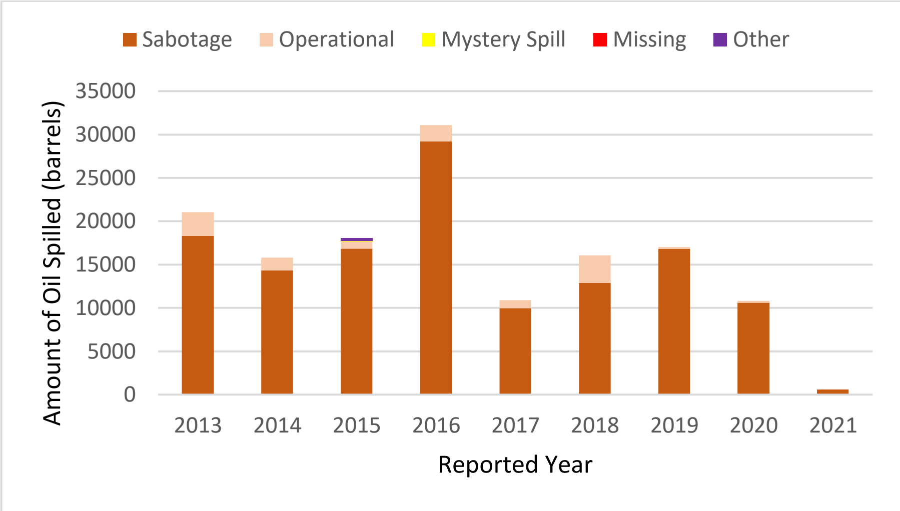

Figure 2.7: Nigeria Oil Spill Graph from 2013 to 2021*(Source: SPDC, 2021)*

Since 1989, SPDC recorded an average of 221 spills per year in its operational areas involving 7,350 barrels annually. The total oil spill from year 1976 to year 1996 was approximately 23,369,470 barrels, of which about 77% were not recovered. This large volume of oil spilled was enough to add up to the revenue for the Nigeria's development (Kadafa, 2012). The highest oil spill since 2013 was that of 2016 with over 29,200 barrels of oil spilled, basically as a result of sabotage from local residents and criminal gangs stealing the crude oil. The remaining 1,880 barrels oil spilled were as a result of operational errors (see Figure 2.7). The most recent oil spill occurred in January 2021 at Elele-Alimini as a result of sabotage, spilling about 149 barrels of oil (see photo in figure 2.8).

However, SPDC response to these oil spills have been encouraging. During the cause of industrial activities and leak is been identified, they would suspend production and then contain the recovered spilled oil (SPDC, 2021). The spilled oil that cannot be recovered will have an impact on the local environment, spreading over a wide area and affecting both terrestrial and marine resources. Inappropriate clean-up actions after oil spillage can make the situation worse (Nwilo and Badejo, 2005).

Oil spills do not only contaminate the surface waters, but also the soil and groundwater as well, therefore making the land not useful for agricultural activities and the water bodies not useful for both man and animal use.

Figure 2.8: Part of spill impart on 18inch Assa-Rumuekpe Pipeline at Elele-Alimini. Picture was taken during Joint Investigation of 10th January 2021*(Source: SPDC, 2021).*

2.3.2 Greenhouse Gases Emissions

Greenhouse gases (GHG) are gases that trap heat or infrared radiation emitted from the Earth's surface, and then reradiate back to the surface of the earth, hence adding up to the greenhouse effect. Greenhouse gases emission comprises primarily of carbon dioxide (CO_2), methane, nitrous oxide, and water vapor.

Major contributors to increasing CO_2 emissions includes land use, land-use change and forestry, mostly due to deforestation (Mengpin and Johannes, 2020). Meanwhile, the major source of increasing GHG emissions is the oil and gas sectors. About 89% of carbon dioxide emissions are from the use of fossil fuels, especially for generation of electricity and heat, transportation, and manufacturing and consumption. As a matter of fact, the United States Agency International Development (USAID, 2019) revealed that the GHG emissions in Nigeria increased by 25% (98.22 $MtCO_2e$) between 1990 and 2014, with average annual change in total emissions of 1%. Climatelinks article (2019) revealed that the total GHG emissions in 2014 were 492.44 million metric tons of carbon dioxide equivalent (MtCO2e), of which 38.2% came from the land-use change and forestry sector, followed by the energy (32.6%), waste (14%), agriculture (13%) and the industrial processes sector contributing 2.1%.

Interestingly, from the Carbon Brief Profile of Nigeria, Daisy stated that the Nigeria's greenhouse gas emissions in 2015 were 506 tonnes of CO_2 equivalent ($MtCO_2e$). This amount was approximately the same as the GHG emitted in UK same year. Out of this amount of GHG emitted in 2015, agriculture, forestry, and other land use (AFOLU) were the leading source accounting for about 66.9% of the total GHG emitted; followed by the energy sector (28.2%), waste (3%), and industrial processes and product use accounting for 1.9% (Offiong, 2019).

2.3.2.1 Sources and Effects of Greenhouse Gases Emissions in the Oil and Gas Industries

Some of the sources of greenhouse gases emissions in the Nigerian oil and gas industries include as flaring, gas venting from oil storage tanks, on-site combustion of fuel, fugitive methane emissions through leaks, etc.

A. Combustion of Fuels

Combustion is the process of burning with very little or no supply of oxygen. Fuel is combusted in oil and gas industries for the purpose of generating the energy needed during production, processing and transportation stages. For instance, powering drilling equipment, supplying energy to separation processes, etc. The combustion of these fuels in stationary equipment such as engines, burners, heaters, boilers, flares, and incinerators result in the formation of CO2 and its equivalent due to oxidation. In gas plants, significant amount of fuel is used in LNG and GTL for the generation of energy required to carry out the combustion processes (Raffaello et al., 2013). These combustion processes continually add up the amount greenhouses released to the atmosphere. During fuel combustion process, very little amount of N_2O may be formed by reaction of nitrogen and oxygen. Methane may also be released in exhaust gases as a result of incomplete fuel (GHG Compendium, 2009).

B. Flaring and Venting of Gas

Oil wells often contains liquid petroleum and natural gases together. These gases could be capture and used to generate or converted to liquid fuels. But most times, they are disposed either by burning at the site of extraction (called gas flaring) or released into the air (called gas venting) (Pitkin, 2013). Gas flaring or venting have been the cheapest and easiest means of getting rid of natural gases associated with oil. However, any of this practice had incredibly damaged the environment and communities, leading to increasing temperature that has render many areas in habitable for both plant and animals (including man). The Nigerian's High Court in 2005, confirmed the illegality of gas flaring by ruling out that the burning of gas by oil companies violates the human rights of local people and must be stopped (Effiong, 2010). Meanwhile, during the process of gas flaring, emissions of CO_2 are formed as products of combustion, with CH_4 emissions occurring as a result of the incomplete combustion. The effectiveness of combustion in gas flaring is called "flare efficiency", and it is mostly assumed to be 94%, but can be as 98% under ideal conditions (Raffaello et al., 2013).

According to the research publication by Kadafa (2012), Niger Delta region has about 123 gas flaring sites, discharging an estimate of 45.8 billion kilo watts of heat from 1.8 billion cubic feet of gas every day. This high volume of gases released had recently Nigerian the second to Russia in total gas flared (Pitkin, 2013). Such high amount of gas released to the atmosphere, has made acid rain very common in the Niger Delta regions, destroying both forest and economic crops (Kadafa, 2012).

C. Fugitive Emissions

Generally, fugitive emissions occur through pressurized equipment such as valves, flanges, seals, or related equipment as a result of due leaks. Likewise, nonpoint evaporative sources such as wastewater treatment, pits, and impoundments, could results to fugitive emissions. These emissions are unintentional emissions, and may arise due to normal wear and tear, improper or incomplete assembly of components, inadequate material specification, manufacturing defects, damage during installation or use, corrosion, fouling and environmental effects (Raffaello et al., 2013).

Fugitive emissions of VOCs leaking from equipment in the oil and gas industries have costly consequences for the health and safety of the people. Basically, these emissions have caused environmental pollution and change of climate in the Niger Delta region. Aside from the loss of income and risk of fire (explosion) generated through fugitive emissions, they also contribute to the amount of greenhouse gas released into the atmosphere. However, there is need for managing leak detection in order to reduce fugitive emissions, (SGS, 2021).

D. Other Emission Sources

Other sources of greenhouse emissions include emissions that are consequence of activities of the reporting company but which result from sources owned or controlled by another party. They include emissions from the combustion of hydrocarbon fuels to generate electricity, heat, steam, or cooling where this energy is imported or purchased (GHG Compendium, 2009). These national sources of GHG emissions have significantly contributed to the choking air in like Lagos and Abuja, which are beleaguered by smog shrouding the skyline of the central cities (Giwa et al., 2017).

According to Raffaello et al. (2013), other emissions of GHG also include:

- ✓ Methane emissions from cold venting
- ✓ Methane emissions from standing and working losses in oil tanks
- ✓ Methane emissions from produced water
- ✓ CO2 and methane emissions from maintenance and facility turnaround activities
- ✓ CO2 and methane emissions from exploratory, drillings and well testing

2.3.2.2 GHG Emission Estimation Methods

In this subsection, some of the methods of estimating GHG emissions as regards to their sources of emissions, would be discussed in line with the *Compendium of Greenhouse Gas Emissions Methodologies for the Oil and Gas Industry* (API, 2009).

A. Combustion Emissions Estimation Methods

The general reaction for the combustion of hydrocarbons, with the assumption of complete combustion, are represented below;

$$C_xH_yO_z + \left(x + \frac{y}{4} - \frac{z}{2}\right) O_2 \rightarrow (x)CO_2 + \left(\frac{y}{2}\right) H_2O \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.1)$$

Where x is stoichiometric coefficient for carbon; y is stoichiometric coefficient for hydrogen; and z is stoichiometric coefficient for oxygen.

Using material balance approach, the emissions of CO2 from fuel combustion are determined firstly by calculating the wt% carbon of each of the fuel components. To accomplish this, multiply the molecular weight of carbon by the number of moles of carbon and then divide by the molecular weight of the compound.

$$Wt\%C_{cj} = \frac{\frac{12lbC}{lbmoleC} \times \frac{XlbmoleC}{lbmoleCj}}{MW_{cj}\left(\frac{lb}{lbmole}\right)} \times 100\% \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.2)$$

Where Wt% C_{Cj} is the carbon content of individual hydrocarbon compound on a mass percent basis; j is any hydrocarbon compound $C_xH_yO_z$ from Equation (2.1); 12 is the molecular weight of carbon; X is Stoichiometric coefficient for carbon (for example X=3 for pentane, C_3H_8); and MW_{CXY} is the molecular weight of individual hydrocarbon compound.

Therefore, with the material balance approach, the carbon content of fuel mixture is then obtained using;

$$Wt\%C_{mixture} = \frac{1}{100} \times \sum_{i=1}^{Components} (Wt\%_i \times Wt\%C_i) \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.3)$$

Where $Wt\%C_{mixture}$ is the carbon content of mixture, on mass percent basis; $Wt\%_i$ is the weight percent of component i; and $Wt\%C_i$ is the carbon content of component i on a weight percent basis, calculated using Equation (2.2).

Using the mass balance approach, the emissions of CO2 from fuel combustion are obtained thus;

$$E_{CO_2} = FC \times \frac{1}{molarvol.\,conversion} \times MW_{mixture} \times Wt\%C_{mixture} \times \frac{44}{12} \dots\dots\dots\dots\dots\dots (2.4)$$

Where E_{CO2} is the mass emissions of CO_2 (lb or kg); FC is fuel consumed (scf or m^3); Molar volume conversion is the conversion from molar volume to mass (379.3 scf/lbmole or 23.685 m^3/kgmole); $MW_{mixture}$ is the molecular weight of mixture; and $44/12$is stoichiometric conversion of C to CO_2.

However, when considering liquid fuels, the emission of CO_2 from combustion under the material balance approach can be calculated using Equation (2.5).

$$E_{CO_2} = FC \times D \times Wt\%C_{mixture} \times \frac{44}{12} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.5)$$

Where FC is the fuel consumed (gal or m^3); and D is fuel density (lb/gal or kg/m^3).

Similarly, emissions from the combustion of solid fuels with the assumption 100% oxidation, is calculated using Equation (2.6).

$$E_{CO_2} = FC \times Wt\%C_{mixture} \times \frac{44}{12} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (2.6)$$

Where FC is the fuel consumed in mass units (lb, kg, tonnes).

B. Process and Vented Emission Estimation Methods

Several vented emissions in oil and gas industries are released into the atmosphere as a result of the process or equipment design or operational practices. In refineries, specialized processes such as catalytic cracking regeneration, catalytic reformer regeneration, etc. emits GHG emissions. However, when considering the Catalytic cracking regenerator, one of the approaches involved in calculating the CO2 emission is the Fluid catalytic cracking units (FCCUs), and it is represented by the following choke burn equations.

$$E_{CO_2} = \left[K_1 \times Q_r \times \left(P_{CO_2} + P_{CO}\right)\right] \times \frac{44\, massunitsCO_2/mole}{12\, massunitsC/mole} \times H \text{ ………………………… (2.7)}$$

$$Q_r = \frac{79 \times Q_a + \left(100 - P_{Oxy}\right) \times Q_{Oxy}}{100 - P_{CO_2 - P_{CO} - P_{O_2}}(2.8)} \text{ ……………………………………………………… (2.8)}$$

Where; $E_{CO_2}$is the emissions of CO_2 (lb/year or kg/year;K_1= carbon conversion factor burn term (0.0186 lb-min/hr-dscf-% or 0.2982 kg-min/hr-dscm-, given in Table 2.2); $Q_r$is the volumetric flow rate of exhaust gas before entering the emission control system, calculated using Equation 2.8 (dscf/min or dscm/min); Qa is the volumetric flow rate of air to regenerator as determined from control room instrumentation (dscf/min or dscm/min);P_{Oxy} is the O_2 concentration in O_2-enriched air stream inlet to regenerator, percent by volume (dry basis); Q_{Oxy} is the volumetric flow rate of O_2-enriched air to regenerator as determined from control room instrumentation (dscf/min or dscm/min);P_{CO2} is the percent CO_2 concentration in regenerator exhaust, percent by volume (drybasis);P_{CO} is the percent CO concentration in regenerator exhaust, percent by volume (dry basis); when no auxiliary fuel is burned and a continuous CO monitor is not required, assume P_{CO} to be zero;P_{O2} is the percent O_2 concentration in regenerator exhaust, percent by volume (dry basis);H is the annual operating time (hrs/yr); 8760 hrs/yr if operating continuously throughout the year.

Table 2.2 Coke Burn Rate Material Balance Conversion Factors

Variable	Variable Purpose	Value	Unit
K_1	Carbon burn term	0.2982 0.0186	(kg min)/ (hrdscm %) (lb min)/ (hrdscf %)
K_2	Hydrogen burn term from O_2 in Air	2.0880 0.1303	(kg min)/ (hrdscm %) (lb min)/ (hrdscf %)
K_3	Hydrogen burn equivalent in excess O_2 and carbon oxides	0.0994 0.0062	(kg min)/ (hrdscm) (lb min)/ (hrdscf)

C. Fugitive Emission Estimation Methods

If CO2 is emitted from pipeline fugitive leaks, the following equation maybe used to calculate the emission.

$$EF_{CO_2,leak} = EF_{CH_4} \times \left(\frac{100}{100\% soiloxidation}\right) \times \left(\frac{defaultmole\%CO_2}{defaultmole\%CH_4}\right) \times \frac{MWCO_2}{MWCH_4} \; \ldots \ldots (2.9)$$

Where: $EF_{CO_2,leak}$ is the emission factor for CO_2 emissions from pipeline fugitive leaks; $\frac{defaultmole\%CO_2}{defaultmole\%CH_4}$ is the conversion from total moles of CH_4 to moles of CO_2, based on default molar concentrations for the gas.

Using the equipment-level average emission factor approach, which allows fugitive emission estimate to be tailored to a particular facility based on the population of major equipment at the facility, the CO2 emission can be obtained using equation (2.10). Most of these major equipment emission factors are CH4-specific. The default CH4 concentration for each industry sector is indicated in the table footnotes. Carbon dioxide emissions from buried pipelines are based on an assumed concentration of 2 mole %.

$$E_{CH_4 \vee (CO_2)} = F_{A(CH_4 \vee CO_2)} \times N \; \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.10)$$

Where $E_{CH_4 \vee (CO_2)}$ is the emission rate of CH4 (or CO2) from a population of equipment; $F_{A(CH_4 \vee CO_2)}$ is the applicable average CH4 or CO2 emission factor for the major equipment type A; and N is the number of pieces of equipment in the plant/process.

Fugitive emissions from the pipeline transport of CO_2, such as for EOR operations, occur in a similar fashion to fugitive emissions from the pipeline transport of natural gas. This emission calculation is based on pressure drop through a pipe. For estimating CO_2 emissions from CO_2 pipelines, equation (2.11) is used.

$$EF_{CO_2} = EF_{CH_4} \times \sqrt{\frac{44}{16}} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.11)$$

Where $\sqrt{\frac{44}{16}}$ is the mass basis CH4 to CO2 conversion; and EF_{CH_4} is the CH_4 natural gas pipeline leak emission factor.

2.4 Energy Modelling Framework

Over the years, especially when energy caught the attention of policymakers in the aftermath of the first oil crisis in the early 1970s, researchers had gone wide on energy demand in order to overcome the limited understanding of the nature of energy demand and demand response due to the presence of the external shocks encountered at that time (Bhattacharyya and Timilsina, 2009). In addition to this, energy models have been employed for efficient energy management energy resources, improvement of energy efficiency and reliability, and reduction of GHG emissions (Ouedraogo, 2017).

Ouedraogo (2017) revealed that in the early years, the energy models developed were only energy supply models. These energy supply models are limited because they only consider one energy sector or one energy system or form, and they only focused on one facet of challenges faced by the oil and gas industries; that is, either on energy supply security, costs, or environmental impacts of energy consumption and production. Meanwhile, some energy models/approaches have now been applied for investigating energy policy and planning that have been concerns especially in developing countries. In order to estimate the quantity of CO_2 emitted from fuel, two energy models can be used; Tier 1 method (which involves Reference Approach and the Sectoral Approach) and the bottom-up method (Anomohanran, 2011).

