M. Sc. Dissertation in Engineering

Long-Term Energy Analysis for Sustainable Strategies in Nigeria Using the LEAP Model

나이지리아의 지속 가능한 국가 전략 마련을
위한 장기 에너지 분석: **LEAP** 모델을 이용하여

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이 논문을 공학석사 학위논문으로 제출함

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Abstract

This thesis developed a set of the long-term energy scenarios for Nigeria considering the impact of vital factors that may influence its energy policies in its future energy system. The energy scenarios were developed through the application of the Long-Range Energy Alternatives Planning System (LEAP) model. The Nigerian LEAP model was developed to identify the future energy demand and how it could be met using a least-cost combination of technology options without similar expansion in greenhouse gases. The developed model incorporated four policy scenarios that differ from one another, and this was intended to capture the vital factors that may influence the energy policies in the future.

The factors that were taken as parameters included the GDP, the households, the population and urbanization growth rates, and the growth rates of the energy-intensive sectors. The four scenarios that were developed were the reference (REF), low-carbon moderate (LCM), low-carbon advanced (LCA), and green-optimistic (GO) scenarios. The results of the modeled scenarios showed that the energy demand is expected to grow at an annual growth rate of 3.58% (REF), 3.53% (LCM), 2.95% (LCA), and 2.61% (GO). The REF scenario energy demand was the highest (with 3,075 PJ by 2040) while the GO scenario was the lowest (2,249.2 PJ). The GHG emission rate was very low for the GO scenario (124.4 MMTCDE) compared to the other scenarios, and this was due to the high level of renewables and the energy efficiency application into the energy mix.

The level of energy policies such as various degrees of energy efficiency and fuel/technology switching was increased from the LCM scenario (which had a moderate policy implementation), the advance LCA scenario, and the more aggressive GO scenario. Furthermore, a cost-benefit analysis was carried out to ascertain the cost of implementing some policies and strategies in Nigeria, including energy efficiency and fuel/technology switching. The results showed that it would cost Nigeria USD1.69 billion to implement policies in the LCM scenario, USD23.8 billion in the LCA scenario, and USD41.4 billion in the GO scenario.

With regard to the least-cost electricity generation options for power plants in the different scenarios in this study, it was shown that on-shore wind power and small hydropower are the least-cost electricity generation options overall. For fossil fuel power plants, CCGT was identified as the least-cost electricity generation option as well as the lowest-GHG-emitting power plant besides biomass, which was considered a low-carbon technology. From the results in general, it was observed that low-carbon and renewable technologies will have an important role to play in the realization of low-carbon development in Nigeria.

To achieve this feat, this thesis further explored some strategies that can ensure low-carbon development in Nigeria, with a view of attaining green growth. These strategies include adopting the green growth ideology and coming up with energy policy reforms, long-term energy plans and targets, energy regulations and standards, environmental tax reforms, urban plans, efficient building designs, and measures to improve the efficiency of the

country's energy and transport system.

This thesis is significant in that it applied a bottom-up approach for the Nigerian energy model, performed a cost-benefit analysis, presented least-cost electricity generation options, and suggested strategic energy policies. The findings from this thesis can be used as a guide in the development of energy policies and sustainable strategies for the attainment of low-carbon development in the long term in Nigeria.

Keywords: Nigeria LEAP model; Scenario Analysis; Least-Cost Electricity generation; Cost-Benefit Analysis; Sustainable Strategies; Low Carbon Development.

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Table of Contents

List of Tables

List of Figures

Chapter 1. Introduction

This thesis deals with the development of an energy model for Nigeria’s long-term energy scenarios. This chapter introduces the general overview of the thesis. It starts with an introduction and then presents the background of the problem, the research questions and objectives, and the methodology, scope, and significance of the study.

1.1 Overview

In the last century, the world saw a transition in energy use from coal to petroleum. Due to the increased globalization and industrialization, the global demand for energy increased exponentially (Suganthi & Samuel, 2012). With the increase in the demand for energy, its production also increased, leading to a situation in which about 80% of the global energy supply came from fossil fuel (International Energy Agency [IEA], 2008). The increase in the reliance on fossil fuel resulted in an increase in the global greenhouse gas emissions, which raised issues about the sustainability of the environment due to problems like climate change and resource depletion (Van Ruijven et al., 2008). Besides the high energy demand of industrialized countries, developing countries rapidly increased their energy consumption, which contributed to sustainability problems (Urban et al., 2007). Therefore, the acknowledgement of the increasing influence of developing countries on the global energy settings cannot be overemphasized.

Energy consumption has been one of the most reliable indicators of the development and quality of life that has been attained by a country, and the necessity of meeting the forecasted energy demand for a given period of time is the rationale behind energy planning (Cormio et al., 2003). According to the World Energy Council, “Energy planning is that part of economics that is applied to energy problems, taking into account the analysis of the energy supply and demand as well as the implementation of the means for ensuring the coverage of the energy needs in a national or an international context” (Energy Dictionary, 1992). The methods that are used in energy planning are classified into planning models by analogy and by inquiry (Kleinpeter, 1995).

The consistency in the methods depends on the time interval, which can be short-term (about 5-10 years), medium-term (10-20 years), or long-term (above 20 years). Since the mid-1970s, energy modeling has been a tool for national energy planning, and it was used to understand the implications of the first oil crisis (Nakata, 2004). The researchers since then have employed different energy models to address the policy and planning concerns of energy, the economy, and the environment (Pandey, 2002).

1.2 Background of the Problem

In many developing countries mostly in Africa and some in Southeast Asia, access to clean energy is known to be unreliable and to have high disruption costs, which affects the production efficiency and competiveness (Emodi & Yusuf, 2015a). Considering that it is endowed with the widest possible range of energy resources, the African continent has experienced relatively low energy consumption in general and low electricity consumption in particular (Moyo, 2012).

Nigeria is experiencing a remarkable paradox: the abundance of energy resources and widespread energy poverty, with about 40% of the population having access to the grid electricity supply and 70% depending on firewood (Eleri et al., 2012). The use of firewood is a major indoor pollution hazard and has caused the death of about 79,000 Nigerians since 2011 due to smoke inhalation (Eleri & Onuvae, 2011). According to a 2013 study by the World Health Organization, the number of deaths caused by smoke inhalation from firewood use by women has reached 98,000 (Emodi & Boo, 2015a).

The Nigerian government has acted to address the issue of energy poverty by increasing the amount of gas power plants for electricity generation (Emodi & Boo, 2015b), while plans are still in progress to introduce other sources of energy services. The plans are being formulated by the government agency Energy Commission of Nigeria (ECN), which is responsible for the strategic planning and coordination of national policies in the field of energy in all its various forms in Nigeria (Energy Commission of Nigeria [ECN], 2015).

ECN carried out a study to ascertain the projected future energy demand and supply of Nigeria under four scenarios. This study was carried out using the Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE), and the results are included in the current National Energy Master Plan (National Energy Master Plan [NEMP], 2014).

1.3 Statement of the Research Problems

Below are the problems that this thesis attempted to address.