The Reference Approach has been employed in some research work to estimate the carbon emissions from supply of fuel to the Nigerian economy rather than only from the actual emissions at the combustion plant can be known. However, Ouedraogo (2017) identified two energy models for developing countries due to the challenges of high reliance on fossil fuel (traditional energies) and the existence of large informal sectors. These energy models are top-down and bottom-up methodologies. Actually, it is more preferable to use the combination of bottom-up and top-down approaches for total impact assessment in developing countries. Such energy approach is the Long-range Energy Alternatives Planning (LEAP).

2.4.1. Top-down and Bottom-up Methods

The top-down and bottom-up approaches have been utilized in assessing long-term energy-system trends and the costs of achieving policy targets (Van-Vuuren, et al., 2009). These approaches have been employed over decades. Example of the top-down method is ENPEP-BALANCE, and that of the bottom-up method include HOMER, RAMSES, MARKAL/TIMES, MESSAGE, etc. (Ouedraogo, 2017)

The top-down approach to GHG emissions, also called the Reference Approach, is the type of energy model that originates from "the top", hence often directed based on decision making from "the top" (Nicholls, et al., 2015). This energy model is a straightforward method that can be applied on the basis of relatively easily available energy supply statistics. According to Van-Vuuren et al. (2009), a typical top-down model approach focuses on the economy as a whole and describes substitution across different inputs on the basis of historically calibrated factors. The top-down energy approach is carried out by using the energy supply of a country to calculate the emissions of CO_2 and its equivalents from combustion of mainly fossil fuels, staring from high level energy supply data (Treanton et al., 2006). In their research work, Raffaello et al. (2013) utilized the reference scenario to forecast the production of oil and gas and also associated emissions, based on current trends and the plans of the Federal Government of Nigeria (which also include existing plans for the reduction of associated gas flaring).

The bottom-up approach is a more detailed energy model. This method uses records of fuel consumed at various combustion plants together with details of fuel supplied to other sources of emission (Anomohanran, 2011). The bottom-up method describes data collected and processed at the local level, often the same as an individual Forest Service facility. However, this approach accounts only for emissions resulting from business operations and employee activities at the "pilot" site location (Nicholls et al., 2015). A typical Bottom-up method for GHG emission estimation focuses on the sustainability of individual energy technologies and their relative costs; and in many bottom-up approaches, the current energy is not necessarily assumed to be optimal (Van-Vuuren et al., 2019). Meanwhile, in the research work by Raffaello et al. (2013), the bottom-up approach was utilized in analyzing low-carbon mitigation for over 200 oil and gas industries in Nigeria, taking account of their size, location, and maturity.

Remarkably, research have shown that the global emission reduction potentials from bottom-up and top- down approaches were very similar, including the uncertainty ranges. Therefore, there is no obvious distinction between the top-down and bottom-up approaches in reality. However, when these two approaches are employed to calculate the emissions of CO_2 and its equivalent in some countries, the results obtained can be different with relatively small difference of about 5% or less, when compared to the total carbon flows involved(Treanton et al., 2006).

2.4.1.1 Algorithm of Top-down Approach

To utilize the Top-down/Reference Approach for GHG emission estimation, the calculation of carbon dioxide emissions from fuel combustion is broken into five steps (Treanton et al., 2006).

Step 1: Estimate Apparent Fuel Consumption in Original Units

Step 2: Convert to a Common Energy Unit

Step 3: Multiply by Carbon Content to Compute the Total Carbon

Step 4: Compute the Excluded Carbon

Step 5: Correct for Carbon Un-oxidized and Convert to CO_2 Emissions

Therefore, the amount of CO_2 emissions from fuel combustion using the top-down/reference approach can be calculated using:

$$CO_2Emissions = \sum_{allfuels} \left[\left(\left(ApparentConsumption_{fuel} \times ConvFactor_{fuel} \times CC_{fuel} \right) \times 10^{-3} - ExcludedCarbon_{fuel} \right) \times COF_{fuel} \times 44/12 \right] \ldots\ldots\ldots\ldots\ldots\ldots (2.12)$$

Where; CO_2 Emissions is the CO_2 emissions (Gg CO_2); Apparent Consumption = production + imports – exports – international bunkers - stock change; Conv Factor (conversion factor) is the conversion factor for the fuel to energy units (TJ) on a net calorific value basis; CC is the carbon content (tonne C/TJ). It is important to note that tonne C/TJ is identical to kg C/GJ. Excluded Carbon is the carbon in feedstocks and non-energy use excluded from fuel combustion emissions (Gg C); COF (carbon oxidation factor) is the fraction of carbon oxidized. Usually the value is 1, reflecting complete oxidation. Lower values are used only to account for carbon retained indefinitely in ashes or soot, and 44/12 is the molecular weight ratio of CO_2 to C.

To carry out Step 1, the following data are required for each fuel and inventory year.

- the amounts of primary fuels produced1 (production of secondary fuels and fuel products is not included);
- the amounts of primary and secondary fuels imported;
- the amounts of primary and secondary fuels exported;
- the amounts of primary and secondary fuels used in international bunkers;
- The net increases or decreases in stocks of primary and secondary fuels.

The apparent consumption of primary fuel and secondary fuel are then calculated using equation (2.13) and (2.14), respectively.

$$ApparentConsumption_{fuel} = Production_{fuel} + Imports_{fuel} - Exports_{fuel} - InternationalBunkers_{fuel} - StockChange_{fuel} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2.13)$$

$$ApparentConsumption_{fuel} = Imports_{fuel} - Exports_{fuel} - InternationalBunkers_{fuel} - StockChange_{fuel} \ldots\ldots \quad (2.14)$$

The quantity of carbon to be excluded from the estimation of fuel combustion emissions is calculated using Equation (2.15).

$$ExcludedCarbon_{fuel} = ActivityData_{fuel} \times CC_{fuel} \times 10^{-3} \ldots\ldots \quad (2.15)$$

Where Excluded Carbon is the carbon excluded from fuel combustion emissions (Gg C), Activity Data is the activity data (TJ), CC is the carbon content (tonne C/TJ).

2.4.2. Long range Energy Alternatives Planning (LEAP)

Long range Energy Alternatives Planning, originally known as the Low Emissions Analysis Platform (LEAP), is a widely used model/software tool for energy policy, change mitigation and air pollution abatement. This computer modelling was developed at Stockholm Environment Institute, Boston (SEI-B) and had been adopted by over 24,000 users and many hundreds of organizations in more than 190 countries worldwide. Users of this model include government agencies, academia, non-governmental organizations, consulting companies, and energy utilities. It has been used at different scales, ranging from cities and states to national, regional and global applications (ClimaSouth Handbook, 2014). The LEAP computer modelling can be used to account for both energy sector and non-energy sector greenhouse gas (GHG) emission sources and sinks. In addition to tracking GHGs, LEAP can also be used to analyze emissions of local and regional air pollutants, making it well-suited to studies of the climate co-benefits of local air pollution reduction (SEI, 2021).

LEAP already consists of Technology and Environmental Database (TED), which provides information that describes the technical characteristics, costs, and environmental impacts of different energy technologies. This is possible because the LEAP model is equipped with the IPCC Tier 1 GHG emission factors and also air pollutants emission factors (Dioha, 2018). Therefore, tacking of energy consumption, production and resource extraction in all sectors of an economy can be carried out with the help of LEAP and its environment database.

Also, the TED include qualitative data in addition to the quantitative data that provides information on the appropriateness and major environmental concerns of a group of technologies. However, the TED does not encompass electricity emission factor for household demand and emissions from the upstream that occurs during generation of electricity. This is because the emission factors of TED are for emissions at the point of release (Dioha, 2018). However, LEAP cannot be categorized as hybrid model. This is because hybrid models are capable of joining modelling policy priorities of equity and sustainability that are specific to and critical for developing countries, as well as current and anticipated changes in energy industries (Ouedraogo, 2017).

2.4.2.1 Algorithm of LEAP

Step 1: Energy demand calculation

The LEAP computer modelling makes use of the final energy consumption, which is calculated as the product of the total activity level and energy intensity at each given branch or sector (Ouedraogo, 2017).

$$ED_{b,s,t} = TA_{b,s,t} \times EI_{b,s,t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.16)$$

Where ED is the energy demand, TA is total activity, EI is energy intensity, b is the branch, s is the scenario, and t is year.

The final energy intensities, which is the amount of energy consumed per unit work (or GDP in the case of a country's energy intensity), can be estimated using equation 2.17.

$$EnergyIntensity = \frac{TE_{cs}}{GDP_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad (2.17)$$

Where; TE_{cs} is the total energy consumed in a sector, GDP_s is the gross domestic product contributed by a sector, and ktoe is kilo-tonnes of oil equivalent.

According to Dioha (2019), useful energy analysis, E, is obtained using equation (2.18).

$$E = Q \times \frac{u}{n} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.18)$$

Where u is the useful energy intensity and n is the efficiency, which has to do with the percentage annual average thermal efficiency of a demand device defined as 100 times the ratio of useful energy delivered to final energy consumed.

To obtain the fuel share of the energy types for each sector, use equation 2.19.

$$FuelShare = \frac{EC_i}{TE_C} \times 100 \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.19)$$

Where; $EC_i$is the consumption of a particular energy type in a particular sector (for example, coal consumed in industry sector), and $TE_C$is the total energy consumed in that sector (for example total energy consumed in industry sector).

To obtain the energy loss for a transformation process, we use the following equation;

$$ET_p = ET_{p,sec,tec} \times \left[\frac{1}{f_{p,sec,tec}} - 1\right] \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.20)$$

Where ET is the net consumption for transformation (energy loss for a transformation process), ETP is product from the transformation process, f is energy transformation efficiency, tec is the technology, p is the type of primary energy, and sec is the type of secondary energy.

Step 2: Carbon emission calculation

To determine the carbon emission from final energy consumption, the following equation is used:

$$CE_{b,s,t} = TA_{b,s,t} \times EI_{b,s,t} \times EF_{b,s,t} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2.21)$$

Where CE is the carbon emissions, $EF_{b,s,t}$ is the carbon emissions factor from sector or branch b, scenario s and year t, and TA is the total activity and EI is the energy intensity.

For estimating carbon emission from energy transformation, equation 2.22 is used.

$$CET = ET_{p,sec,tec} \times \frac{1}{f_{p,sec,tec}} \times EF_{p,sec,tec} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2.22)$$

Where CET is the carbon emission, $EF_{p,sec,tec}$ is the emission factor from one unit of primary fuel type p, used to produce the secondary fuel type sec through the technology tec.

2.5 Energy Transition

With the increasing trend of the emissions of greenhouse gases and also limitations of oil and gas reserves, many oil companies and oil-exporting countries are now shifting their focus away from fossil-fuel dominated energy resources to low/zero-carbon emission source, hence transition of energy. One of the key factors of achieving this is the potential of hydrogen as an energy vector due to its energy content (Bedani et al., 2020). While there are many uncertainties induced by the transition of energy, there is almost a consensus among forecasts provided by various organizations that the share of renewables in the energy mix will rise (Bassam et al., 2018).

Energy transition is the radical transformation of global energy sector from fossil-fuel dominated energy supply mix to zero-carbon emission sources. This process has been driven by economic growth, population growth, depletion of existing energy resources, change in technology, and quest to re-duce cost and inefficiency (Nwaneto et al., 2018). Meanwhile, policies like carbon pricing and the European Union's Emission Trading Scheme, have also been developed for gradual energy shift to low/zero-emitting carbon sources (Johnston et al., 2020). However, in November 2020, the Managing Editor of JPT, Pam Boschee, revealed that the transition of energy that the world seek cannot be achieved with a simple flip of a switch, but it requires some time. It also requires huge investment of capital, materials, and energy (Solé et al., 2018). Therefore, there is complexity in this energy shift, and the process goes far beyond only the replacement of one source of fuel with another energy source. Notwithstanding, some developed Asian countries like China, and to an extent, India are building energy strategies that address both air quality and emissions concerns, as well as establish expectations for continued growth in energy demand. China has prioritized the use of natural gas as city gas to displace residential and commercial coal heating. Also, in the United States, there is rapid changes in its stated emissions commitment from the Obama Administration to the Trump Administration (Johnston et al., 2020).

Energy transition dynamics, has raised some interesting questions for the oil and gas industries globally. How can the oil and gas industries manage a shifting strategic landscape and at the same time provide returns to shareholders – not only to survive but also to play the leading role in the de-carbonization process? However, some of the oil and gas industries in the world are responding in the following ways, according to Johnston et al.:

- Diversifying business models to emphasize customer-facing downstream opportunities around electrification and energy services, particularly opportunities around coal-to-gas switching or lower GHG-intensity oil and gas as a complement to renewable energy.
- Supporting the growth of deep de-carbonization technologies for oil and gas at the company and industry level, including carbon capture, utilization, and storage (CCUS); methane efficiency; zero-emissions production; and hydrogen.
- Reexamining geography and geopolitics to reduce exposure to potential "stranded assets," particularly long cycle oil projects in high cost or high political risk jurisdictions, while identifying projects or partnerships in jurisdictions with more long-term oil and gas demand.
- Adopting climate-focused Environment Social Governance (ESG) principles into business models; organizing messaging to markets, governments, and the public about both the energy transition and the expected need for oil and gas for decades to come, as well as the value of oil and gas industries in building the next generation of clean energy resources and technologies.

2.5.1 Nigerian Renewables

Owusu and Asumadu-Sarko (2016) defined renewable energy sources as the sources of energy from natural and persistent flow of energy happening in our immediate environment. These energy sources replenish themselves naturally without being depleted in the earth, and they include bioenergy, hydropower, geothermal energy, solar energy, wind energy and ocean (tide and wave) energy. However, it is interesting to outline that most researchers consider natural gas as a renewable energy resources, hence having roles to play in energy transitions. As stated in the report of the 27th World Gas Conference held at Washington DC 2018, Natural gas (renewable natural gas) provides the fastest and most economic path to a less carbon intensive and cleaner air world, hence a major contributor to reducing carbon emissions and cleaning polluted air.

According to bp Statistical Review of World Energy (69th edition), the total renewable energy consumed in Africa at the end of 2019 was 0.41 Exajoules, with Nigeria accounting for less than 0.17 Exajoules. Even with the fact that Nigeria is more dominated by oil and gas energy sources, they are still much endowed with renewable energy sources (see Table 2.3). As such, development and utilization of renewables should be given high priority, especially in the light of increased awareness of the adverse environmental impacts of fossil-based generation (Olayinka, 2012).

Table 2.3: Nigeria Potential Renewable Energy (source: energypedia, 2020)

S/N	**Energy Sources**	**Estimated Reserve**
1	Large Hydropower	11,250 MW
2	Small Hydropower (<30 MW)	3500 MW
3	Fuel Wood	11 million hectares of forest and woodland
4	Municipal Waste	30 million tonnes/year
5	Animal Waste	245 million assorted animals in 2001
6	Energy Crops and Agricultural Residue	72 million hectares of agricultural land
7	Solar Radiation	35 – 70 kWh/ m^2/ day
8	Wind	2 – 4 m/s at 10m height

Meanwhile, renewable energy are key components of sustainable growth and development not only in the Nigerian economy, but virtually in the world. Some of the reasons for this statement include (Olayinka, 2012):

- They generally cause less environmental impact than other energy sources. The implementation of renewable energy technologies will help to address the environmental concerns that emerged due to greenhouse gas emissions such as carbon dioxide (CO_2), oxides of nitrogen (N_xO), oxides of sulfur (SO_x), and particulate matters because of power generation from oil, natural gas, and coal. A variety of renewable energy resources provide a flexible array of options for their use.
- They cannot be depleted. If used carefully in appropriate applications, renewable energy resources can provide a reliable and sustainable supply of energy almost indefinitely. In contrast, fossil fuel resources are diminished by extraction and consumption.
- They favor system decentralization and local solutions that are somewhat independent of the national network, thus enhancing the flexibility of the system and providing economic benefits to small, isolated populations

Renewable energy has an important role to play in both the urban rural areas of Nigeria. Unlike fossil fuels, renewables have supply security because has constantly been replenished from natural resources as they are used. Some of the sure benefits of renewables, according to Olayinka (2012), include:

- Their rate of use does not affect their availability in the future, hence are inexhaustible.
- The resources are generally well distributed all over the world, even though wide spatial and temporal variations occur. Therefore, all regions of the world have reasonable access to one or more forms of renewable energy supply.
- They are clean and pollution-free, hence are sustainable natural form of energy.
- They can be cheaply and continuously harvested and are therefore a sustainable source of energy.

2.5.1.1 Hydro Energy

With large water bodies and some few natural water falls in Nigeria, if properly harnessed, should provide the most affordable and accessible option to option to off-grid electricity services, especially to the rural areas. However, this is not so, as hydropower currently accounts for only 29% of the total electrical power supply.

Hydropower is an essential energy sources harnessed from water moving from higher to lower level as an effect of gravity, primarily to turn turbines and generate electricity (Owusu and Asumadu-Sarkodie 2016). From a recent research, virtually all parts of Nigeria have potential sites for SHP with an estimated total capacity of 3500MW. This indicates Nigeria's high potential of generating electricity through hydropower. One of the hydropower private companies in Nigeria, NESCO, with the assistance of the government installed eight SHP stations with an aggregate capacity of 37.0 MW. Most of these stations are found in Niger state and around Jos at Kwall and Kurra Falls (Riti and Shu, 2016).

2.5.1.2 Solar Energy

Solar energy are renewables that have their base sources technologies draw directly from the Sun's energy. Some renewables such as wind and ocean thermal, uses solar energy after they have been absorbed on the earth and converted to other forms (Owusu and Asumadu-Sarkodie, 2016). Solar energy is obtained from sun irradiance to generate electricity using PV, and this renewable has known to already reach the inflection point (Bassam et al., 2018).

Nigeria lies within a belt of high intensity from the sun, hence has higher potential for solar energy. The National Renewable Energy and Energy Efficiency Policy (NREEEP, 2015) stated that Nigeria has well distribution of solar radiation which varies from about 12.6 MJ/m^2 day^{-1} in the coastal latitudes to about 25.2 MJ/m^2 day^{-1} in the fair North, likewise an average sunshine of six hours in a day. With this laid fact, it is possible to generate 1850×10^3GWh of solar electricity in a year (which is over 100 times the current grid electricity consumption level in Nigeria), even if solar module were used to cover 1% of Nigeria's land area. Notwithstanding, with the pilot projects, surveys, and studies undertaken by the Sokoto Energy Research Center (SERC) and the National Center for Energy Research and Development (NCERD) under the supervision of the Energy Commission of Nigeria (ECN), several PV-water pumping, electrification, and solar-thermal installations (such as solar cooking, solar crop drying, solar incubators, solar chick brooding, etc.) have been established. However, Nigerian need more utilization and development of solar energy, not just in the urban area but also in the rural areas.

2.5.1.3 Wind Energy

Wind energy harness kinetic energy from moving air. In Nigeria, this energy is available in the coastal region at annual average speed of about 2m/s and in the northern region of about 4m/s. With the density of air of about 1.1 kg/m^3, the wind energy intensity perpendicular to the wind direction ranges between 4.4 W/m^2 in the coastal region and 35.2W/m^2 in the northern region. These laid facts have already proven that Nigeria has high potential of wind energy. Still, only few wind-energy plants have been installed over the years, especially in the northern part of the country. This has however, resulted to low share of wind energy in the national energy consumption, with no commercial wind plans connected to the national grid. However, promising attempts have being made in the Sokoto Energy Research Centre (SERC) and Abubakar Tafawa Balewa University, Bauchi, to provide the capability for the development of wind energy technologies (Riti and Shu 2016).

2.5.1.4 Bioenergy

Bioenergy are renewables derived from biological sources such as crops (such as sweet sorghum, maize, and sugarcane), forage grasses and shrubs, animal wastes, and wastes arising from forestry, agriculture, municipal, and industrial activities. This renewable source is not common in Nigeria, but lot of research works have been carried out on it. Most developed countries like the United States, utilizes bioenergy for transport using biodiesel, electricity generation, cooking and heating. According to some research carried out on biofuel, feedstock such as water lettuce, water hyacinth, dung, cassava leaves, and processing waste, urban refuse, solid (including industrial) waste, agricultural residues, and sewage, are employed in Nigeria for economically feasible biogas production (Riti and Shu 2016).

Nigeria, with long practice in agricultural activities, produces fresh animal waste of about 227,500 tons every day. Since researchers has proven that 1kg of fresh animal waste can produce about 0.03 m^3 biogas, then Nigeria has great potential of producing over 6 million m^3 of biogas every day, when properly harnessed (Akinbami, 2001). Other important biomass resources associated with lumber industry that can be transformed into biofuel are sawdust and wood wastes.

2.5.2 Implications of Energy Transition Dynamics in Nigeria

Currently the world is undergoing transition into renewable energy due to depletion and environmental impacts of fossil-fuel sources, energy security and volatile nature of crude oil prices. However, virtually not all countries would experience this energy-shift, even if they would not at the same time. This maybe as a result of high cost of investing into renewable energy resources. Therefore, it may be easier for developed countries because their high financial capabilities and technology advancement, but how about developing and underdeveloped countries, especially those in Africa? In Africa’s emerging petroleum economies, petroleum resources are readily available and new reserves are been discovered by the day. What will then happen to countries like Nigeria, who have solidly relied on fossil fuel revenues for economic growth and development over decades? What would happen to the oil and gas discoveries since 2010? Will they be left unexplored and unexploited? What fate does this leave the Nigerian economy when she fully adopts low-carbon emitting energy resources? What would happen to the oil and gas industries and the resources that have been put together for effective oil and gas production? These and many more are questions would take time to answer. However, it’s obvious that Nigeria is not going to mop up oil and gas reserves even in 20 years’ time.

As the pace of energy transition presents opportunities and advantages, it also lay down challenges. While it is important to adopt energy transition by enumerating its benefits to the Nigerian economy and the environment, it is also vital to investigate the economic implications of these energy transition. And the results from the investigations would help the government map out realistic plans, understand deliverable and targets, carry out economic analyses, carry out adjustments where necessary to effectively manage the de-carbonization of energy system for a very long time, if not for ever (Nwaneto et al. 2018).

2.5.2.1 Technical and Economic Implications

The transformation into low-carbon energy resources, obviously, is associated with both technical and economical efforts. Most likely, the technologies use in oil and gas companies to supports the production of fossil fuel and its equivalents, do not support the production of renewables, therefore there is need for upgrade or change of technology to accomplish this energy transition. This upgrade would require more financial support, as most renewable energy options are inherently more expensive to scale up than energy derived from fossil fuels (Yoshida et al., 2009).

In terms of economic effort, all de-carbonization scenarios characteristically model a transition from energy systems based on high fuel and operational costs, to systems based on higher capital expenditure (CAPEX) and lower fuel costs (Nwaneto et al., 2018). Total transition into low carbon will doubtlessly require huge investment cost in form of the total cost of developing and constructing renewable energy-based plant, excluding any grid-connection charges (CAPEX). For instance, for 20% of Nigerian electricity demand to be supplied through renewables would require over NGN 19 trillion or USD 49 billion, based on the average of 1USD to NGN 391.4, of which solar power-plants alone amounted to about NGN 2.774 trillion (Nwaneto et al., 2018). This estimated investment cost is very high for Nigerian Federal Government, and it is far beyond the Nigeria 2021 fiscal year budget of NGN 13.588 trillion (BBC News, 2020). However, further cost savings could be made by deploying grid-scale solar power as 6.83 GW of power can be generated with about NGN 1.72 trillion, though at the expense of increased complexity of grid management (Nwaneto et al., 2018).

2.5.2.2 Implications on Policies

As demand for energy increases, low carbon energy policies will have significant impact on the oil and gas sector basically from three directions irrespective of the country. According to Johnston et al. (2020), the first direction is the deviation from policies that have supported oil and gas production into policies that involves carbon taxes as a way of reducing GHG emissions. Secondly, a suite of policies that are intended to encourage the use of substitute technology and fuel, particularly renewable energy, for instance Green New Deal-type policies, which aim for 100% renewables. With this, the oil and gas industries might seek to go through criminal and civil prosecution for alleged past misbehavior on climate change. The third policy direction deals with an alternative to the traditional linear economy in which we keep resources in use for as long as possible, extract the maximum value from them while in use then recover and regenerate products and materials at the end of each product service life. However, these policies would have great impact on the downstream operations of the oil and gas companies through their refining, fuel logistics, and petrochemical businesses.

2.5.2.3 Implications on Industrial Competitiveness and Production Cost

Transiting into low carbon energy will have great impact on industrial competitiveness and production cost, as well as GDP.

Several factors, however, influence the magnitude of the impacts of energy transition on GDP. According to Nwaneto et al. (2018), these factors may include but not limited to;

- The structure of the Nigerian economy.
- The costs of alternative energy sources for example fossil fuel prices, technological costs of fossil fuel driven energy sources, etc., prices of electricity, investment in renewables deployment, and.
- The sources of infrastructure, equipment and if the required services are imported or locally sourced.

The National Bureau of Statistics (NBS) revealed that the production of oil and gas accounts for high share of the Nigerian GDP, of over 8.73% of the total real GDP in the third quarter of 2020. This implies that the transition of energy would have great effect on fossil fuel exporters in the short term in accordance with the degree of diversification in the Nigerian economy, due to reduction in revenues from export and local sale of petroleum products and notably, high investment costs of renewables. However, this negative impact can be aborted by investing on renewable energy resources in a way to create ripple effect on all sectors of the economy. This can be achieved through a clear-cut but well-thought-out strategy, favoring both the local manufacturers and service providers in renewables deployment contracts, and can eliminates bottlenecks that plague high employment generating and renewables deployment supporting sectors of the economy such as construction, manufacturing, and engineering sectors (Nwaneto et al., 2018)

CHAPTER THREE

3.0 RESEARCH METHODOLOGY

3.1 Modelling Approach

The LEAP computer modelling software was employed to analyze Nigeria energy system and climate mitigation. This modelling approach covers energy extraction, conversion, transmission, and consumption through energy devices, in agriculture, service, industry and residential sectors of the Nigerian economy. This modelling approach generally estimate energy demand using different approaches depending on the modeler, research question and the level of data available. These energy demand estimations include final energy demand, useful energy demand, stock and transport analysis (Dioha and Emodi, 2019). The energy demand module calculates the final energy demand activity level, energy intensity or energy use per unit of activity using Equation 2.16, and also the carbon emissions of the final energy consumption using Equation 2.18 (Ibitoye, 2013; Ouedraogo, 2017).

One importance of using this modelling approach is its ability to conduct cost-benefit analysis for different scenarios, which requires the discount rate to calculate the NPV. However, economic variables such as population, number and size of household, gross domestic product, etc., were needed, and key assumptions were made.

3.2 Model Structure and Data

3.2.1 Overview of the Nigerian LEAP Model (NLM)

The Nigerian LEAP Model (NLM) was developed for assessing the current energy consumption pattern and for simulating alternative energy futures, along with greenhouse gas emissions from year 2018 to year 2060. The year 2018 was considered as the base year and 2060 as the end year of the analysis. In the NLM, four end-use sectors were considered; residential, agricultural, industry and service sectors.

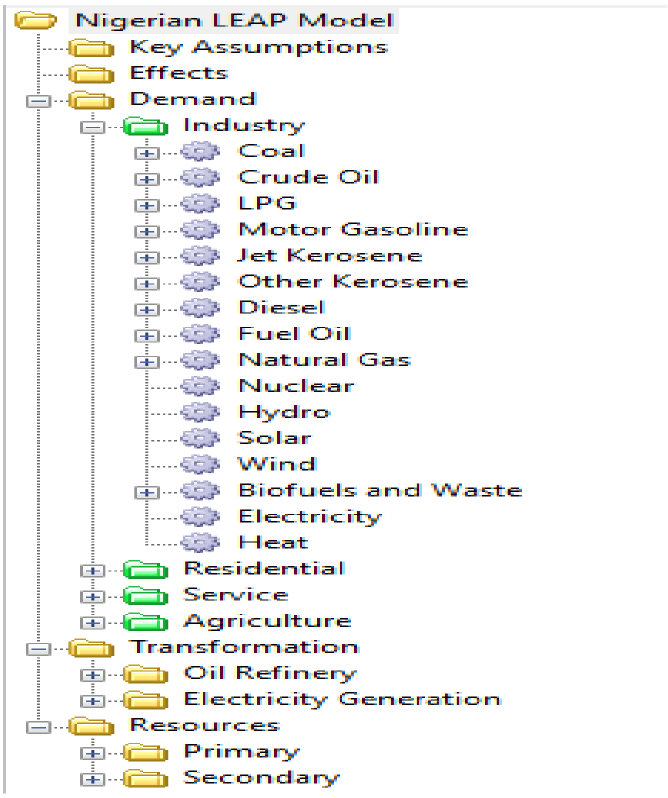

Figure 3.1: Tree Structure of the Nigerian LEAP Model (NLM)

3.2.2 Sources of Data

Lot of data were needed for the development of the Nigerian LEAP Model. These data were majorly for the year 2018.

The demographic data of Nigeria (population and growth rate) was obtained from the 2018 World Bank Database (www.data.worldbank.org).

The Nigeria energy data balances were obtained from the ***International Energy Agency 2018 Data and Statistics***. The GDPs from the Agricultural, service and industrial sectors, likewise their growth rates were from the excel file of the ***National Bureau of Statistics Final Draft Q4 2018***, with the monetary conversion of 1USD to 360NGN.

For analyses on Nigeria resources and oil refining, data were obtained from ***bp Statistical Review of World Energy*** (http://www.bp.com/statisticalreview), ***Mini-Grid Market Opportunity Assessment: Nigeria*** (Lane et al., 2018), ***Full Report Oil and Gas Industry Audit Report*** (Nigeria Extractive Industries Transparency Initiative, NEITI, 2018), ***2018 Nigeria Oil and Gas Industry Annual Report*** (Department of Petroleum Resources), ***Solid Minerals Audit 2018 Report*** (Prepared by TajudeenBadejo& Co, NEITI 2018), and ***A Review of the Power Sector in Nigeria*** (Buharimeter; Center for Democracy & Development).

3.2.3 Key Assumptions

However, due to insufficient availability of data, some assumptions were made and some values/data were calculated.

- Regarding the growth rate of GDP in the sectors, the data obtained from NBS were used. These growth rates were assumed in all scenarios regardless of the policies involved.
- The final energy intensities and the fuel shares for the four sectors were estimated using Equation 2.17 and 2.19, respectively. These values were assumed to change with the growth rates of the sectors GDP and the household growth rate of the residential sector.
- The importation cost for fuel used was $0.61 per liter, according to NNPC head MeleKyari (www.energyvoice.com). This importation cost was assumed the same for all the considered oil products.
- The discount rate was assumed at 10% and the inflation rate was assumed 12.1%, based on the headline inflation rate as reported by the CBN in March 2012.

3.2.4 Technologies and Fuels

Under the transformation section, oil refinery was looked into and the output fuels considered were:

- Liquefied Petroleum Gas (LPG)

- Residual fuel oil (base oil and fuel oil)
- Gasoline
- Diesel
- Kerosene
- Jet Kerosene

3.3 The Nigerian LEAP Model (NLM) Scenario Design

Scenarios are generated to describe how energy system will evolve in the future under various conditions. In NLM, the Reference Scenario (REF) and Low Carbon Scenario (LOW) were designed for exploring the energy demand and greenhouse gases mitigation potentials of the energy policies of the Nigeria's economy between the years of analysis.

3.3.1 Current Account

3.3.1.1 Demand

The demand is divided into residential, industry, agriculture and service (together with transportation). In 2018, a total energy of 5.78 billion GJ (137966 ktoe) were consumed by these sectors, with residential sector taking the lead consumption rate of 4.42 billon GJ while agricultural sector consuming the least of 0.20 million GJ on only oil products (IEA, 2018). The relative demand by each sector is shown in Figure 3.2.

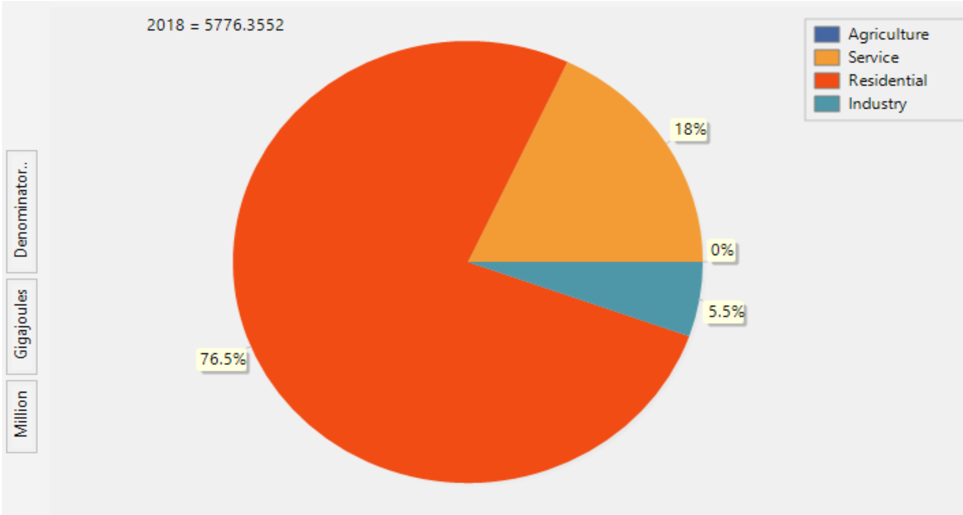

Figure 3.2: Nigeria Economy Sector Useful Energy Demand in 2018 (Million GJ)

The residential sector demand was based on persons. According to data provided by World Bank, Nigeria population in 2018 was 195.90 million persons with a growth rate of 2.60%. From IEA records, the total energy consumption of these persons in 2018 was 105563 ktoe, which mainly is produced from LPG (0.07%), kerosene (0.51%), electricity (1.27%), biofuels and wastes (98.20%). In the industrial sector, 7522 ktoe energy were consumed mainly from coal (0.39%), LPG (0.01%), fuel oil (6.13%), Natural gas (33.44%), electricity (4.21%), Biofuels and wastes (55.82%). Also, in the service sector, a total of 24877 ktoe of energy were consumed from Motor gasoline (54.27%), jet kerosene (0.79%), kerosene (0.004%), diesel (31.23%), electricity (2.45%), and biofuels and wastes (11.26%). Finally, the total energy consumed in the agricultural sector was 4.00 ktoe from diesel only.

Demand Cost: The sectors demand cost was calculated based on the activities in each sector. Due to insufficient availability of data, the activity cost of agriculture, service and industry sectors were assumed to be 50% less than the 2018 sector GDPs. While the activity cost of the residential sector in 2018 was assumed to be 50% less than the 2019 expenditure on fuel/light of NGN 2016.20 billion, according to NBS (2020).

3.3.1.2 Transformation

In the transformation/supply section, “oil refinery” was created based on the cost, capacities, lifetime, energy losses and historical production. Actually, five outputs from the Nigerian oil refinery were considered; LPG, Residual fuel oil, diesel, Kerosene, gasoline, and jet kerosene. The output price, according to the Centre of Petroleum Energy Economics and Law (CPEEL, 2020), was between $21.00 per barrel to $30.00 per barrel. In this research, an average value output price of $25.50 per barrel was used, and was the same value for all output fuels. However, it was estimated that the cost incurred for oil refinery module as a whole in Nigeria is $100 million

Also, from the report of bp Statistical Review of World Energy, Nigeria production in 2018 was 96.40 million toe, with capacity of 344000 bpd of production capacity; and having production loss of 7.60% according to the Full Report Oil and Gas Industry Audit Report (NEITI, 2018). The lifetime used in this research was 49.03years, according to the 2018 Nigeria Oil and Gas Industry Annual Report (DPR, 2018).

3.3.1.3 Resources

Nigerian resources was grouped into primary and secondary.

Primary Resources: These includes wind, solar, hydro, Nuclear, Crude oil, Natural gas, Coal Bituminous and biomass. According to data obtained from bp Statistical Review of World Energy, Nigeria in 2018, have oil and gas reserves of 37 billion barrel and 5.40 trillion cubic meters, respectively. Also, from the Solid Minerals Audit 2018 Report Prepared by Tajudeen Badejo & Co (NEITI 2018), Nigeria had a coal reserve of 2.75 billion metric tonnes. However, the yields of renewable resources in Nigeria (wind, solar, hydro and biomass) assumed to be unlimited in this research.