1) The study that was carried out by ECN did not develop scenarios considering the various parameters that can influence the energy demand. The only parameter that was considered was the gross domestic product (GDP), which is not the only determinant of energy demand increase. Other variables, such as population, income, household size, technology, and energy prices, also influence the energy demand. Also, the least-cost options were not presented in the ECN study.
2) The impact of the future energy policy implementation and strategies were not considered in the ECN study. The impact of various energy policies is expected to alter the energy consumption pattern of the country in the short, medium, and long term. In addition, incentives such as the feed-in tariff may also affect the country's energy consumption pattern.
3) The effect of greenhouse gas (GHG) emission on the environment was not taken into account in the ECN study. The contribution of GHGs to climate change cannot be left out when performing energy modeling because this will have a direct impact on the society. The effect of climate change can be observed in almost all parts of Nigeria, and as such, the consideration of GHG reduction is important.
4) Provisions were not made to identify the power plants with least-cost electricity generation potential in Nigeria's future electricity mix. This is very important because it will aid in the identification of the most economical generation expansion plan to achieve a certain level of

reliability in meeting the forecasted electricity demand. Furthermore, the investment in energy technologies can be decided based on cheaper power plants and a considerably lower GHG emission rate.

1.4 Research Questions

This thesis presents two research questions derived from the research problems. The first question was developed from the first, third, and last problems stated in section 1.2 while the second research question concerns the problem also stated in section 1.2. Below are the research questions in this thesis.

1) What are the projections of the energy demand in Nigeria and how will the demand be met using a least-cost combination of technology options without a similar expansion in GHGs?
2) Which sustainable energy policy options are recommended to improve the socioeconomic and energy situation in Nigeria?

1.5 Research Objectives

To answer the aforementioned research questions and to address the research problems, the following objectives were adopted by this thesis:

1) to develop the long-term energy scenarios for Nigeria using the Long-Range Energy Alternatives Planning System (LEAP), considering the vital factors that may influence the future energy policies;
2) to examine the long-term energy impact of the aforementioned energy

scenarios in terms of the energy supply mix, energy demand, electricity generation mix, and GHG emissions;

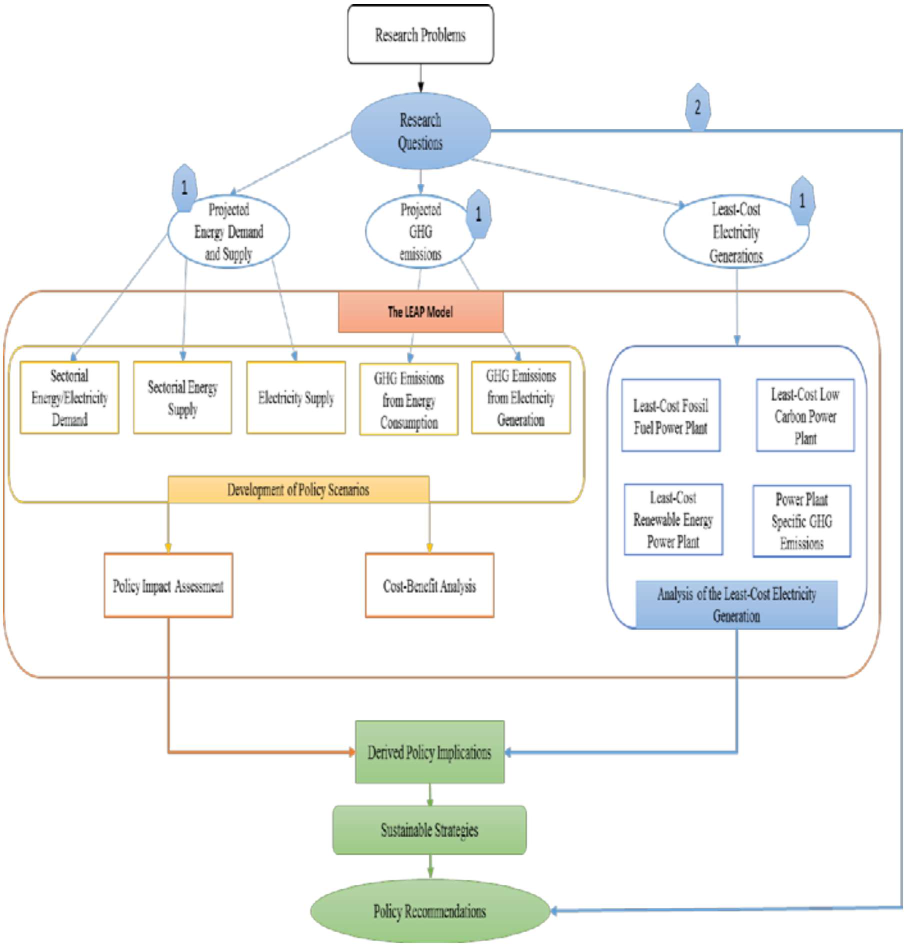
3) to further explore the least-cost electricity generation options; and
4) to recommend sustainable energy policy options that can improve the energy situation in Nigeria using a low-carbon approach.

1.6 Methodology

A graphical representation of the research methodology that was employed in this study is presented in Figure 1-1, including a general overview of the methodology and the procedures under it. It also includes the research problems, questions, objectives, and methodological framework. Furthermore, included in this section is the detailed step-by-step methodological procedure.

First, a general overview of the Nigerian energy sector is given, with an extensive review of the various energy resources, the past trend of the energy demand and supply, and an insight into the roles of the relevant government agencies and policies. This is intended to guide the reader with regard to the current situation of the energy sector in Nigeria as it relates to this thesis. The next step is a review of the existing energy forecasting models and literatures applying the LEAP model. This was done to explore the characteristic features of the existing energy forecasting models and to establish a basis for the selection of the model that was used in this thesis. The literature review examines the scholarly contributions in the economic literature that applied the LEAP model to various economic sectors in different countries. This further establishes the rationale behind the development of four policy scenarios (one reference scenario and three alternative scenarios) for the Nigerian LEAP model.

Figure 1-1: Methodologies



The developed policy scenarios were projected from the base year, 2010, to the target year, 2040. This was done considering various parameters that can alter the energy system in the future: GDP, income, population, household size, and sector growth rate. The projection/forecast includes the energy demand and supply, electricity demand and supply (including capacity expansion), GHG emissions, and costs and benefits.

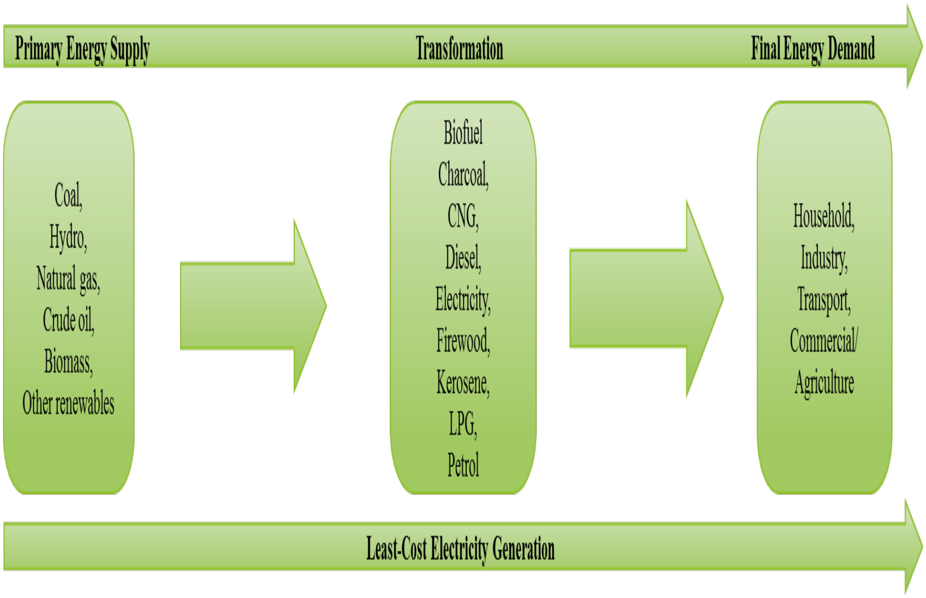
The developed alternative scenarios were examined to assess the impact of the various policies and strategies applied to each scenario compared to the reference scenario. The methodology was extended to include least-cost electricity generation, which was carried out through the optimization of the selected power plants that were used in the analysis of the different scenarios. The power plants' specific GHGs emissions over the period under observation were also determined using the least-cost electricity generation methodology.