Among the primary resources, Nigeria only exports Natural gas and crude oil. As recorded by the NEITI 2018, Nigeria federation exported 55858 mbbl of crude oil with export benefit of $12.38 per Gigajoules. Also, $10.09 per Gigajoules were obtained from the sales of federation natural gas of 633.55 thousand metric tonnes in 2018.

Secondary Resources: These include heat, jet kerosene, kerosene, LPG, diesel, residual fuel oil, gasoline and electricity. According to 2018 Nigeria Oil and Gas Industry Annual Report (Department of Petroleum Resources), Nigeria resource import are majorly oil products. These include LPG, aviation fuel, base oil, fuel oil, household kerosene, and petrol. The Nigeria resource import and import cost in 2018 are listed in table 3.2. However, the import cost of $0.61/liter (www.energyvoice.com) was assumed for all imported resources.

Table 3.1: Nigeria 2018 Resource Imports and Quantities(source: 2018 Nigeria Oil and Gas Industry Annual Report, DPR)

S/N	Resource Imports	Import quantity (Liters)
1.	Jet kerosene (Aviation fuel)	820010017.19
2.	Kerosene (household)	317461912.35
3.	LPG	375590660.45
4.	Diesel	4424817932.53
5.	Residual fuel oil (Fuel oil + base oil)	(43786839.35 + 450204837.02)
6.	Gasoline (petrol)	19647782753.24

3.3.1.4 Greenhouse Gas Emissions Analysis

Greenhouse gases (GHG) emissions from demand and oil refinery section of the Nigerian LEAP Model (NLM). The analyses was carried out by creating effect branches under each relevant demand technology (coal, crude oil, LPG, Motor gasoline, jet kerosene, other kerosene, diesel, biofuels and wastes, fuel oil and natural gas) for each sector and oil refinery feedstock fuel (crude oil). To create these effect branches, we selected from the default IPCC Tier 1 emission factors stored in the TED database by right-clicking on the technology and then selected the "*Add Multiple Effects*" option. In the case where the IPCC Tier 1 technologies do not contain entries for all fuels, the closest match entries were selected.

3.3.2 Reference Scenario (REF)

The Reference scenario (REF), also called Baseline scenario, was developed based on the past trend and base year data of energy demand growth and population growth rate in Nigeria. In this scenario, it was assumed that there is no new policy, and any future government targets or policies were excluded. Hence it was expected that the demand and supply of energy (transformation) will continue in the same trend.

In the REF, the demand growth rate for all the sectors, likewise the useful energy intensity, were assumed proportional to the GDP and population growth rate. The residential demand growth rate and useful energy intensity is to be the same as the population growth rate of 2.59%. For the agriculture, industry and service sectors, the demand and useful energy intensity growth rate were the same with their GDP growth rates of 2.12%, 1.69% and 3.05%, respectively.

Regarding the transformation section of oil refinery, the historical production growth rate of 5.40% and exogenous capacity growth rate of 1.70%, were from the data provided by bp Statistical Review of World Energy, 2019.

3.3.3 Low Carbon Scenario (LOW)

The Low Carbon Scenario (LOW) was designed based on Nigeria's targets to harness her renewable energy resources in order to complement its fossil fuel consumption and guarantee energy security, and at the same time reducing the amount of GHG emissions, hence transiting to low-carbon energy system.

In this LOW, demand for non-renewables (oil products inclusive) in all sectors were reduced to one-hundredth of the REF, except for the LPG used in the residential sector (same with the REF). In the other sectors, hydro, solar and wind energy demand were assumed to contribute 5% and 20% in 2020 and 2030, respectively. Also, biofuels and wastes were assumed to contribute 20% by in all sectors.

CHAPTER FOUR

4.0 RESULTS AND ANALYSIS

Based on the various parameters of socioeconomic development listed in Chapter 3, the results obtained for the REF and LOW scenarios using the Nigeria LEAP Model (NLM), are discussed in this section.

4.1 Energy Demand Projections

The energy demand for the two scenarios were projected from the base year of 2018 to the end year of 2060 (see Figure 4.1 and 4.4). As a result of increase in population, urbanization, income, GDP, etc., the energy demand under the two scenarios has continuous increase but at different growth rate until the end of the analysis.

4.1.1 Reference Scenario

Under the REF scenario, the total energy demand in 2018 from the four sectors of the Nigeria economy was 2.85 billion Barrels of Oil Equivalents (BOE). This energy demand is estimated to increase to 8.79 billion BOE in 2040, and with an average growth rate of 10.80% it projected to reach 24.68 billion BOE by 2060 (see figure 4.1).

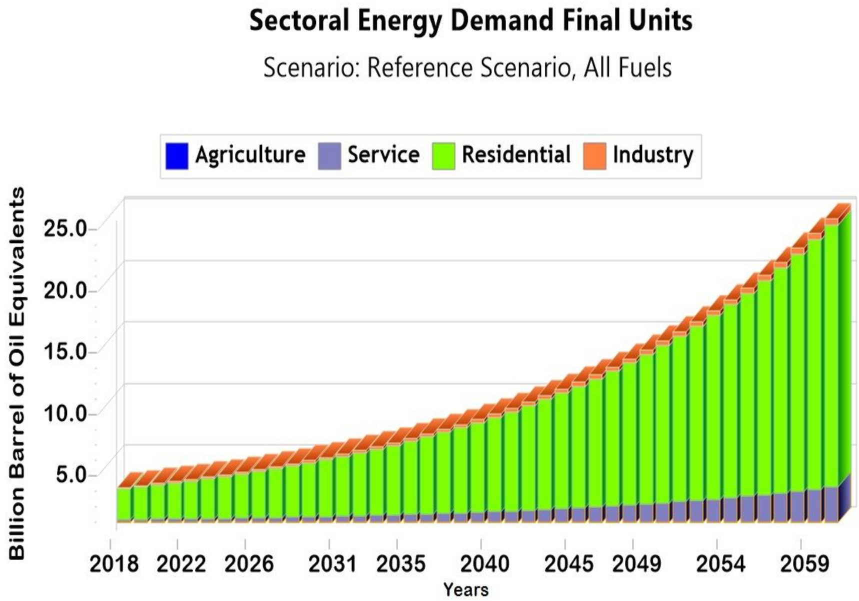

Figure 4.1: Nigeria Sectoral Energy Demand Final Units (REF)

Among the four sectors of the Nigerian economy, the residential sector consumes more energy, and agricultural sector consumed the least. In 2060, the total energy consumed would reach 24.68 billion BOE, and residential sector is expected to account for 86.3%, while industry and service sectors accounting 2.1% and 11.6%, respectively with the remaining percentage for agricultural sector (see Figure 4.2).

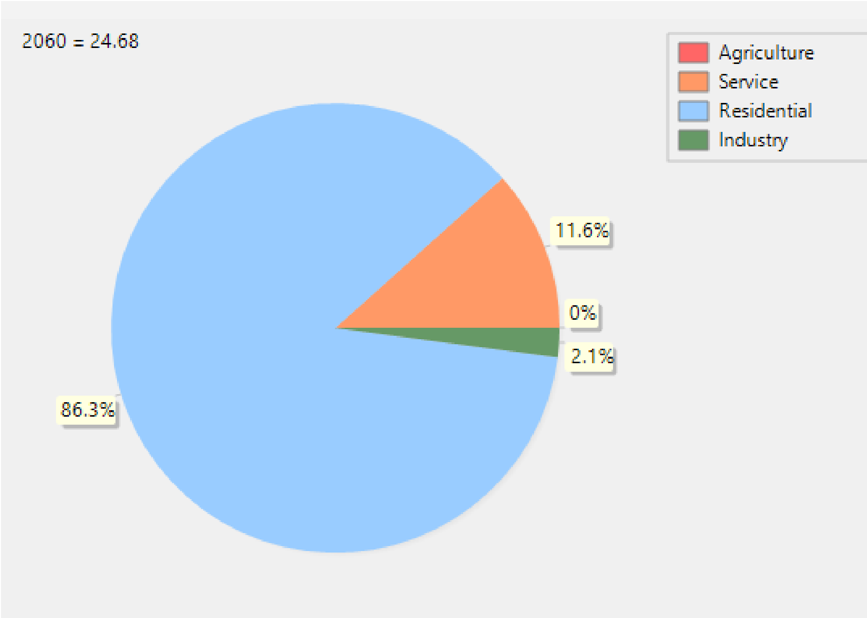

Figure 4.2: REF Scenario Sectoral Energy Demand (2060, billion BOE)

Also, as clearly seen in Figure 4.3, the dominant energy demand in the REF scenario is biomass with total consumption of 2.65 billion BOE and 22.50 billion BOE, in the base year and end year, respectively. This was followed by gasoline and diesel with energy demand of 0.10 and 0.06 billion BOE, respectively in the base year; and expected end year values of 1.28 billion BOE and 0.73 billion BOE, respectively. The least consumed energy is coal bituminous, with a base and end year value of 0.23 million BOE and 0.96 million BOE, respectively.

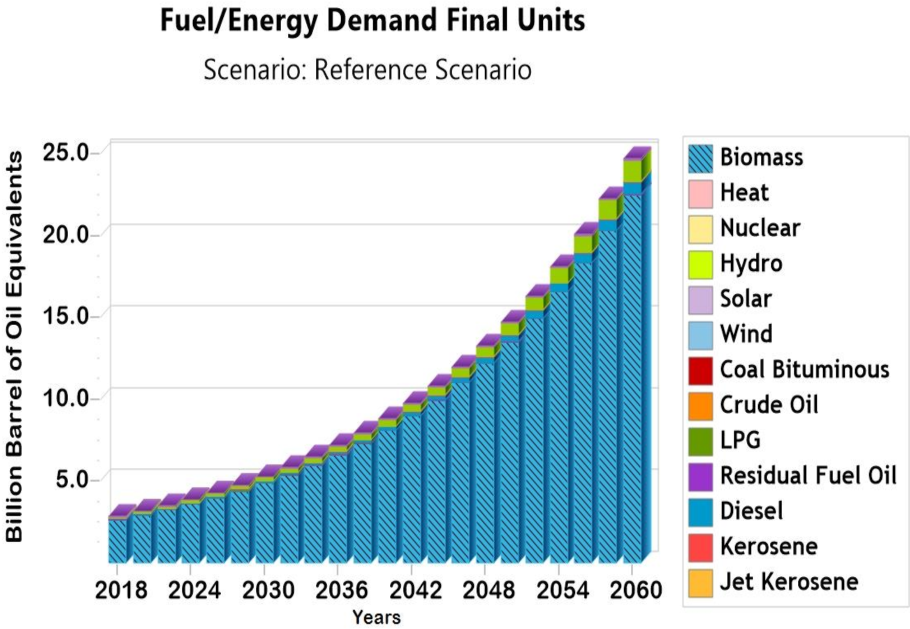

Figure 4.3: All Sector Nigerian Energy/Fuel Demand (REF)

The high consumption of biomass was majorly from the residential and industrial sectors. In Nigeria, greater number of households, especially in rural areas, utilizes more of local cooking and lighting technologies such as three stone open fire, wood fuel, charcoal stove, etc. In the industrial sectors, especially the emerging bio-refineries, there are high utilization of first generation of feedstock (such as sugarcane, starch-based crops, and oil seeds) for bio-fuel production. For instance, NNPC identifies sugarcane, sweet potatoes, and maize as the main raw materials for bio-ethanol production (Ben-Iwo, et al., 2016). Likewise, the high demand of gasoline and diesel is because of increasing numbers and usage of vehicles, generators, aircraft etc. in Nigeria transportation system.

4.1.2 Low Carbon Scenario

With the outlaid assumptions and energy targets for Nigeria to attain a low carbon energy system, the demand for energy continued to increase. In the LOW scenario, the projected energy demand from all sectors of the economy is expected to reduce to 2.14

billon BOE by 2030, from the base year energy demand of 2.85 billion BOE (see Table A.2 in Appendix A). However, from 2031, there seems to be gradual increase in energy demand and with an average demand growth rate of about 3.90%, the energy demand is expected to reach 10.91 billion BOE by 2060, which is more than half of the REF scenario (see Figure 4.4 and 4.5).

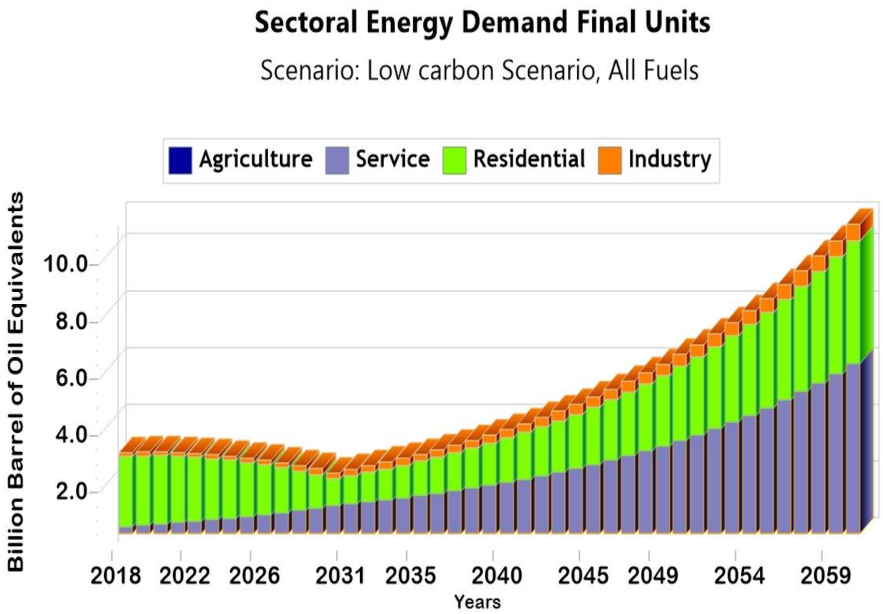

Figure 4.4: Nigeria Sectoral Energy Demand Final Units (LOW)

Among the four sectors of the Nigerian economy, the service sector still has the highest rate of energy demand, then followed by the residential sector, with the least been agricultural sector. By the end year with a total of 10.91 billion BOE energy demanded, it is expected that the energy demand from the service and residential sector would be 5.98 and 4.34 billion BOE, respectively. And the service sector accounting 54.8% of the total energy demand, while the residential and industry sectors will account 39.8% and 5.4%, respectively and the remaining percentage goes for agricultural sector (see Figure 4.5). The high energy demand from the residential sector is mostly as a result more usage of cooking technologies and lighting.

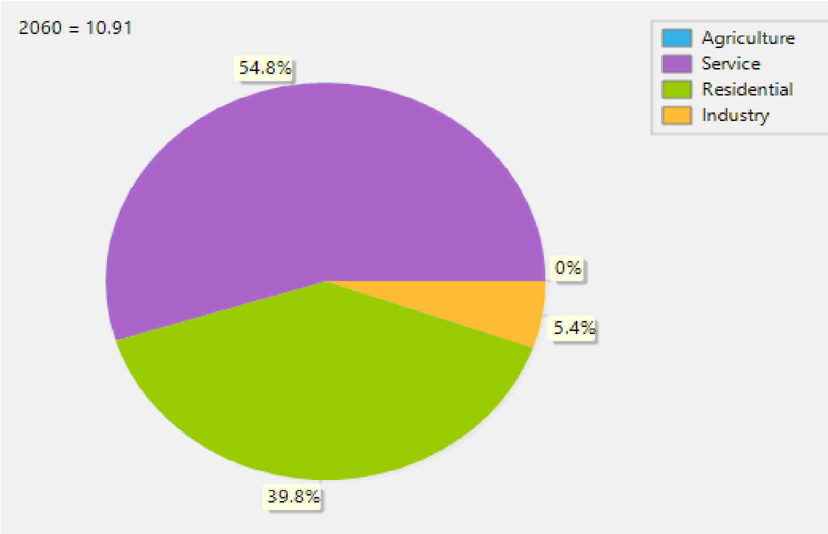

Figure 4.5: LOW Scenario Sectoral Energy Demand (2060, billion BOE)

In the LOW scenario, there are more utilization of renewable energy resources than the non-renewables, due to the FGN target of minimizing emissions of greenhouse gases. Non renewables energy resources such as Natural gas, gasoline, jet kerosene, household kerosene, diesel, residual fuel oil, LPG and coal bituminous, were observed to have continuous decline, which would also result in decrease in their supplies. In 2060, among other energy resources demanded, biomass have the highest demand of 5.97 billion BOE, then followed by wind, solar and hydro, each having 1.64 billion BOE, see Figure 4.6.

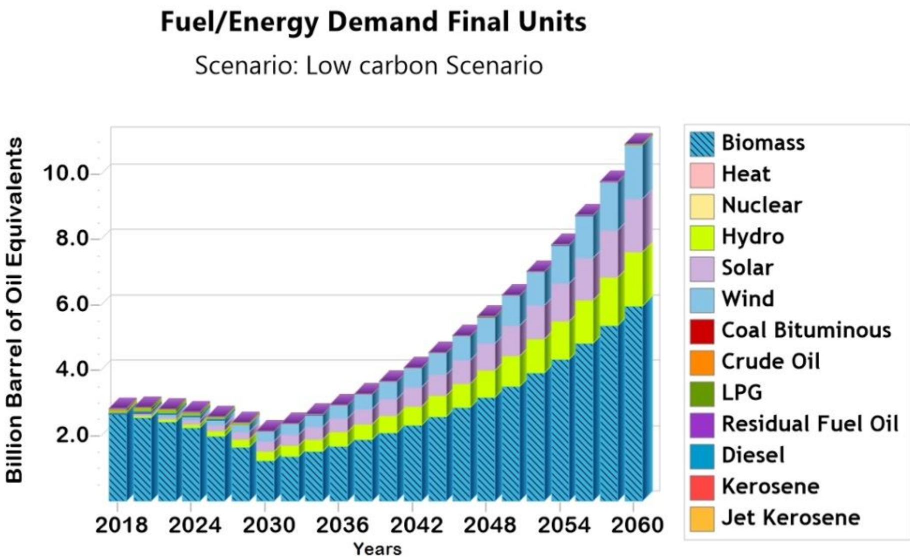

Figure 4.6: All Sector Nigerian Energy/Fuel Demand (LOW)

4.1.3 Scenario Comparison on Energy Demand Projections

The total energy demand from all the sectors of the Nigeria economy (agriculture, service, industry and residential) projected by the Nigerian LEAP Model for the two scenarios for the analysis periods are displayed in Table 4.1and Figure 4.7.