Sustainable strategies were developed from various successful country case studies, and this was in relation to the developed scenarios. Policy implications were then drawn from the scenarios' results, the cost-benefit analysis, and the least-cost electricity generation to provide sustainable policy recommendations.

1.7 Scope of the Research

This study focused on modeling the future energy demand and supply in Nigeria using the LEAP model, as well as the GHG emission. A graphical representation of the research scope is shown in Figure 1-2. Concentration was given to the following: (i) the primary energy supply mix, including coal, hydro, natural gas, crude oil, biomass, and other renewables; (ii) transformation (biofuel, charcoal, compressed natural gas, diesel, electricity, firewood, kerosene, liquefied petroleum, gas, and petrol); (iii) final energy demand (household, industry, agriculture, and transport sectors); (iv) GHG emission reduction potentials; and (v) least-cost electricity generation.

Figure 1-2: Scope of Research



Through LEAP modeling, the following four scenarios were examined: the reference (REF), low-carbon moderate (LCM), low-carbon advanced (LCA), and green-optimistic (GO) scenarios. The scenarios, which included various energy technologies, services, strategies, and policies, were analyzed to determine the most appropriate low-carbon approach of meeting the energy demand at the least cost and with low GHG emissions.

1.8 Significance of the Research

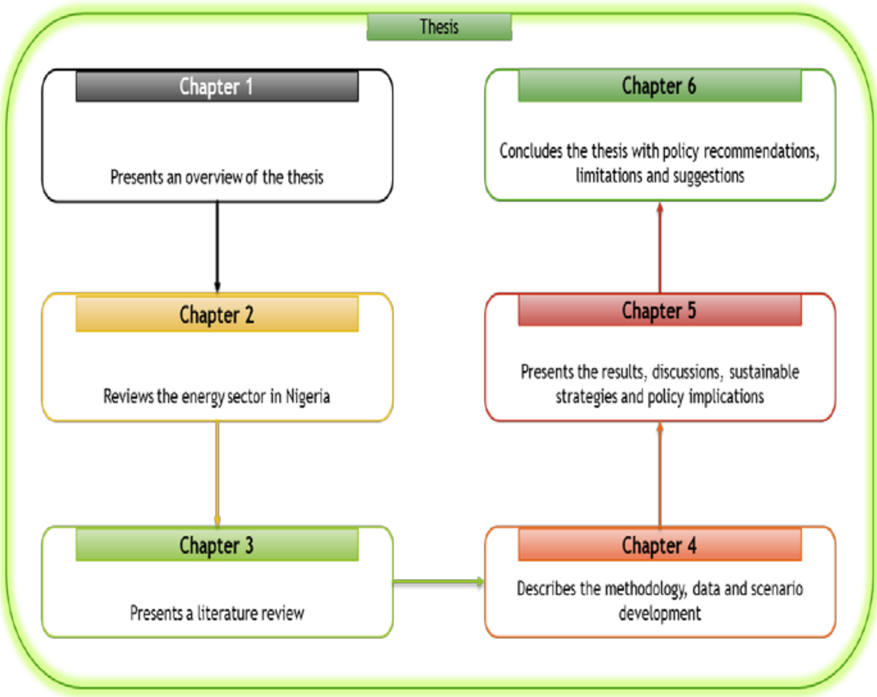
This research is significant for the reasons cited below.

- Based on the Nigerian LEAP model, a bottom-up energy model for the Nigerian energy system was derived in this research. The bottom-up model is the first of its kind in the Nigerian context and covers important energy-intensive sectors.
- The three distinctive alternative scenarios drawn up in this research expand the possibility of capturing the future energy pathways for Nigeria. Although the future is uncertain, considering more changes in each scenario increases the chances of capturing the future pathways for the Nigerian energy system.
- This study will add to the body of knowledge in the Nigerian context by exploring the influences of energy policies and strategies on the future energy services in Nigeria. This was made possible through policy impact assessment, cost-benefit analysis, and least-cost electricity generation. This is important to the Nigerian government and policymakers in particular, and to the Nigerian society in general.

1.9 Structure of the Thesis

This thesis is divided into seven chapters, and a graphical representation of the thesis structure is shown in Figure 1.3. Chapter 2 presents the current situation of the energy sector in Nigeria. The chapter extensively reviews the energy resource potentials in Nigeria and the energy supply and consumption, and then presents insights into the existing government agencies and policies concerned with energy development. Chapter 3 reviews the available literature on both the existing energy forecasting models and the models applying the LEAP model. The chapter explains the characteristics of the existing energy forecasting models and then reviews the available literature with LEAP model application. Chapter 4 describes the methodological approach that was applied in this thesis.

Figure 1-3: Thesis Structure



This includes a description of the LEAP model and the algorithm that it uses in forecasting the future energy demand, supply, GHG emissions, costs and benefits, and least-cost electricity generation. The scenario development and data collection processes are also discussed in Chapter 4.

The results of the developed policy scenarios are presented in Chapter 5. This chapter also discusses the impact of the energy policies on the scenarios, the costs and benefits, and the least-cost electricity generation and presents some sustainable strategies for low-carbon development in Nigeria. Further, the chapter summarizes the policy implications. Chapter 6 concludes the thesis with some policy recommendations and presents the research limitations and suggestions for further studies.

Chapter 2. The Energy Sector in Nigeria

The chapter presents the status quo of Nigeria's energy sector and is divided into five sections. The first extensively reviews the various conventional and renewable energy resources in Nigeria. The second and third sections presents the primary energy supply and consumption respectively. The forth section presents an insight into the various government ministries, parastatals and agencies that are relevant in the Nigerian energy sector. The last section in this chapter explore the Nigerian energy policies and strategies.

2.1 A Brief History on the Nigerian Power Sector

The Federal Government of Nigeria (FGN) have been responsible for the formulation of energy policy development and regulation, including operation and investment in the Nigerian energy sector before 2005[1]. After which the FGN established the Electricity Power Sector Reform Act (Federal Government of Nigeria [FGN], 2005). The Federal Ministry of Power (FMP) conducted regulation of the power sector, while the National Electric power Authority (NEPA) handled operation in the sector. Part of the responsibility of NEPA was for power generation, transmission and distribution[2]. NEPA however ran a monopoly system from its inception in 1972 to its defunct in 2005, with control of power generation capacity of about 94%, while transmission, system operators, distribution and their marketing sector was

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[1] www.energypedia.info/wiki/Nigeria_Energy_Situation
[2] www.nigeriaelectricityprivatisation.com/?page_id=2

100% owned by them (Nigeria Bureau of Public Enterprise [NBPE], 2015).

Inefficiencies in operations and financial performance in NEPA led the amendment of the Electricity and NEPA Acts by the FGN in 1998 to remove the monopoly held by NEPA and encourage the participation of the private sector[3]. A reform agenda was specified in the National Electric Power Policy (2001), while the legal basis for the unbundling of NEPA and formulation of successor companies (including privatization) was provided in the EPSRA (National Mirror, 2014). NEPA was restructured to form the Power Holding Company of Nigeria (PHCN) in 2007 which stop existing after 30th September 2013[4].

The FGN sort various means to sell off its stake in the electricity services industry[5] (i.e. privatization), but retained the transmission grid as a public entity (Aladejare, 2014). The generation companies are now called the GENCOs, while the distribution companies were called the DISCOs, and the FGN operates the Transmission Company of Nigeria[6] (TCN) (KPMG, 2013). The generators and transmission lines are interconnected in the national grid system which is controlled at the National Control Center, Oshogbo. Figure 2-1 shows the TCN/NIPP[7]/IPP[8] projects in Nigeria as presented by PHCN[9].

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[3] www.placng.org/new/laws/E7.pdf

[4] www.nigeriaelectricityprivatisation.com/

[5] The state-owned electricity generation companies was placed for sale by the Nigerian government in two ways in which one was the outright sale of the thermal power stations, while the other was through concession of the hydroelectric stations

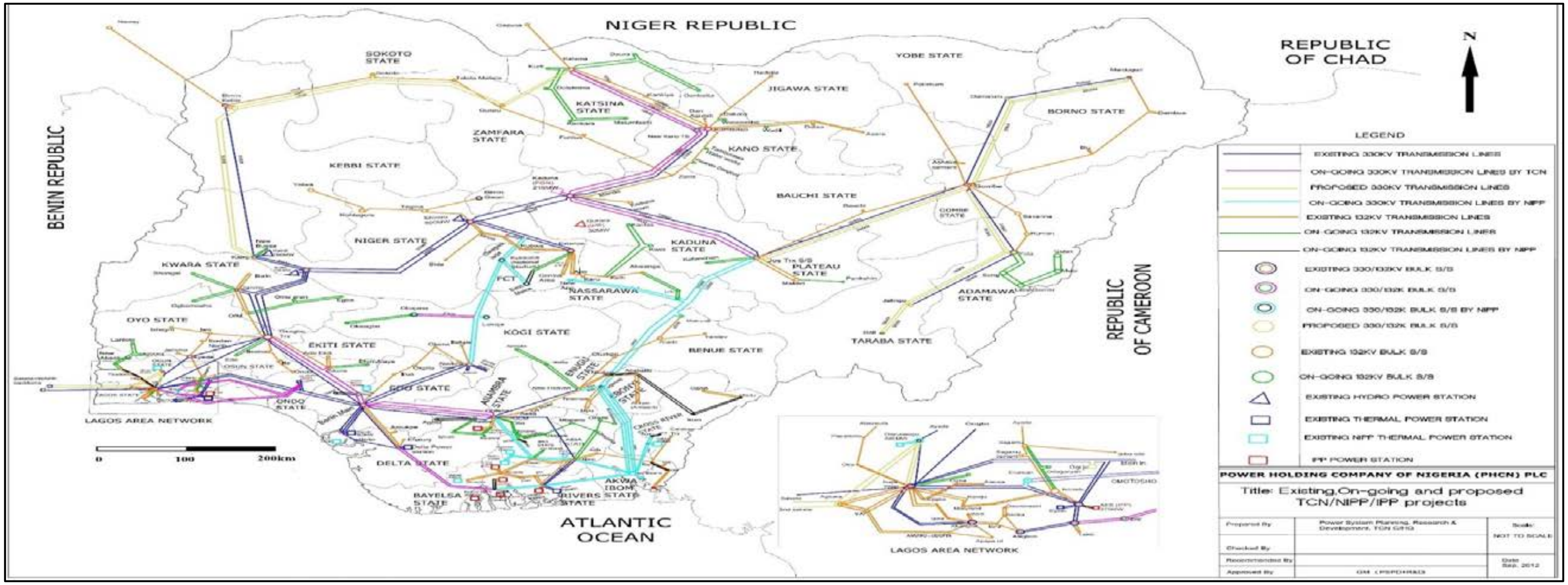
[6] The TCN is divided into two divisions; the systems operator division and a market operator division.

[7] National Integrated Power Project

[8] Independent Power Producer

[9] This was presented in 2012.

Figure 2-1: Map of existing, on-going and proposed TCN/NIPP/IPP projects for electricity transmission in Nigeria[10]



10 Transmission Company of Nigeria [TCN], Akpan (2014).

The FGN took the next step in setting up the Nigerian Electricity Regulatory Commission (NERC) and the Nigerian Bulk Electricity Trading Plc. (NBET)[11]. The Operators of the Nigerian Electricity Market[12] (ONEM) was established with the responsibility of the wholesale market and settlement operator. After the establishment of the agencies, the FGN then placed the new NIPP power plants for sale. Although most of the GENCOs companies were bound to suffer at a loss, the FGN allocated N50 billion to them so as to reduce the impact of the loss (KPMG, 2013). The NBET buys electricity from the GENCOs and sales it to the DISCOs for sale to the final electricity consumers[13].

The steps discussed above were taken to unbundle the PHCN and this is classified as the pre transition electricity market (pre-TEM) development[14]. However, until the TEM becomes fully functional, some rules govern the electricity market in which the GENCOs charge the ONEM (Detail Commercial Solicitors, 2014). The financing requirement for the market are set by the ONEM on the basis of the MYTO 11[15]. The aim was to develop a framework which can oversee the arrangement of electricity trading during the pre-TEM period is still in-effect. The TEM will be functional when electricity market become fully privatized and private sector oriented[16]. The location of

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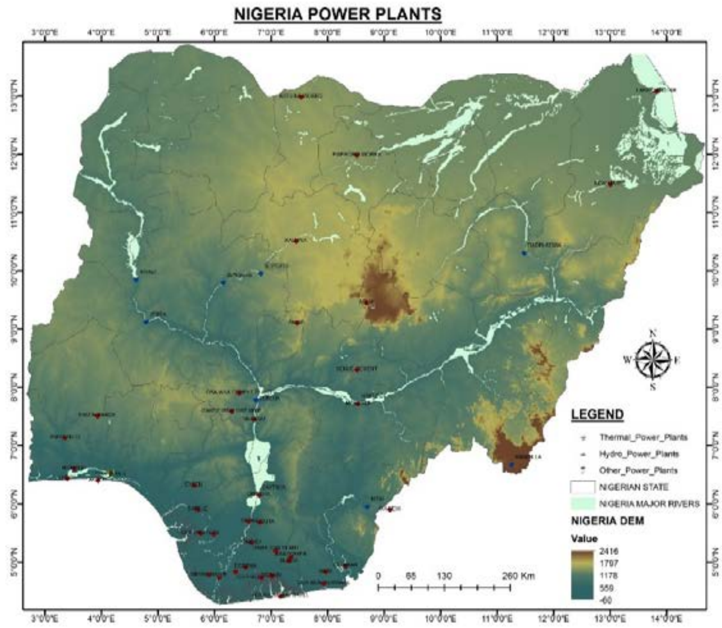
[11] The NBET was set-up, although not fully effective, but was intended to come into full operation when the Nigerian electricity market becomes completely privatized and then the power purchase agreements will be signed and passed on to the DISCOs (The Presidency, 2013).
[12] This responsibility extends to the management of the metering system of the TCN, DISCOs and the GENCOs.
[13] See www.nbet.com.ng
[14] For a more insight into this, see Detail Commercial Solicitors (2015)
[15] Multi-Year Tariff Order 2.
[16] See www.lexology.com/library/detail.aspx?g=f77e24d6-8338-47d6-9e4d-ed5b89a51862

the GENCOs (power plants) is shown in Figure 2-2.