Table 4.1: Nigeria Energy Demand Projection

Energy Demand	**2018**	**2020**	**2025**	**2030**	**2040**	**2050**	**2055**	**2060**
LOW Scenario (Billion BOE)	2.85	2.88	2.66	2.14	3.66	6.30	8.29	10.91
REF Scenario (Billion BOE)	2.85	3.15	4.07	5.26	8.79	14.72	19.05	24.68

From the results obtained, there seems to be steady increment in energy demand from all sectors of the Nigerian economy under the REF scenario, but at different growth rates. But in the LOW scenario, energy demand was seen to increase from 2018 to 2020, then began to decrease from 2021 (2.85 billion BOE) to 2030 (2.14 billion BOE). However, the demand was observed to start increasing from 2031 (2.26 billion BOE) till the end year of the analysis (10.91 billion BOE). However, between year 2018 and year 2019, there were no obvious differences in energy demand under the two scenarios. But from 2020, energy demand from the REF scenario seems obviously higher than that of the LOW scenario. With an average growth rate of 5%, the energy demand under the REF scenario will attain 24.68 billion BOE (equivalent to 3.43 billion toe), by 2060.

Also, having an average growth rate of 3.9% from 2031, the projected energy demand under the LOW scenario is10.91 billion BOE (equivalent to 1.51 billion toe), by year 2060. The end year energy demand under the LOW scenario is more than half of the REF scenario for same year. This low demand rate is explained by the huge potential of Nigeria for improving energy efficiency, which will in turn reduce their consumption rate. With the low energy demand rate in the LOW scenario, the aftermath of consuming fossil fuels will be reduced compared to the REF scenario.

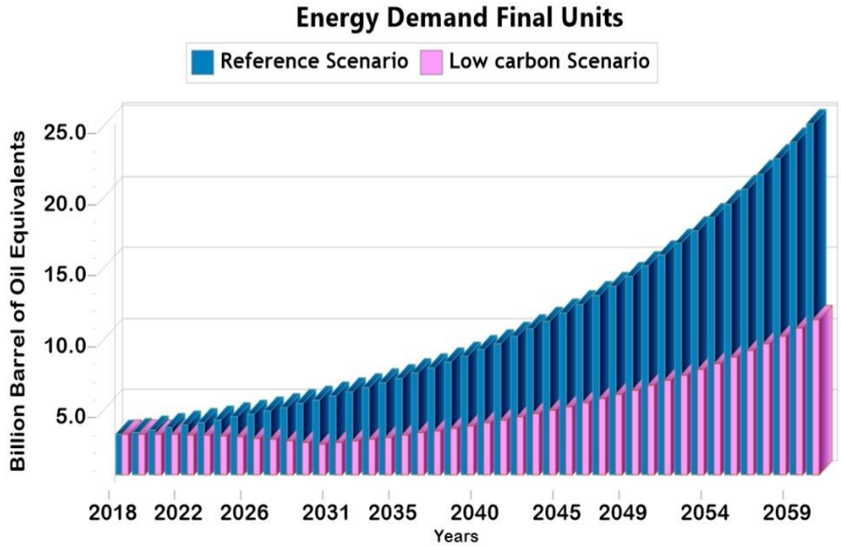

Figure 4.7: Nigeria Energy Demand (REF and LOW)

4.2 Transformation Projection

Under the transformation/supply analysis, the processes involved only in the Nigeria oil refinery were considered.

4.2.1 Reference Scenario

With the available data utilized in this research, the total crude oil production from Nigeria oil reserves in the base year was 132.21 million BOE, with exogenous capacity of 132.21 million BOE/year. The output fuels produced in the base year were gasoline (79.16 million BOE), jet kerosene (1.16 million BOE), household kerosene (3.13 million BOE), diesel (45.57 million BOE), residual fuel oil (2.7 million BOE) and LPG (0.50 million BOE). The crude oil production is forecast to increase with average growth rate of 1.7%, hence attaining 161.85 million BOE at an exogenous capacity of 161.85 million BOE/year by 2030 and 268.38 million BOE at an exogenous capacity of 268.38 million BOE/year by 2060 (see figure 4.8 and 4.9).

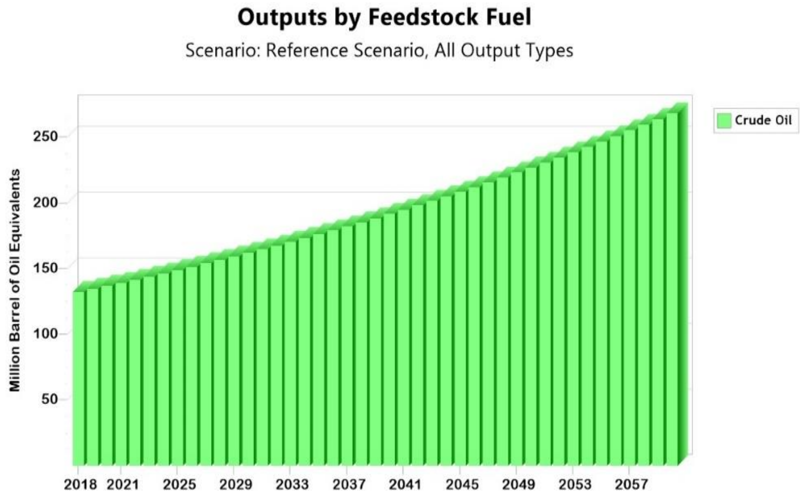

Figure 4.8: Nigeria Oil Refinery Output by Feedstock Fuel (REF)

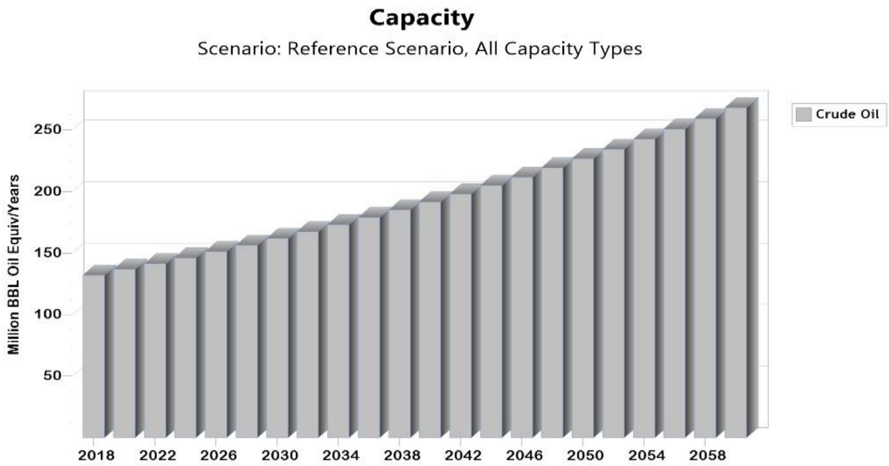

Figure 4.9: Nigeria Oil Refinery Annual Exogenous Capacity (REF)

With an increasing exogenous capacity and increasing petroleum product demand, the production by output fuels continues to increase (see figure 4.10). In the end year and with an exogenous capacity of 268.38 million BOE/year, gasoline have the highest of 164.38 million BOE, followed by diesel (94.61 million BOE), household kerosene (4.46 million BOE), jet kerosene (2.40 million BOE), residual fuel oil (1.84 million BOE) and then the least being LPG (0.70 million BOE). Therefore, the quest for more oil reserves and the demand for petroleum products under the REF scenario, results to increasing oil and gas exploration and production.

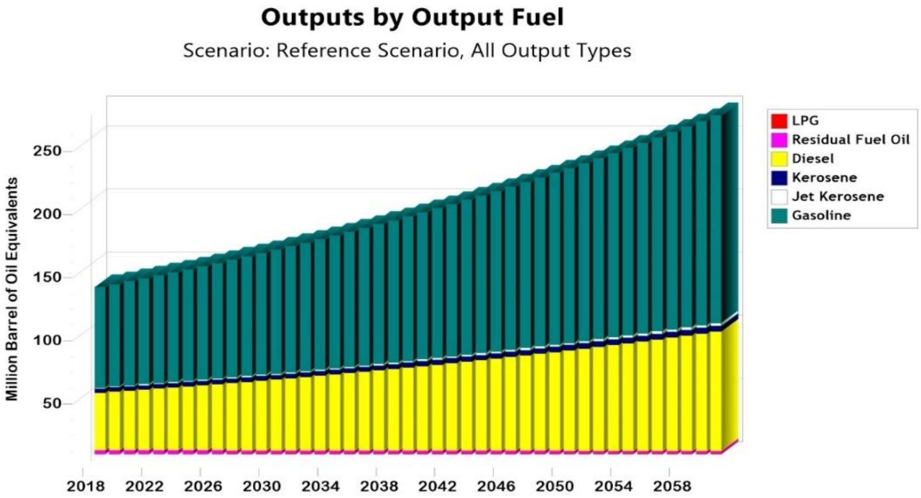

Figure 4.10: Nigeria Oil Refinery Output by Output Fuels (REF)

4.2.2 Low Carbon Scenario

Under LOW scenario, the total production from the Nigerian oil reserves in the base year was 132.21 million BOE. With an average growth rate of 1.7%, crude oil production is projected to increase to 141.43 million BOE in 2022 at an exogenous capacity of 141.43 million BOE/year.

However, there was rapid decline in crude oil output with a negative growth rate of 4.3% in 2023 (135.41 million BOE at a capacity of 143.84 million BOE/year), then to 2030 (94.63 million BOE at a capacity of 161.85 million BOE/year) with a negative growth rate of 85%, see figure 4.11. This decline was because of less demand and consumption of petroleum products to achieve FGN target of reduction in GHG emission and climatic changes. This is expected to cause lot of destabilizations in the oil and gas industries. Nevertheless, since Nigeria still depend on crude oil for revenue, there seems to gradual increment of crude oil output with a positive growth rate of 5.9%, from 2031 (4.9 million BOE) till the end year (26.13 million BOE), but far less than the production from the base year (see figure 4.12). This gradual increase would be because of energy diversity, as there would be gradual utilization of both renewables and non-renewable energy resources, reducing Nigeria's overdependence on crude oil, therefore sufficiently meeting the energy demand of the people.

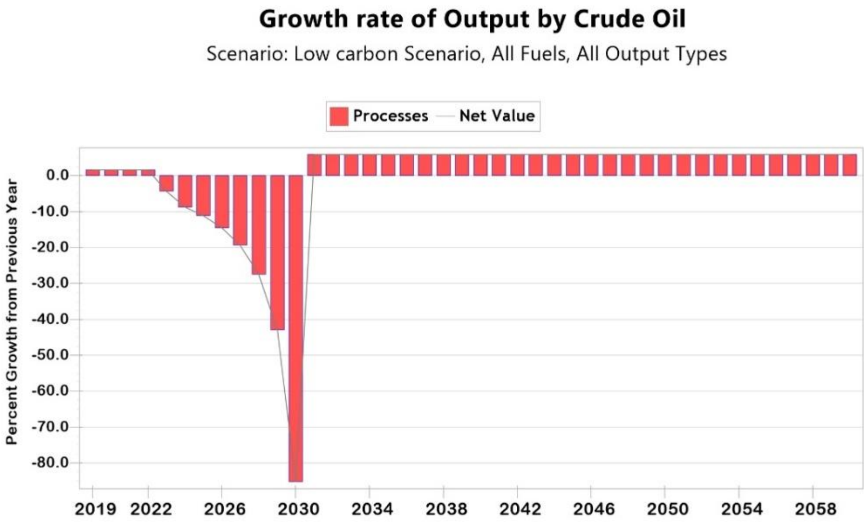

Figure 4.11: Growth Rates of Output by Crude Oil (LOW)

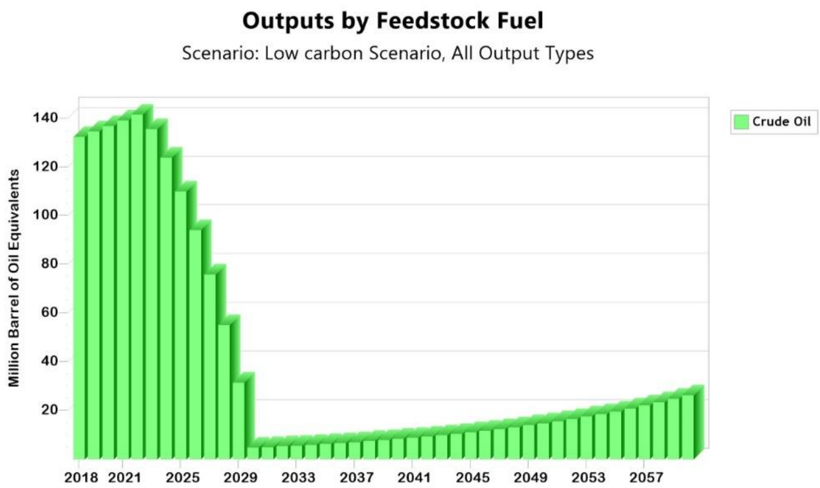

Figure 4.12: Nigeria Oil Refinery Output by Feedstock Fuel (LOW)

The exogenous capacity of the oil refinery is the same for both REF and LOW scenarios, having base year and expected end year capacities of 132.21 million BOE/year and 268.38 million BOE/year, respectively. Hence regardless of Nigeria targets of transiting into low-carbon energy system, the exogenous capacity of the oil refinery will remain the same.

Also, as clearly seen in figure 4.13, the output by all fuels considered will continue to increase from the base year to 2022. As the FGN carries out the low-carbon policies, there will be less demand of non-renewable and high demand of renewable, hence less productions of petroleum products. This effect is seen from 2023 where the total output of fuels decreased to 135.41 million BOE at an exogenous capacity of 143.84 million BOE/year; gasoline having 81.18 million BOE, diesel 46.73 million BOE, household kerosene 3.07 million BOE, residual fuel oil 2.43 million BOE, jet kerosene 1.18 million BOE and LPG 0.81 million BOE. This rapid decline is projected to continue till 2030, from whence there seems to be gradual increment of output from the oil refinery, on a very low production scale compare the base year.

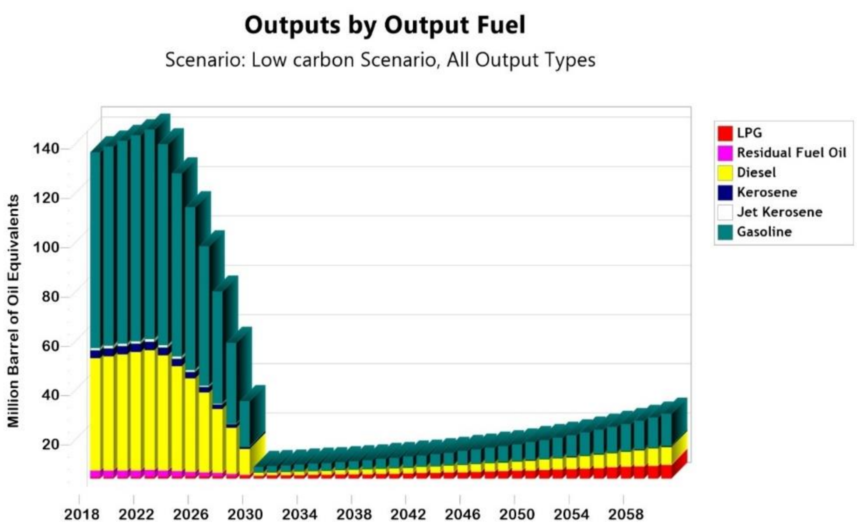

Figure 4.13: Nigeria Oil Refinery Output by Output Fuels (LOW)

However, the highest output fuels still remain gasoline and diesel because of their high demand and consumption rates by all sectors of the economy, while the least fuel output is LPG because of its demand and consumption rate.

4.2.3 Scenario Comparison on Transformation Projection

With the same increment of exogenous capacities in both scenarios, the output feed stock (crude oil) and the output fuels from the oil refinery were different for different periods and at different scenarios.

As seen in figure 4.14 (also in table B.3 in Appendix), with the same exogenous capacity under the REF and LOW scenarios, the rate of crude output in the REF scenario is at a continuous increasing level, due to increasing demand. While the rate of oil production under the LOW scenario fell due to drastically decrease in demand. Obviously, even at a very low demand of oil products as a result of engaging the low carbon system policies, producers are still reluctant to close oil wells.

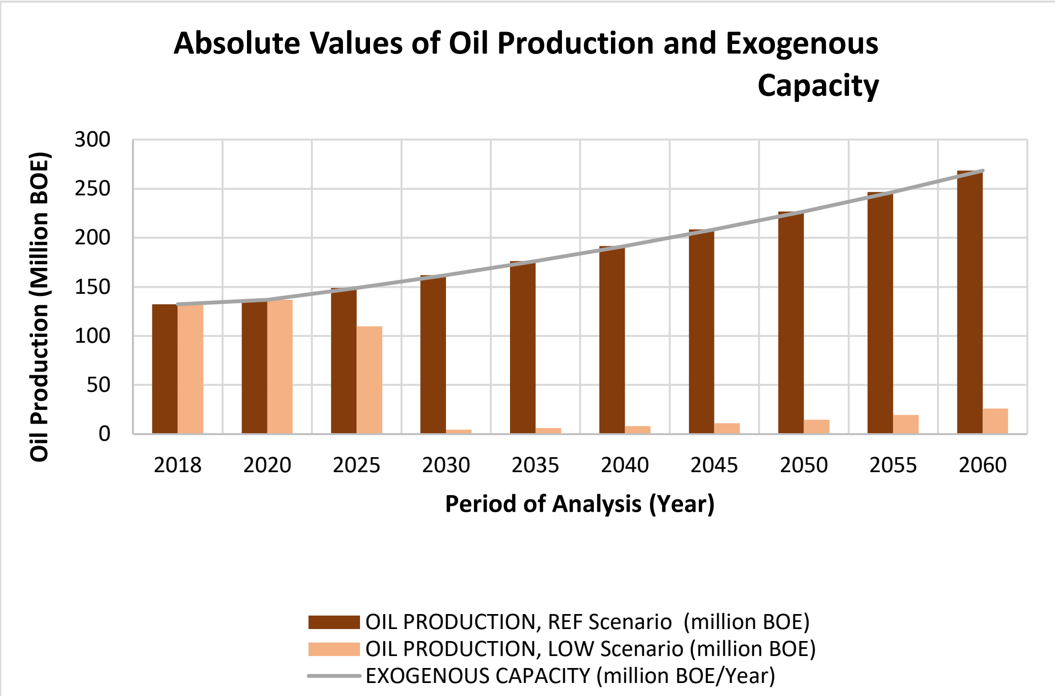

Figure 4.14: Absolute Values of Oil Production and Exogenous Capacity

As clearly seen in figure 4.14, by the base year, with an exogenous capacity of 132.21 million BOE/year, oil production under the REF and LOW scenarios were the same (132.21 BOE). But due to implementation of low carbon energy policies for GHG mitigation, from 2030 up until the end year of the analysis, oil production under the LOW scenario seems to drop drastically compare to the REF scenario.