Figure 2-2: Nigeria Power Plants. Source: Nwoko (2015a)



2.2 The Nigerian Energy Resources

Several energy resources are available in Nigeria in abundant proportions. This includes conventional and non-conventional (renewables) energy resources, and are vastly distributed across the regions of the country. The energy resources in Nigeria are discussed in terms of conventional and renewable energy resources, in the following sections.

2.2.1 Conventional Energy Resources

Nigeria has considerable reserves of conventional energy resources. It is one of the world's largest producer of oil and it has the largest reserves of natural gas on the African continent. It therefore became the world's fourth leading exporter of liquefied natural gas (LNG) in 2012. Nigeria is also a member of the Organization of the Petroleum Exporting Countries (OPEC), which it joined in 1971 after over 10 years of oil production that began in the late 1950s (U.S Energy Information Agency [EIA], 2014a). Coal reserves stand at 2.175 billion tons, but production has long since ceased as the government has concentrated on the oil and gas resources.

Nigeria is also rich in tar sand or oil sand, which is a combination of clay, sand, water, and bitumen (a heavy black viscous oil). Tar sands can be mined and processed to extract the oil-rich bitumen, which can be refined into oil (Oil Shale and Tar Sands Programmatic EIS [OSTSPEIS], 2014). Table 2-1 lists the conventional energy reserves in Nigeria and their potentials.

Table 2-1: Conventional Energy Reserves in Nigeria and their Potentials

(Source: National Bureau of Statistics [NBS], 2007)

Resource type	Reserves		Production	Domestic Utilization (natural units)
	Natural units	Energy units (Btoe)		
Natural gas	187 trillion SCF	4.19	6 billion SCF/day	3.4 billion SCF/day
Crude oil	36.22 billion barrels	5.03	2.5 million barrels/day	450,000 barrels/day
Tar sands	31 billion barrels of equivalent	4.31	Insignificant	Insignificant
Coal & lignite	2.175 billion ton	1.52	–	–

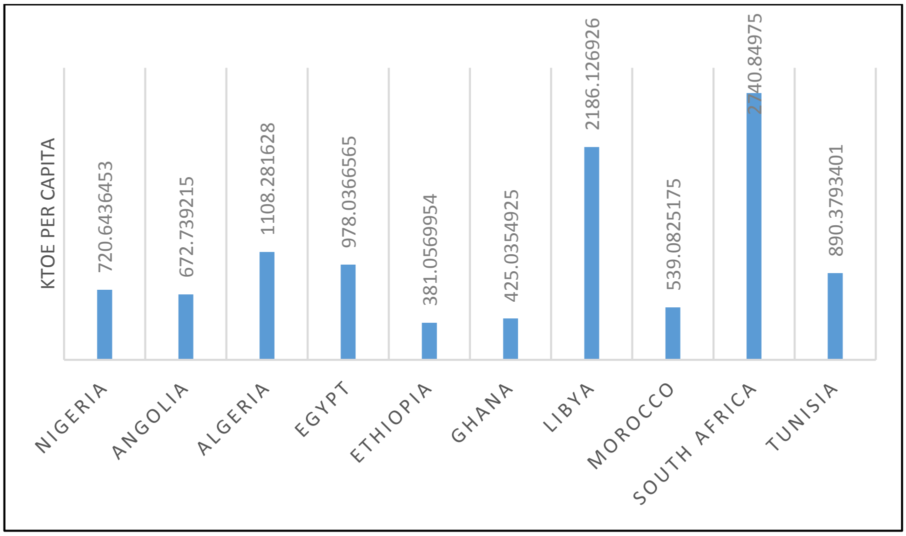
Nuclear element	None	–	–	–

According to the US Energy Information Agency estimate, the total primary energy consumption in Nigeria in 2012 was about 4.5 quadrillion Btu (British thermal units). This comprised 80% from traditional biomass and waste (wood, charcoal, manure, and crop residue) and much smaller percentages from oil and natural gas (Figure 1). The Nigerian oil and gas sector is regulated by the Nigerian National Petroleum Corporation (NNPC), which was established in 1977 with the secondary responsibility of overseeing the development of the upstream and downstream oil sectors[17].

Despite the large energy resources in Nigeria, energy consumption is relatively low compared with other African countries with comparable energy resources (Figure 2-3). This low energy consumption is due to the recurrent scarcity of petroleum products at vehicle petrol stations, while frequent electricity "black-outs" have resulted in a high reliance by the Nigerian populace on personal electricity generators.

[17] See "Oil and Gas in Nigeria". Available online at: www.mbendi.com/indy/oilg/af/ng/p0005.htm.

Figure 2-3: Energy consumption per capita in some African countries in 2012[18]

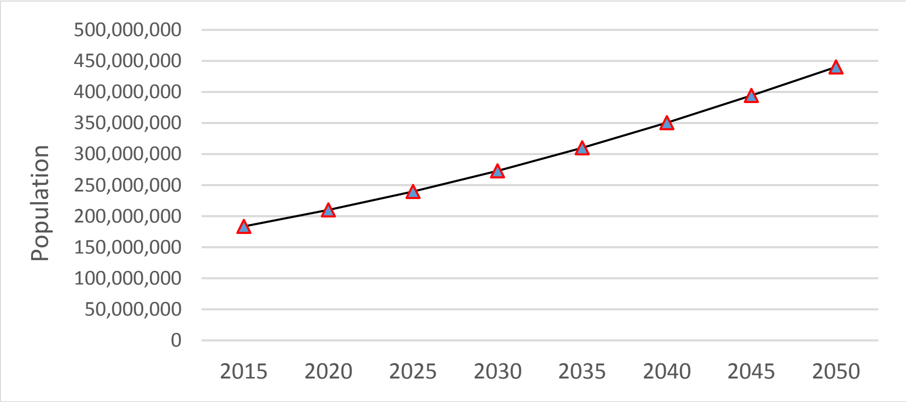


Despite the scarcity of petroleum products, energy demand has been increasing in Nigeria, because of the increase in economic development and the growth of the population. According to Sambo et al., (2006), the major driver behind increasing energy demand is the population growth, while the most important determinant is the level of economic activity, measured by the country's gross domestic product (GDP).

Nigeria's population is projected to grow from 178,516,904 (as of 2014) to 183,523,432 by 2015, 273,120,384 by 2030, and 440,355,062 by 2050 (Figure 2-4). To address the needs of this increasing population, the Energy Commission of Nigeria (ECN) analyzed the country's energy sector from 2000 to 2030 using the Wien Automatic System Planning (WASP) package and the Model for Analysis of Energy Demand (MAED).

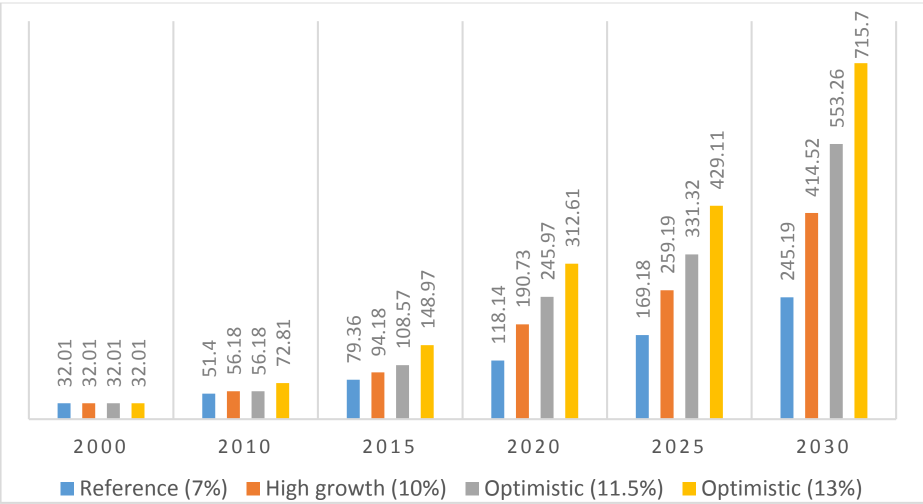
[18] The World Bank (2014)

Figure 2-4: Projections of population growth in Nigeria[19]



The results (Figure 2-5), based on reference, high growth, and two optimistic (11.5% and 13% GDP growth) scenarios, project that energy demand in Nigeria will increase by 2.5, 3, 3.5, and 4.5 times, respectively, from 2000 to 2015, and by 8, 13, 17, and 22.5 times, respectively, from 2000 to 2030.

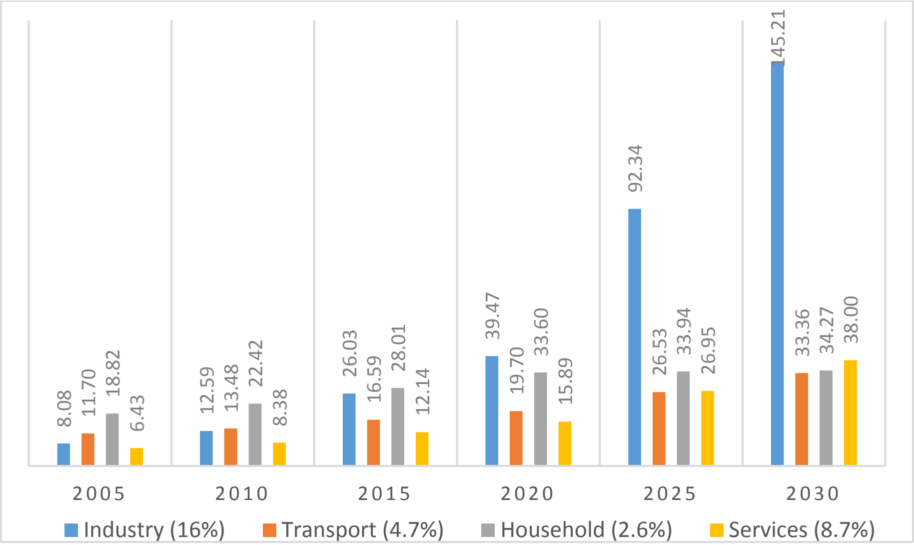
Figure 2-5: Projections of total energy demand (Mtoe) in Nigeria



[19] World Meters (2015)

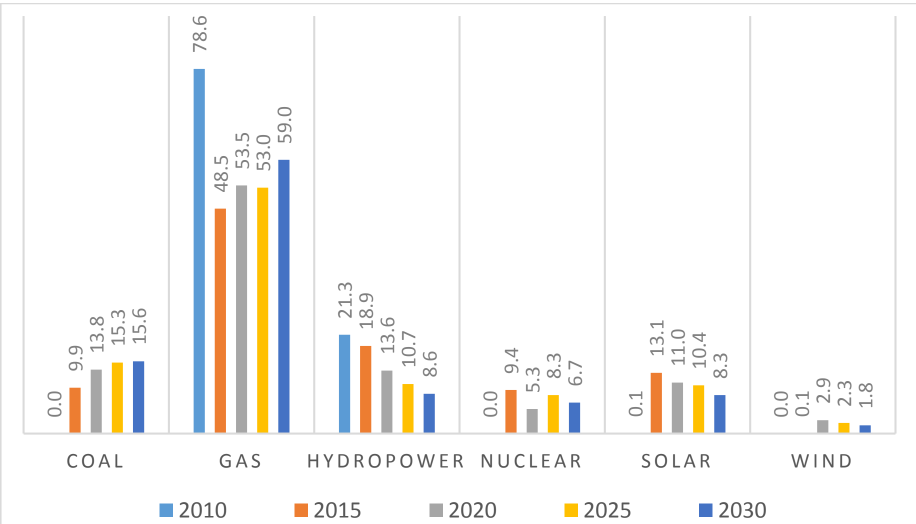
As described by the ECN, the increase in energy demand will develop in-line with the high level of economic activity expected in Nigeria, as measured by the total GDP. The sectorial energy demand (Figure 2-6) shows that although the industrial sector had lower energy demand in 2005 (8.05 Million Tonnes of Oil Equivalent (Mtoe)), it will have the highest energy demand by 2030 at 145.21 Mtoe with GDP growth rate of 16.27%, as the economy begins to improve based on increased industrial activity. The service sector is projected to have the second highest growth rate of 8.7%, while the residential sector is expected to have the lowest average growth rate of 2.6%. These projections for increasing energy demand can only be met if effective policies are put in place.

Figure 2-6 Total energy demand (Mtoe) based on 10% GDP growth rate



The ECN undertook a study using MESSAGE[20] under the auspices of the IAEA[21] to ascertain the future fuel mix for the diversification of Nigeria's electricity supply. The study used six different types of fuel for the optimization: coal, natural gas, hydropower, nuclear, solar, and wind energy. Oil was not considered in the optimization because of its use for export to the international energy market, meeting domestic energy demand and no current plans by the government to establish oil power plants in the future. The results is shown in Figure 2-7.

Figure 2-7: Nigeria's current and future electricity generation capacity (%) by fuel (Reference case)



These results were based on the reference case scenario, and show that energy from coal and nuclear sources (currently not part of the nation's

[20] Model for the Energy Supply Strategy Alternatives and their General Environmental Impact.
[21] International Atomic Energy Agency.

electricity generation mix) will account for 15.6% and 6.7% of the total, respectively, by 2030. The proportion of Nigeria's energy generated by hydropower will decrease from 21.3% in 2010 to 8.6% by 2030. The high growth and optimistic scenarios follow similar supply patterns (Sambo, 2008).