In the end year, with an exogenous capacity of 268.38 million BOE/year, the maximum crude oil designed to flow into the distillation unit of the refinery in 2060 is expected to be 268.38 million BOE. This seems so for the REF scenario. However, under the LOW scenario, the amount of crude oil that flowed into the crude unit in 2060 is expected to reduce drastically to one-tenth of that of the REF scenario same year (26.17 million BOE). This is expected because with the FGN target for low carbon energy system, the demand and consumption of petroleum products from the sectors of Nigerian economy is most likely to reduce, resulting to decrease in supply. And except there is proper management and utilization of the Nigerian renewable energy technological system, this low rate of production under the LOW scenario would affect revenue (GDP), relationship with other countries, and also development in the country, since oil and gas sector have proven to greatly contribute to the growth and development of the economy in terms of GDP. Hence, the implication of switching into low carbon energy system.

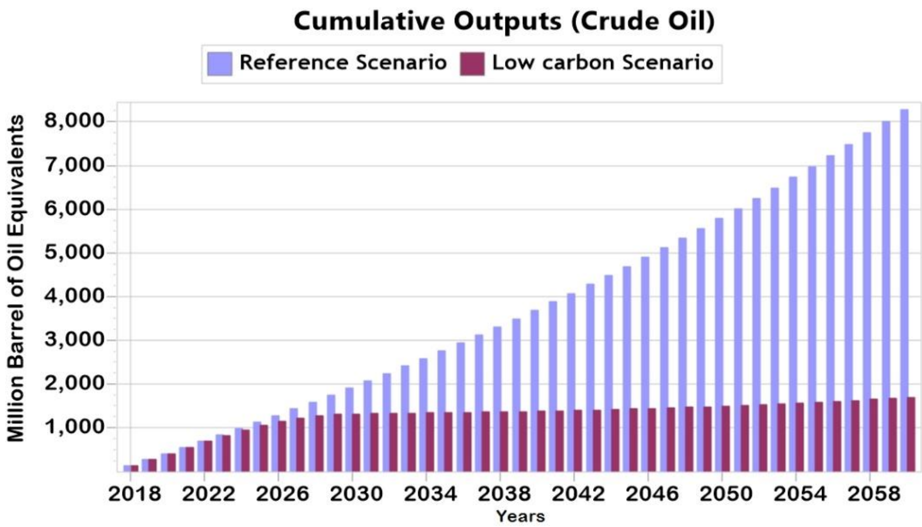

Figure 4.15: Cumulative Crude Oil Production

Nigeria will still depend on oil and gas for revenue even with the more utilization of renewable energy resources. Therefore, as clearly seen in figure 4.15, the cumulative crude oil production under the REF scenario has a linear progressive from the base year to the end year, hence the straight-line graph. With an average growth rate of 4%, the cumulative oil production by 2060 under the REF scenario will reach 8.28 billion BOE. However, under the LOW scenario, oil production is expected to increase gradually from 2030 with 4.63 million BOE, hence the cumulative oil production by 2060 is expected to 1.70 billion BOE, which is one-fifth of the REF.

4.3 Energy Balance

The energy balance for both REF and LOW scenario is discussed in this section using a Sankey diagram, with more focus on the base year and end year. A Sankey diagram shows the flow of energy resources consumption in a sector, and the width of each flow is proportional to the quantity of resources.

In the base year, 2018, both scenarios have the same energy production and flow of resources as represented in the Sankey diagram in figure 4.16. In 2018, the total primary energy supply was 3.01 billion BOE and the total energy demand was 2.85 billion BOE, hence unmet energy requirement of 0.16 billion BOE.

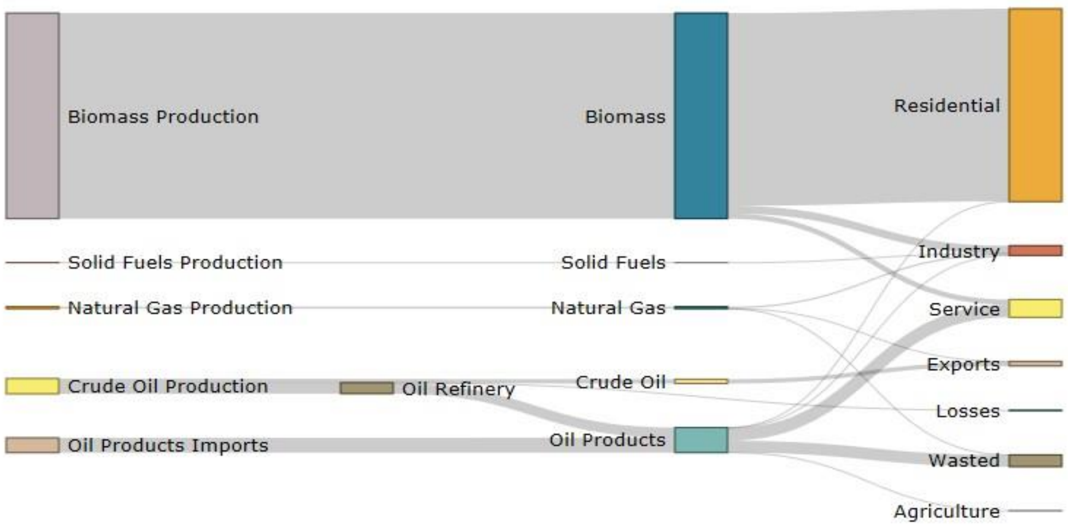

Figure 4.16: Base Year Sankey Diagram (Same for REF and LOW scenario)

According to the base year Sankey diagram in figure 4.16, there was high biomass production among the energy resources. Out of the 2.65 billion BOE of biomass produced, 93.6% were used in the residential sector, 3.8% used in the industry sector, and 2.6% used in the service sector. Likewise, the production of crude oil and natural gas were 198.98 and 26.54 million BOE, respectively. Out of the 198.98 million BOE crude oil produced, 143.09 million BOE were refined, out of which 92.4% were processed into oil products and the remaining 7.6% (10.87 million BOE) were loss due to oil spillage. Also, out of the 26.54 million BOE natural gas produced, 80.3% were used in the industry, 19.7% were exported and the remaining were loss due to gas flare. The total oil products imported was 191.34 million BOE and together with the 132.21 million BOE oil products were refined, there was a total of 323.57 million BOE of oil products. Out of this 323.57 million BOE oil products, 50.3% were used in the service sector, 1.1% were used in the industry sectors, 0.4% were used in the agricultural sector, 1.5% were used in the residential sector, and the remaining 46.7% were wasted.

4.3.1 Energy Balance for Reference Scenario (Year 2060)

Figure 4.17 shows the end year Sankey diagram. Obviously by 2060, the total biomass produced will reach 22.50 billion BOE, with residential sector still having the highest consumption of 94.7%, followed by service sector of 3.6%, then industrial sector of 1.7%. Also, the total solid fuels production is expected to reach 0.96 million BOE, which is about 76% increment from the base year. All of these solid fuels produced is expected to be consumed by the industrial sectors.

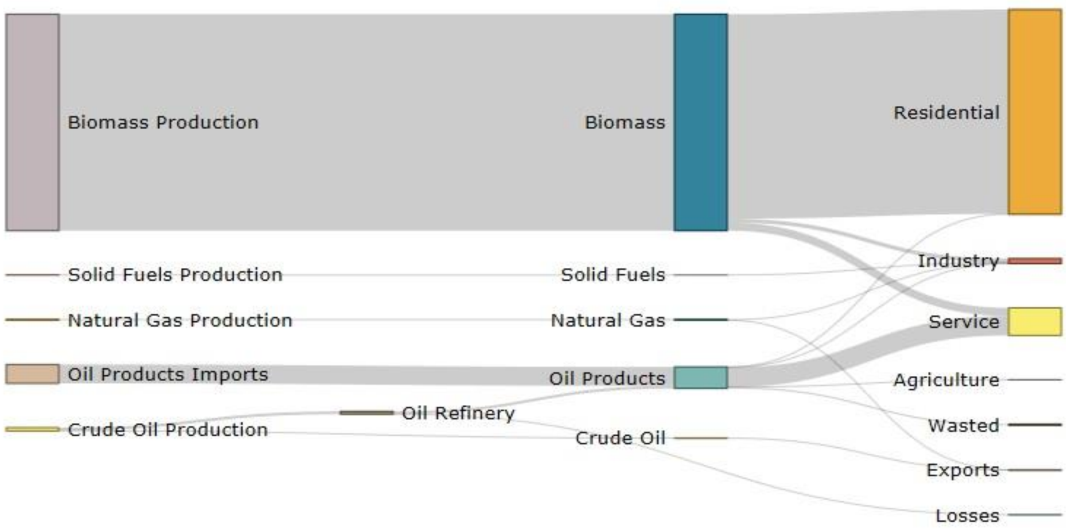

Figure 4.17: Sankey Diagram for REF Scenario (Year 2060 only)

The production of crude oil and natural gas by the end year is expected to reach 0.35 and 0.09 billion BOE, respectively; which is almost double that of the base year. From the crude oil produced, 83% (0.29 billion BOE) were refined and 17% were exported. Out of the total crude oil refined, it is expected that 8% (about 22 million BOE) would be loss. Also, an expected oil products of 2 billion BOE were to be imported, making a total of about 2.3 billion BOE to be supplied and 7% would be wasted.

Also, a total of 1.97 billion BOE oil products is expected to be imported by 2060. The service sector would continue to utilize more of oil products, especially in terms of transportation, as the population of Nigeria continue to increase. By the end year, out of 1.97 billion BOE of oil product imported plus 0.27 billion BOE of oil products refined, making a total of 2.24 billion BOE of oil products, service sector is expected to consume 90.6%, then residential is expected to consume 1.8% while industrial and agricultural sectors are expected to consume 0.4% and 0.008% respectively, and the remaining 6.7% would be wasted.

4.3.2 Energy Balance for Low Carbon Scenario (Year 2060)

The flow of resources in the LOW scenario for the end year (2060) is represented in the Sankey diagram shown in figure 4.18. The total biomass produced is expected to reduce to 5.97 billion BOE (about one-fourth of the REF scenario same year), out of which residential sector still consumes 72.5%, while the service and industrial sectors will consume 24.5%, 2.5% and the remaining percentage for agricultural sector.

Also, with the expected total production of renewable energy and hydropower resources of 3.27 billion BOE and 1.68 billion BOE, respectively, service sector would have the highest consumption rate, followed by industrial sector.

Due to more utilization of renewable energy resources, production of crude oil and natural gas in the end year is expected to drop to 0.08 billon BOE and 0.01 billion BOE, respectively, which is about one-fifth of the REF for same year. However, these crude oil and natural gas produced were majorly exported, while natural gas of 0.87 million BOE was used in agricultural sector and others were lost.

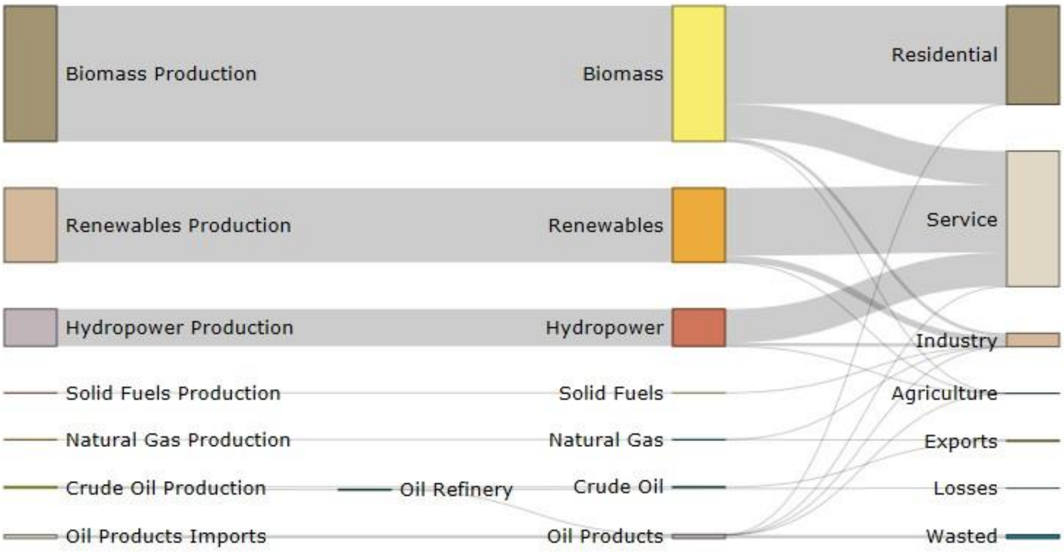

Figure 4.18: Sankey Diagram for LOW Scenario (Year 2060 only)

The importation of oil products reduced to about 0.15 billion BOE, which is more than one-thirteenth that of the oil products imported in same year for REF scenario. Therefore, importation of oil products is expected to reach 152.67 million BOE while exportation would reach 61.13 million BOE by 2060. Also from the Sankey diagram in figure 4.19, it is obvious that due to more utilization of renewable energy resources, there will be no need to import oil products otherwise large percentage imported would be wasted. Also, huge percentage of crude oil produced would be exported, while other would be lost in oil spillage. Even though crude oil are been exported, most countries would not have interest buying them, since every country is now looking for ways into low-carbon energy systems.

4.4: Greenhouse Gas Emission Projection

The results obtained from the greenhouse gas (GHG) emissions analysis for all sectors of the Nigerian economy and the country's oil refinery, in both REF and LOW scenarios, are displayed in this section. The GHG emissions were analyzed based on

100-Year GWP Direct at point of emissions and were measured in million metric tonnes of carbon dioxide equivalent (million $MtCO_2e$).

4.4.1 Reference Scenario

In the REF scenario, there were high emissions of GHG as a result of various economic activities from the agricultural, service, industrial and residential sectors. In the base year, the total GHG emissions from the demand and supply sections of the analyses were 232.93 and 6.66 million $MtCO_2e$, respectively, making a total of 239.59 million $MtCO_2e$ (see Appendix C). In the base year, the highest GHG emissions were from the residential sector (147.46 million $MtCO_2e$), followed by the service sector (71.01 million $MtCO_2e$), then that of the industrial sector (14.45 million $MtCO_2e$) and the least from the agricultural sector (0.01 million $MtCO_2e$).

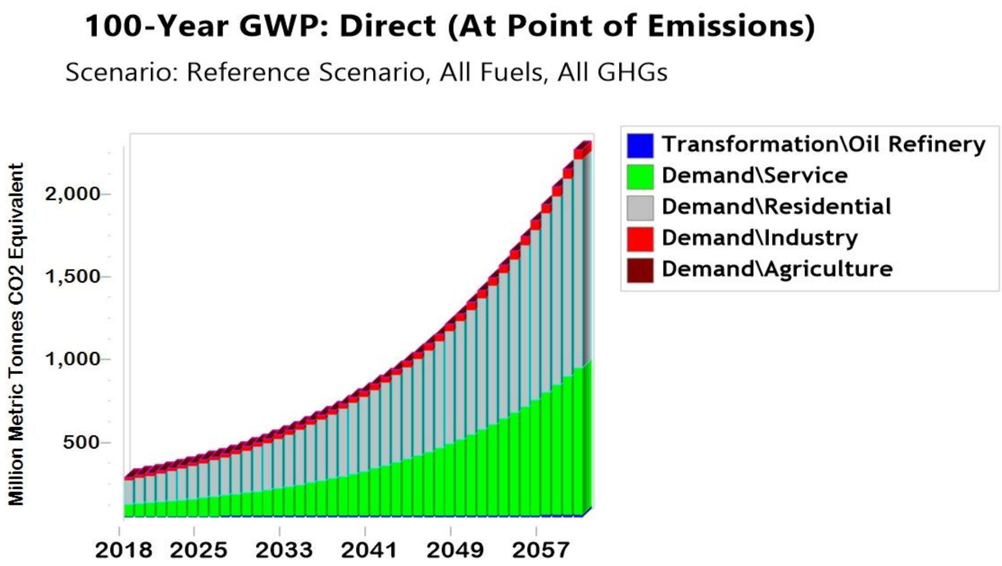

Figure 4.19: GHG Emissions from Demand (REF)

Obviously, as seen in figure 4.19, GHG emissions in 2060 from the demand section is expected reach 2205.10 million $MtCO_2e$ while that from the processes involved in the oil refinery will attain 13.52 million $MtCO_2e$, resulting to a cumulative GHG emissions of over 38.32 billon $MtCO_2e$ by 2060. These emissions are expected to increase as more fossil fuels, wood fuels and other local cooking technologies etc., are being utilized daily.

With an average growth rate of 6%, the cumulative GHG emission from all sections is expected to increase to over 4.34 billion $MtCO_2e$ in 2030 and 38.32 billion $MtCO_2e$ in 2060. The agricultural sectors still emit the least amount of GHG, due to their least consumption of energy (diesel only). However, the emissions of GHG from the processes involved in the oil refinery is still less compare to the demand sectors. Therefore, the higher the non-renewable energy consumed, the higher the tendency of high GHG emissions in the REF scenario.

4.4.2 Low Carbon Scenario

From the analysis results obtained in the LOW scenario, there seems to be gradual increase of GHG emissions from all sections (demand and transformation), despite the FGN renewable energy policies, however, not high compared to that of the REF scenario. With the same REF scenario emission results on the base year (239.58 million $MtCO_2e$), these emissions were observed to decrease with an average rate of 5% until 2024 (192.31 million $MtCO_2e$). However, from 2025 till 2031, there was drastically average decrease of 25%, resulting to 78.51 million $MtCO_2e$ in 2031. But from 2032, the GHG emissions is seen to increase resulting to total of 361.57 million $MtCO_2e$ in 2060. Out of these economic sectors, GHG emissions from the residential sector seems higher due to more consumption of energy, while agricultural sectors emitted the least.