2.2.1.1 Crude oil

Nigeria produces mostly light sweet crude oils that are predominantly exported to the world market. Table 2-2 shows the characteristic features of the crude oils produced in Nigeria and their ports of sale used for export.

Table 2-2: Characteristic features of Nigeria's crude oil

(Source: Energy Intelligence, 2015)

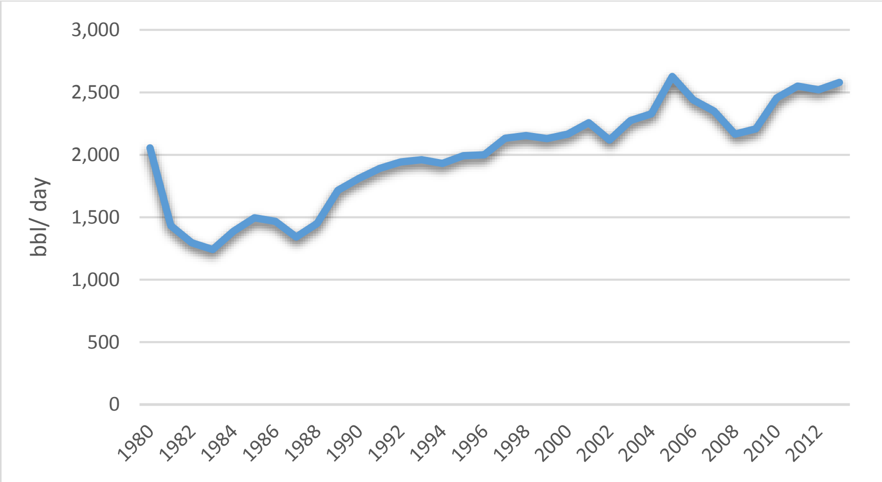
Product name	**Sulphur content (as % of mass)**	**API gra vity (in degr ees)**	**Ports of sale**
Agbami	0.044	47.2	0ffshore
Amenam Blend	0.12	38.2	Unity FSO/Odudu Terminal
Amenam/ Mars Blend	0.94	33.5	-
Antan Blend	0.27	26.4	Knock Taggart FPSO/ Antan Te rminal
Bonga	0.26	29.1	Bonga FPSO
Bonny Light	0.16	33.4	Bonny
Brass River	0.16	-	Brass River Terminal
EA Crude	0.08	35.1	Sea Eagle FPSO
Erha	0.12	31.8	Erha FPSO
Escravos	0.17	34.2	Escravos
Forcados (to Europe)	0.16	30.8	Forcados
Odudu	0.15	30.5	-
Okono	0.15	30.50	-
Oso Condensate	0.06	45.7	Qua Iboe
Qua Iboe	0.14	36.3	Qua Iboe
Ukpokiti	0.14	36.3	-
Yoho Crude	0.08	39.3	Falcon FPSO

In Nigeria, commercial production of crude oil began in 1958 based on proven recoverable reserves of 1.48 × 106 billion tonnes. Production rose from an initial quantity of 3.1 million metric tonnes to 20.3 million tonnes in 1960, 54.2 million tonnes by 1970, and 104.1 million tonnes in 1980, all in response to demand from international markets rather than from domestic demand. On average, local consumption accounted for just 3% of production, while the remaining 97% was exported. Since 1980, three domestic petroleum refineries have supplied petroleum products for local consumption: the Kaduna Refinery with a capacity of 110,000 bbl/d (barrels per day), Port Harcourt Refinery with a capacity of 210,000 bbl/d, and Warri Refinery with a capacity of 125,000 bbl/d (Oyedepo, 2014).

As shown in Figure 2-8, the production of crude oil in Nigeria increased rapidly between 1980 and 2012; however, the rate of increase was dependent on the economic and geopolitical situations in both producing and consuming countries. Nigeria's current production capacity of 2.4 million bbl/d remains low because of problems in the Niger Delta[22] and OPEC production restrictions. However, projections have placed future (2030) production at over 5.0 million bbl/d (Ajao et al., 2009).

[22] The Niger Delta region has been known for militant activity, but this activity was halted by the intervention of the late Nigerian President Umaru Yar'Adua who granted amnesty to the militants.

Figure 2-8: Crude oil production in Nigeria[23]



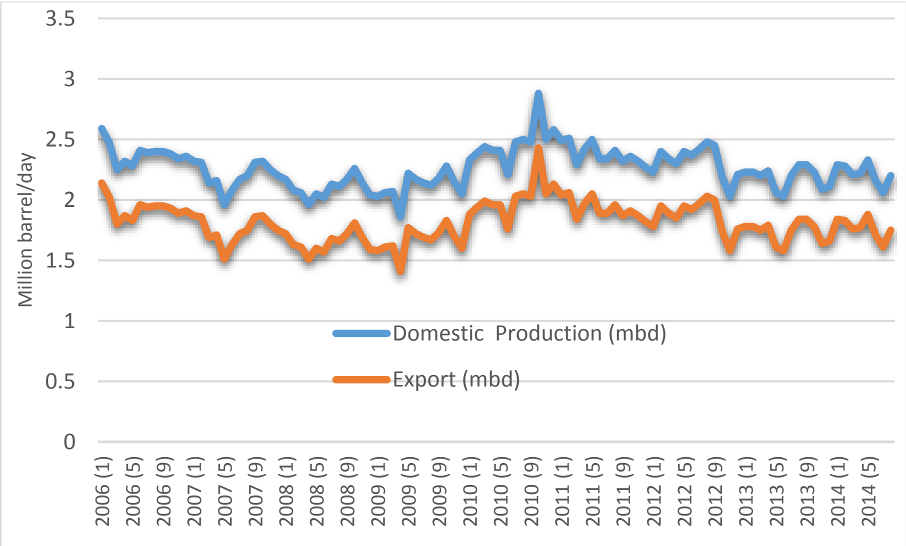
Crude oil production reached its peak in 2005, but has subsequently declined significantly because of the activities of militants in the Niger Delta region. These activities came to a halt in 2009 when amnesty was granted to the militants and by 2010, oil production began to increase as oil companies began operating at full capacity. The Nigerian government also took drastic measures to attract investment in deep-water acreage in order to diversify the location of oil fields and increase oil production. This has resulted in the production of an additional 800,000 bbl/d since 2003. However, crude oil production declined from 2011 to 2012 because of heavy floods and supply disruptions.

In addition to the challenges faced by the government, the indigenes of the Niger Delta region suffer from the effects of environmental damages resulting from pipeline vandalism. When pipelines are vandalized, crude oil is

[23] EIA (2015a)

stolen to supply illegal refineries. The result is damage to the environment and the risk of a pipeline explosion for local communities. The rates of domestic production and export of crude oil did not improved significantly between 2006 and 2014 (See Figure 2-9) because of the issue of crude oil theft.