As more demand were focused on renewable energy resources, there was decrease in demand for fossil fuel in the LOW, then there would be decrease in the rate of refining and production processes at the oil refinery, hence resulting to low emissions from oil refinery. But the GHG emissions from the oil refinery processes was observed to decrease gradually from the base year (6.66 million $MtCO_2e$) to 2022 (7.12 million $MtCO_2e$). However, by carrying out strategies for low-carbon from 2024, GHG emissions from processes of oil refinery were seen to decline drastically from 6.82 million $MtCO_2e$ in 2023 to 0.23 million $MtCO_2e$ in 2030. Then from 2031, the GHG emission from oil refinery processes was seen to gradually increase to 1.32 million $MtCO_2e$ in 2060 (see figure 4.20).

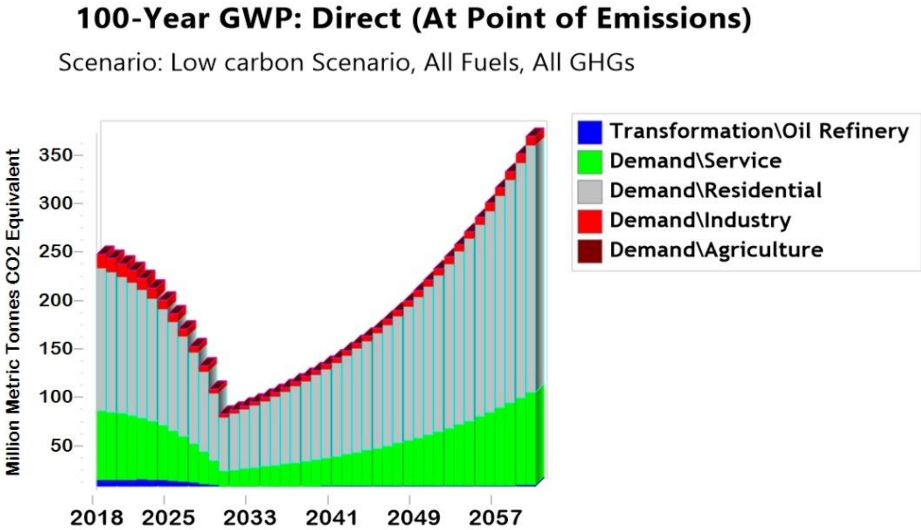

Figure 4.20: GHG Emissions from Demand (LOW)

4.4.3 Scenario Comparison on GHG Emission Projection

One of the greatest effects and concern of energy consumption is the emissions of greenhouse gases. From the analysis carried out, the cumulative GHG emission in the REF and LOW scenarios were the same (239.58 million $MtCO_2e$). Applying the energy polices from 2019, the cumulative GHG emissions in both were observed to be affected. In the 2030, the cumulative GHG emissions in the REF scenario was 472.20 while that of the LOW scenario was 78.51 million MtCO2e. And by 2060, it is expected that the cumulative GHG emissions in the LOW scenario would reach 361.57 million MtCO2e while that of the REF would be over six times that of the LOW scenario (2218.61 million MtCO2e). Hence, it is obvious in figure 4.21 that when the energy mitigation policies are applied, the cumulative GHG emitted in the LOW scenario by 2060 would even be less that the cumulative GHG emitted in 2026, 34 years ago, under the REF scenario (363.26 million MtCO2e).

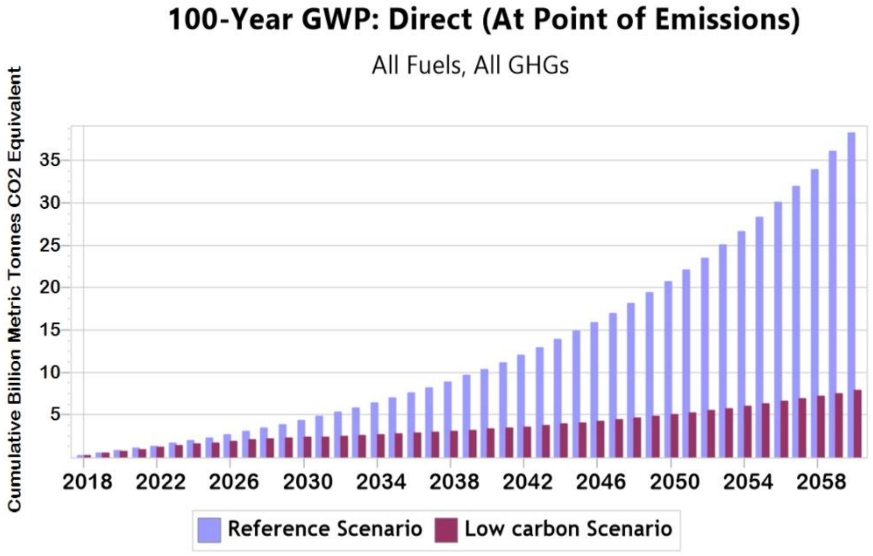

Figure 4.21: Cumulative GHG Emissions (REF and LOW)

Emissions of GHG is expected to increase in both scenarios, with the ratio of REF scenario to LOW scenario approximately 1:1 until 2025. In 2030, the ratio of cumulative GHG emission in REF to LOW scenario is 2:1. And obviously, by the end year, the ratio of REF to LOW cumulative GHG emitted will be approximately 5:1. This decline under the LOW scenario is expected because of the FGN target of attaining low carbon energy system in Nigeria.

Notwithstanding, since Nigeria still have oil and gas reserves, they will continue to utilization of fossil fuels and other carbon contents. Hence the gradual increase of GHG emissions under the LOW scenario but these increments were not as high compared to the REF scenario. And by 2030 and the end year, the cumulative GHG emitted in the LOW scenario is expected to be 2.01 and 30.41 billion MtCO2e, respectively, less than that of the REF scenario (see figure 4.22). This implies that more utilization of renewable energy resources as targeted by the FGN will go a long way in reducing the effects of global warming in Nigeria and the world, therefore making the country more habitable for man and animals/plants.

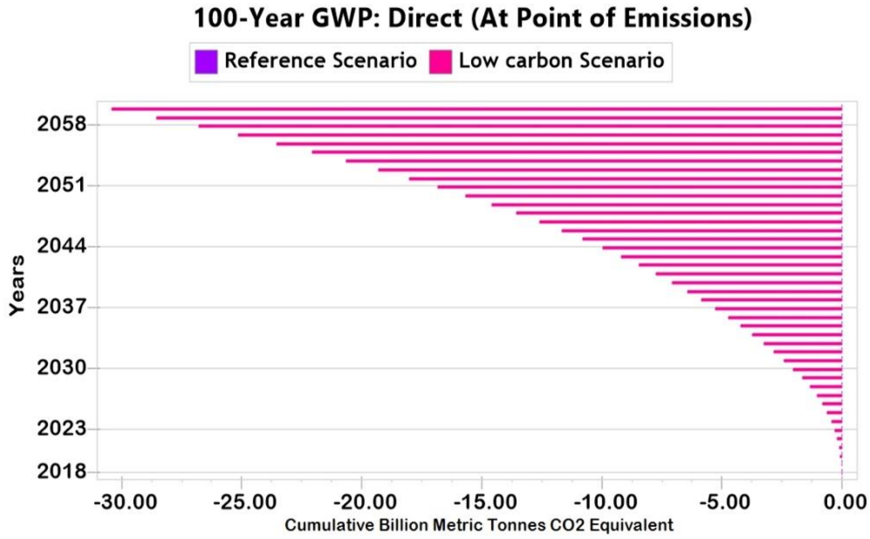

Figure 4.22: Cumulative GHG Emissions Comparison (Difference vs REF)

4.5 Cumulative Cost-Benefit Analysis

Cost benefit analysis is a tool used for improving decision-making. Based on a discount rate of 10% and inflation rate of 12%, couple with the monetary information used as stated in Chapter 3, the results obtained from the REF and LOW scenarios are discussed in this section. These results would also assist the FGN on which scenario to implement.

The cumulative cost benefit from 2018 to 2060 is represented in figure 4.23 and Table 4.2. In the REF and LOW scenario, the cumulative NPV cost benefit between the periods of analyses would reach 469.10 and 226.92 trillion USD, respectively. These NPV from the two scenarios turns out positive, which implies that the discounted present value of all future cash flows related to the investment in both the REF and LOW scenario will be positive, and therefore attractive.

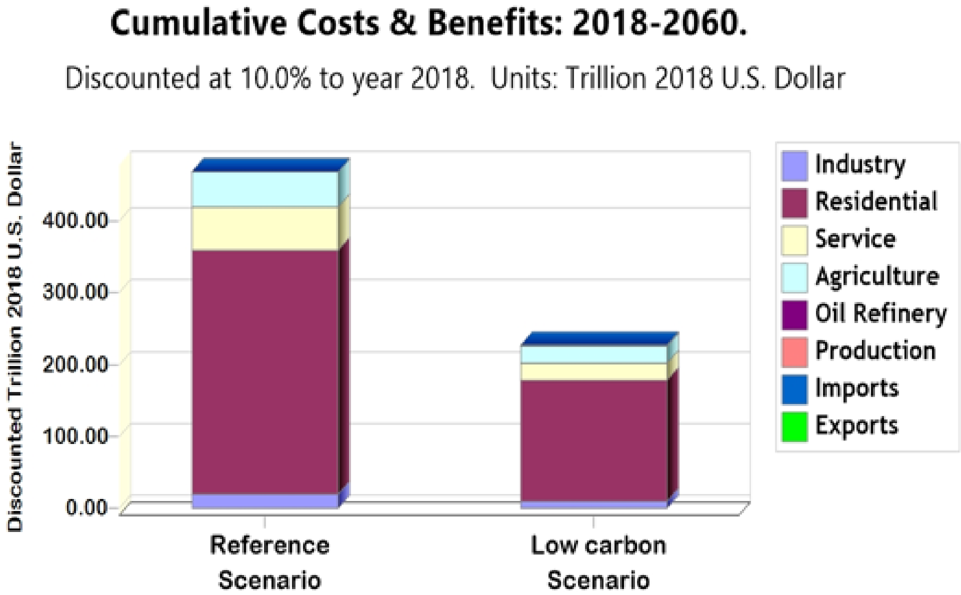

Figure 4.23: REF and LOW scenario Cumulative Cost and Benefit: 2018 - 2060

In the REF scenario, the cumulative cost under the demand sector within the period of analysis is expected to reach 468.59 trillion USD, which is more than two times that of the LOW scenario (226.68 trillion USD). Among these four sectors in the REF scenario, residential have the highest of 339.58 trillion USD, followed by service of 60.65 trillion USD, then agriculture of 49.01 trillion USD, with the least being industry of 19.34 trillion USD, and that from the oil refinery would attain 20 billion USD. Also, the cumulative cost under production, resource imports, and export would reach 170 billion USD, 370 billion USD, and 40 billion USD, respectively. And considering the emissions of greenhouse gases, it is expected that a cumulative of 38.32 billion $MtCO_2e$ would be emitted at the end of the period of analysis.

Regarding the LOW scenario, the cumulative NPV of energy demand in all the four sectors for the analysis period would attain 226.68 trillion USD. Among these four sectors, the residential has the highest of 167.67 trillion USD, followed by the service sector of 24.70 trillion USD, then agriculture of 24.09 trillion USD, and the least being industry of 10.22 trillion USD. The cumulative NPV in the transformation section, oil refinery, would attain 10.0 billion USD, which is half of the REF scenario. The cumulative NPV under exports seems the same with the REF scenario (40 billion USD), but that for production and imports would reach 110 billion USD and 170 billion

USD, respectively. Also, concerning the total GHG emission, it is expected that within year 2018 and year 2060, a total of 7.91 billion $MtCO_2e$ would be emitted. This amount of GHG emitted in the LOW scenario is approximately one-fifth of the REF scenario.

Table 4.2: Cumulative Cost– Benefit Summary

Cumulative Costs & Benefits: 2018-2060.		
Discounted at 10.0% to year 2018. Units: Trillion 2018 U.S. Dollar		
SECTOR	**REFERENCE SCENARIO**	**LOW CARBON SCENARIO**
Demand	**468.59**	**226.68**
Industry	19.34	10.22
Residential	339.58	167.67
Service	60.65	24.70
Agriculture	49.01	24.09
Transformation	**0.02**	**0.01**
Oil Refinery	0.02	0.01
Resources	-	-
Production	0.17	0.11
Imports	0.37	0.17
Exports	-0.04	-0.04
Other Costs		
Unmet Requirements	-	-
Environmental Externalities	-	-
Non-Energy Sector Costs	-	-
Total Net Present Value	**469.10**	**226.92**
GHG Emissions *(Billion $MtCO_2e$)*	**38.32**	**7.91**

4.5.1 Scenario Comparison on Cost-Benefit Analysis

According to Ibrahim and Kirkil (2018), it is better to view cost-benefit analysis graphically in terms of differences versus the Reference scenario.

Figure 4.24 shows the cumulative discounted social costs of Nigeria LEAP Model in terms of difference verses the REF scenario. Social costs are actually the total cost arising from economic activity, which are borne by members of the society (Pearce and Sturmey, 1966). In short, social costs are the overall impact of an economic activity on the welfare of society, including fuel, oil, maintenance, insurance, depreciation, etc. As seen from the figure 4.24, the cumulative discounted social cost under the LOW scenario reached a negative 242.18 trillion USD, by year 2060. This implies that by the end year of the analyses, the overall cost impact of an economic activity on the welfare of society, including fuel, oil, maintenance, insurance, depreciation, etc., under the LOW scenario would be 242.18 trillion USD less than that of the REF scenario.

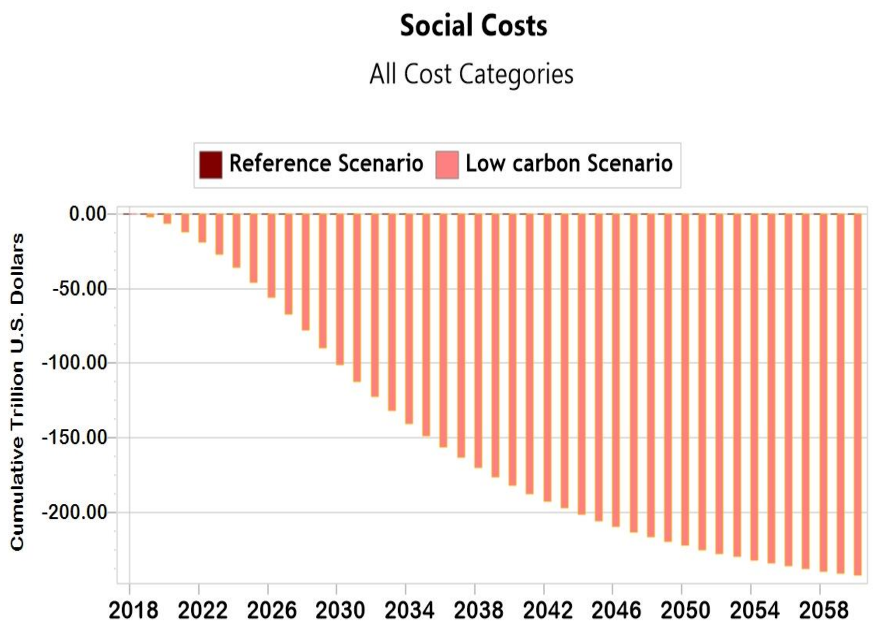

Figure 4.24: Cumulative Social Cost (Difference Verses REF Scenario)

Likewise, as seen in figure 4.25, the cumulative cost of production under the LOW scenario reached a negative of 66.24 billion USD by year 2060. This also implies that the cumulative production cost of energy resources under the REF scenario would be 66.24 billion USD greater than that of the LOW scenario by the end year of the analyses.

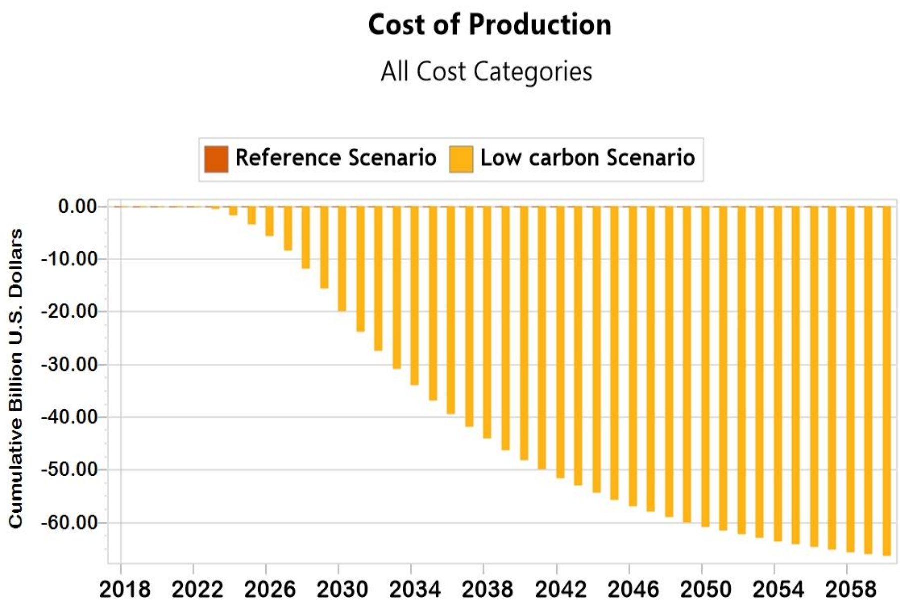

Figure 4.25: Cumulative Production Cost (Difference Verses REF Scenario)

Also, as seen in table 4.3, which shows the cumulative cost summary relative to the Reference scenario, the total net present value of LOW is 242.18 trillion USD less than that of the REF by the end of the analysis period.

Also, in the LOW scenario, GHG savings would reach 30.41 billion $MtCO_2e$. This means that the cumulative greenhouse gas emission by the end year under the LOW scenario would be 30.41 billion $MtCO_2e$ less than that of the REF scenario, hence resulting to less cost of avoided GHG emission of 7963.83 USD per $MtCO_2e$ in the LOW scenario compare to the REF scenario. This cost of avoided GHGs emission implies that for over 7000USD would be saved for every one $MtCO_2e$ that was supposed to be emitted when the LOW carbon scenario is been considered.

Table 4.3: Cumulative Cost– Benefit Summary Relative to REF Scenario

Cumulative Costs & Benefits: 2018-2060.Relative to Scenario: Reference Scenario	
Discounted at 10.0% to year 2018. Units: Trillion 2018 U.S. Dollar	
SECTOR	**LOW CARBON SCENARIO**
Demand	**-241.92**
Industry	-9.13
Residential	-171.91
Service	-35.95
Agriculture	-24.92
Transformation	**-0.01**
Oil Refinery	-0.01
Resources	-
Production	-0.06
Imports	-0.20
Exports	-
Other Costs	
Unmet Requirements	-
Environmental Externalities	-
Non-Energy Sector Costs	-
Total Net Present Value (NPV, Trillion USD)	**-242.18**
GHG Savings *(Billion $MtCO_2e$)*	**30.41**
Cost of Avoided GHGs *(USD/$MtCO_2e$)*	**-7963.93**

CHAPTER FIVE

5.0 CONCLUSION AND POLICY IMPLICATION

Over the years, Nigeria economy have depend solidly on fossil fuel as a major source of energy, and these fossil fuels are insufficient in meeting the energy demand of over 206 million people. Hence, the urgent need for energy sustainability and diversity.

Couple with the environmental effects of consuming fossil fuel, especially increasing GHG emissions, if remedy is not been considered, the amount of GHG to be emitted in 40years time would be eight times greater than what is emitted today. Therefore, the main objective of this research is to utilize LEAP computer software computer modelling in forecasting energy demand from four major sectors of Nigeria economy, predict production of crude oil/petroleum product, project GHG emissions from energy demand and production, and perform cumulative cost-benefit analysis between 2018 to 2060, under two scenarios; Reference and Low carbon. The results obtained under the two scenarios would assist the FGN on deciding the policy path to be followed. The summary of the results is also shown in the Appendix.

Focusing on the end year results, the total energy demand under the REF and LOW scenarios expected to be nine times and four time that of 2018, respectively. With this higher energy demand in the REF scenario, there would be increasing pressure on all means of energy supplies (local, regional, and international), as well as on carbon mitigation systems accentuating the need for energy conservation and GHG emissions reduction actions. Although, the cumulative NPV with respect to demand between the period of analysis, under the REF and LOW scenarios shows positive values of 468.59 and 226.68 trillion USD, respectively, which signifies that any of the two scenarios would be favorable to the government. However, the cumulative GHG emissions under the LOW scenario (between the period of analysis), would be 30.41 billion $MtCO_2e$ less than that of the REF scenario. This seems good, and obviously will result to more friendly and habitable environment.

Considering oil production/output, under the REF scenario, the cumulative oil production by 2060 would reach 8.28 billion BOE while it would attain 1.70 billion BOE under the LOW scenario. This is obviously because of more utilization of renewable energy resources, hence energy sustainability and diversity. In 2060, out of the 0.35 billion BOE crude oil produced under the REF scenario, the oil refinery would refine and supply oil products of 0.29 billion BOE. Therefore, there would be need to import 1.97 billion BOE oil products to meet with the demand for 2.24 billion BOE oil products by the end year. However, in as much as government/investors would receive revenue from the sales of imported oil products, it would also require them to spend more in order to meet the energy demand of her growing population.

However, under the LOW scenario, with more utilization of renewables of 3.27 billion BOE in 2060, there would be reduction in demand for oil product to 0.18 billion BOE. And out of these oil products demanded, only 17% would be utilized by the four sectors of the economy while the remaining 83% would be wasted. Also, out of 80 million BOE of crude oil produced in same year, 25%would be lost through maybe oil spillage, while the remaining 75% would be exported. Now, which country would show interest in buying these crude oil since majorly all countries are switching into low-carbon energy systems? Even if there would be a country, it would be at a giveaway price.

Obviously, at a discount rate of 10% and inflation rate of 12%, the two scenarios have positive cumulative NPV. However, implementing low-carbon energy polices involved would result to more friendly and habitable environment, and energy sustainability and diversity regardless of the population growth rate; bearing in mind that oil production and oil products utilizations would be seriously affected, reducing to one-tenth of the REF scenario by the end year. However, one major challenge would be on management of these sustainable technologies. So, in as much as Nigeria is trying to energy-switch, the knowledge and skills needed for proper management of renewable energy technologies is of great necessity.

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APPENDIX

APPENDIX A: SUMMARY REPORT

Table A.1: Summary Report for REF Scenario

Scenario: Reference Scenario							
Branch	2018	2020	2025	2030	2040	2050	2060
Energy Demand (Billion GJ)	16.56	18.34	23.68	30.59	51.11	85.57	143.48
One Hundred GWP (Billion MtCO2e)	0.24	0.27	0.34	0.48	0.76	1.30	2.22

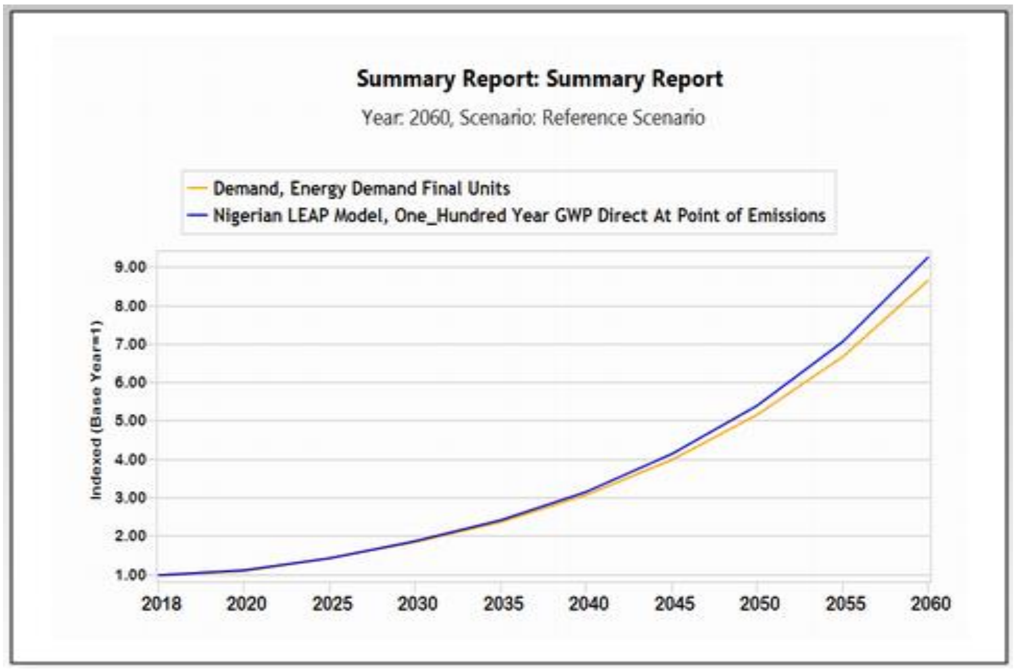

Figure A.1: Summary Report for REF Scenario

Table A.2: Summary Report for LOW Scenario

Scenario: Low	

carbon Scenario							
Branch	2018	2020	2025	2030	2040	2050	2060
Energy Demand (Billion GJ)	16.56	16.72	15.47	12.44	21.29	36.65	63.42
One Hundred GWP (Billion MtCO2e)	0.24	0.23	0.18	0.07	0.13	0.21	0.36

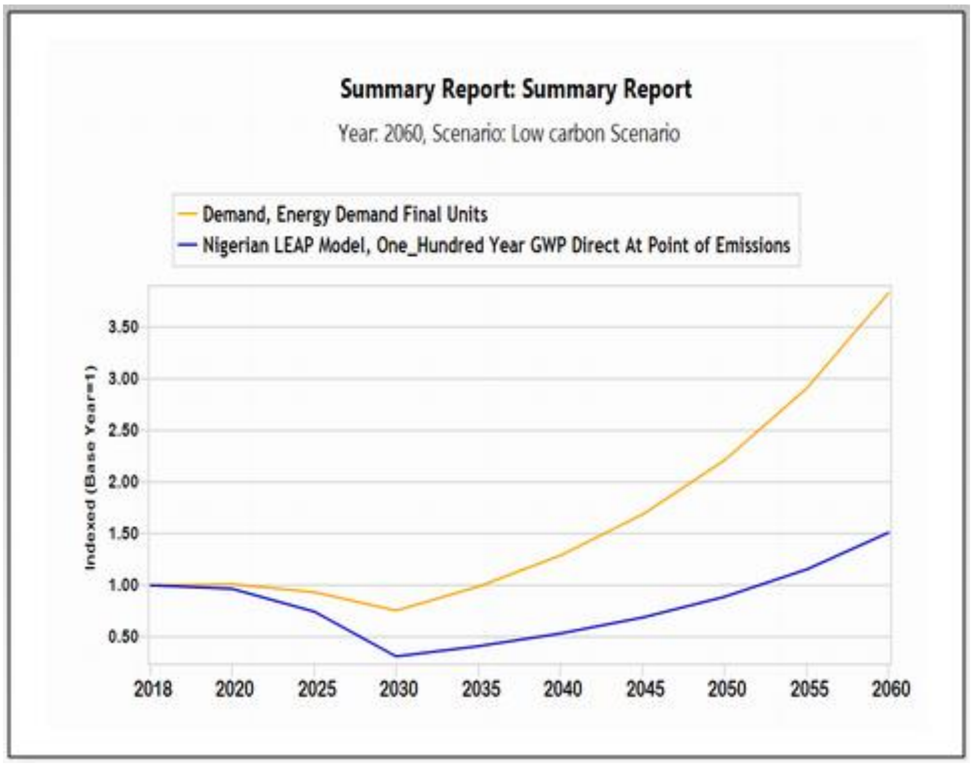

Figure A.2: Summary Report for LOW scenario

APPENDIX B: TRANSFORMATION IN OIL REFINERY

Table B.1: Oil Refinery Capacity

All Capacity Transformation\Oil Refinery Units: Million BBL Oil Equiv/Years						
Scenario	2018	2020	2030	2040	2050	2060
Low carbon Scenario	132.21	136.75	161.85	191.57	226.75	268.38
Reference Scenario	132.21	136.75	161.85	191.57	226.75	268.38
Total	**264.42**	**273.49**	**323.71**	**383.15**	**453.50**	**536.76**

Table B.2: Crude Oil Output (Production)

Outputs by Feedstock Fuel All Fuels, All Output Types Branch: Transformation\Oil Refinery Units: Million Barrel of Oil Equivalents						
Scenario	**2018**	**2020**	**2030**	**2040**	**2050**	**2060**
Low carbon Scenario	132.21	136.75	4.63	8.23	14.65	26.13
Reference Scenario	132.21	136.75	161.85	191.57	226.75	268.38
Total	**264.42**	**273.49**	**166.48**	**199.80**	**241.40**	**294.52**

Table B.3: Absolute Values of Oil Production and Exogenous Capacity

PERIOD OF ANALYSIS (YEAR)	**EXOGENOUS CAPACITY** **(million BOE/Year)**	**OIL PRODUCTION (million BOE)**	**OIL PRODUCTION (million BOE)**
		(REF Scenario)	**(LOW Scenario)**
2018	132.21	132.21	132.21
2020	136.75	136.75	136.75
2025	148.77	148.77	109.91
2030	161.85	161.85	4.64
2035	176.09	176.09	6.18
2040	191.57	191.57	8.24
2045	208.42	208.42	10.99
2050	226.75	226.75	14.67
2055	246.69	246.69	19.59

2060	268.38	268.38	26.17

APPENDIX C: GHG EMISSIONS (100-Year: Direct at Point of Emissions)

Table C.1: Scenario GHG Emissions from Demand

All Fuels, All GHGs Branch: Demand Units: Million Metric Tonnes CO2 Equivalent						
Scenario	**2018**	**2020**	**2030**	**2040**	**2050**	**2060**
Low carbon Scenario	232.92	222.77	74.27	125.38	212.24	360.24
Reference Scenario	232.93	258.86	439.86	750.23	1,284.09	2,205.09
Total	**465.85**	**481.63**	**514.13**	**875.61**	**1,496.34**	**2,565.32**

Table C.2: Scenario GHG Emissions from Oil Refinery

All Fuels, All GHGs Branch: Transformation\Oil Refinery Units: Million Metric Tonnes CO2 Equivalent						
Scenario	**2018**	**2020**	**2030**	**2040**	**2050**	**2060**
Low carbon Scenario	6.66	6.89	0.23	0.41	0.74	1.32
Reference Scenario	6.66	6.89	8.15	9.65	11.42	13.52
Total	**13.32**	**13.77**	**8.38**	**10.06**	**12.16**	**14.83**

Table C.3: Nigeria LEAP Model GHG Emissions

All Fuels, All GHGs Branch: Nigerian LEAP Model Units: Million Metric Tonnes CO2 Equivalent						
Scenario	**2018**	**2020**	**2030**	**2040**	**2050**	**2060**

Low carbon Scenario	239.59	287.89	74.51	125.80	212.99	361.57
Reference Scenario	239.59	277.61	448.01	759.88	1,295.52	2,218.61
Total	**479.17**	**565.49**	**522.53**	**885.68**	**1,508.51**	**2,580.18**

APPENDIX D: ENEGRY BALANCE

Table D.1: Energy balance for Base Year (2018) REF and LOW scenario

Year: 2018. Units: Million Barrel of Oil Equivalent	Natural Gas	Gasoline	Jet Kerosene	Kerosene	Diesel	Residual Fuel Oil	LPG	Crude Oil	Coal Bituminous	Biomass	Total
Production	26.54	-	-	-	-	-	-	198.98	0.23	2,654.99	2,880.74
Imports	-	135.19	5.43	2.90	42.02	4.03	1.80	-	-	-	191.37
Exports	-5.24	-	-	-	-	-	-	-55.89	-	-	-61.13
Total Primary Supply	21.30	135.19	5.43	2.90	42.02	4.03	1.80	143.09	0.23	2,654.99	3,010.98
Oil Refinery	-	79.16	1.16	3.13	45.57	2.70	0.50	-143.09	-	-	-10.87
Total Transformation	-	79.16	1.16	3.13	45.57	2.70	0.50	-143.09	-	-	-10.87
Industry	21.30	-	-	-	-	3.49	0.01	-	0.23	100.78	125.82
Residential	-	-	-	4.04	-	-	0.63	-	-	2,486.96	2,491.63
Service	-	102.32	1.49	0.01	58.88	-	-	-	-	67.25	229.95
Agriculture	-	-	-	-	0.03	-	-	-	-	-	0.03
Total Demand	21.30	102.32	1.49	4.05	58.91	3.49	0.64	-	0.23	2,654.99	2,847.44
Unmet Requirements	-0.00	-112.02	-5.09	-1.98	-28.69	-3.24	-1.65	0.00	-	-	-152.67

Table D.2: Energy Balance for End Year (2060) REF Scenario

Scenario: Reference Scenario, Year: 2060, Units: Million Barrel of Oil Equivalent	Natural Gas	Gasoline	Jet Kerosene	Kerosene	Diesel	Residual Fuel Oil	LPG	Crude Oil	Coal Bituminous	Biomass	Total
Production	92.32	-	-	-	-	-	-	346.35	0.96	22,504.00	22,943.62
Imports	-	1,224.07	21.32	32.14	668.72	15.68	6.41	-	-	-	1,968.35
Exports	-5.24	-	-	-	-	-	-	-55.89	-	-	-61.13
Total Primary Supply	87.08	1,224.07	21.32	32.14	668.72	15.68	6.41	290.46	0.96	22,504.00	24,850.84
Oil Refinery	-	164.38	2.40	4.46	94.61	1.84	0.70	-290.46	-	-	-22.07
Total Transformation	-	164.38	2.40	4.46	94.61	1.84	0.70	-290.46	-	-	-22.07
Industry	87.08	-	-	-	-	14.28	0.03	-	0.96	411.84	514.19
Residential	-	-	-	34.52	-	-	5.43	-	-	21,253.21	21,293.16
Service	-	1,276.43	18.63	0.09	734.47	-	-	-	-	838.94	2,868.56
Agriculture	-	-	-	-	0.18	-	-	-	-	-	0.18
Total Demand	87.08	1,276.43	18.63	34.62	734.64	14.28	5.46	-	0.96	22,504.00	24,676.09
Unmet Requirements	-	-112.02	-5.09	-1.98	-28.69	-3.24	-1.65	-	-	-	-152.67

Table D.3: Energy Balance for End Year LOW Scenario (2060)

Scenario: Low carbon Year: 2060, Units: Million Barrel of Oil Equivalent	Natural Gas	Gasoline	Jet Kerosene	Kerosene	Diesel	Residual Fuel Oil	LPG	Crude Oil	Coal Bituminous	Wind	Solar	Hydro	Biomass	Total
Production	6.1	-	-	-	-	-	-	84.2	0.0	1,637.4	1,637.4	1,637.4	5,967.8	10,970.2
Imports	-	112.0	5.1	2.0	28.7	3.2	1.7	-	-	-	-	-	-	152.7
Exports	-5.2	-	-	-	-	-	-	-55.9	-	-	-	-	-	-61.1
Total Primary Supply	0.9	112.0	5.1	2.0	28.7	3.2	1.7	28.3	0.0	1,637.4	1,637.4	1,637.4	5,967.8	11,061.7
Oil Refinery	-	12.8	0.2	0.3	7.4	0.1	5.3	-28.3	-	-	-	-	-	-2.2
Total Transformation	-	12.8	0.2	0.3	7.4	0.1	5.3	-28.3	-	-	-	-	-	-2.2
Industry	0.9	-	-	-	-	0.1	0.0	-	0.0	147.6	147.6	147.6	147.6	591.3
Residential	-	-	-	0.3	-	-	5.3	-	-	-	-	-	4,330.4	4,336.1
Service	-	12.8	0.2	0.0	7.3	-	-	-	-	1,489.7	1,489.7	1,489.7	1,489.7	5,979.0
Agriculture	-	-	-	-	0.0	-	-	-	-	0.1	0.1	0.1	0.1	0.5
Total Demand	0.9	12.8	0.2	0.3	7.4	0.1	5.3	-	0.0	1,637.4	1,637.4	1,637.4	5,967.8	10,906.9
Unmet Requirements	0.0	-112.0	-5.1	-2.0	-28.7	-3.2	-1.7	-	-	-	-	-	-	-152.7