Figure 2-9: Rates of domestic production and export of crude oil in Nigeria[24]



The oil price in Nigeria has been in line with the OPEC price and has fared well over the years, reaching its peak in 2008, but declining in 2009 (Figure 2-10). The price of oil in Nigeria was US$102.33 per barrel in August 2014; however, with the recent fall in the crude oil price[25], which is US$53 for West Texas Intermediate (WTI) and US$57.33 for Brent crude, the country's economy will be adversely affected. The previous rise in the crude oil price was due to high oil consumption in countries such as China and India, in

[24] CBN (2015a)
[25] According to www.oilprice.net on 2nd January 2015

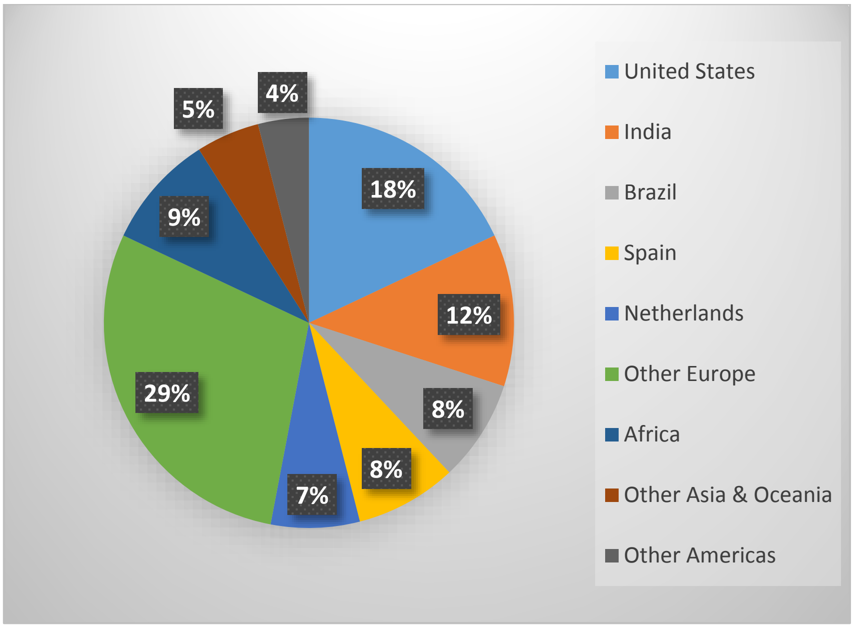
conjunction with conflict in key oil exporting countries such as Libya[26].

Figure 2-10: Crude oil prices in Nigeria. Source: CBN (2015b)

High oil prices induced companies in Canada and the United States (US) to start drilling for new hard to extract crude in North Dakota's Shale formations and Alberta's oil sands. This has resulted in a "Price-War" between OPEC and the US (VOX, 2015). The US, which was the largest single importer of crude oil from Nigeria (Figure 2-11) in 2012, ceased importing oil at the end of 2014. Other countries have also reduced their oil imports from Nigeria, including the countries of the European Union.

[26] www.useconomy.about.com/od/commoditiesmarketfaq/p/high_oil_prices.htm

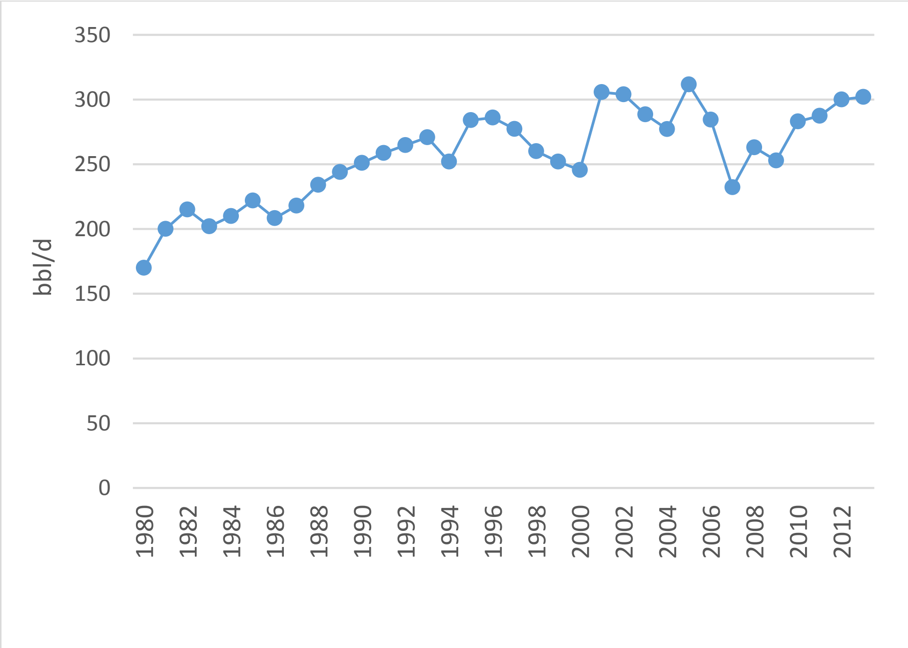
Figure 2-11: Crude oil and condensate exports in Nigeria in (2012)[27]



Fuel subsidies cost the Nigerian government US$8 billion in 2011 alone, which constituted 30% of federal government expenditure, 4% of the country's GDP, and 118% of the capital budget. However, the Nigerian government removed the fuel subsidy on the 1st of January 2012. Subsequently, oil consumption in Nigeria has increased, as shown in Figure 2-12. Downstream industries in Nigeria, which include domestic refineries and various petrochemical industries, use the crude oil produced in Nigeria. These refineries produce products such as linear alkyl benzene, benzene, heavy alkylate, and deparaffinated kerosene for domestic consumption (Nigerian National Petroleum Corporation [NNPC], 2015a).

[27] EIA (2015b)

Figure 2-12: Crude oil consumption in Nigeria[28]

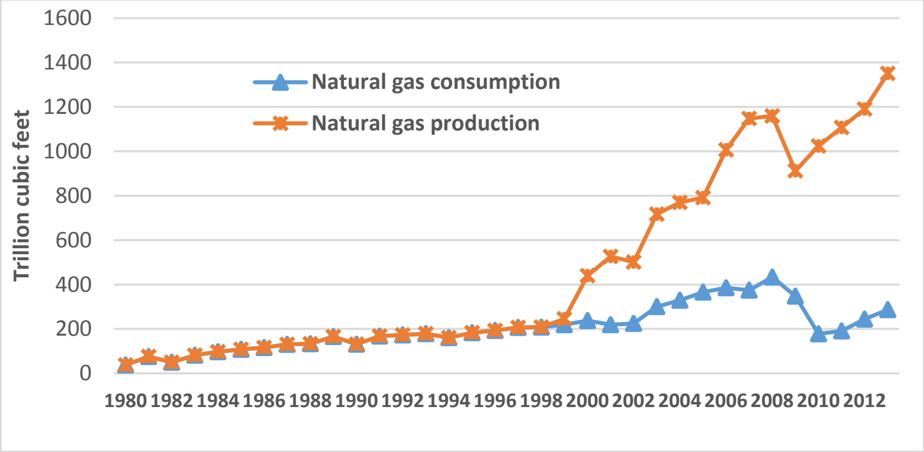


2.2.1.2 Natural Gas

The estimated proven reserves of natural gas in Nigeria stand at 182 trillion cubic feet (TCF) with a mean gauge pressure of about 12 bar, a calorific value of 35 mJ/m3, and a mean specific volume of 1.56 × 10-3 m3/kg. In 2012, the production rate was about 1.35 TCF of dry natural gas (Figure 2-13), making Nigeria the 25th largest producer of dry natural gas in the world (ECN, 2007; EIA, 2015d, 2015e).

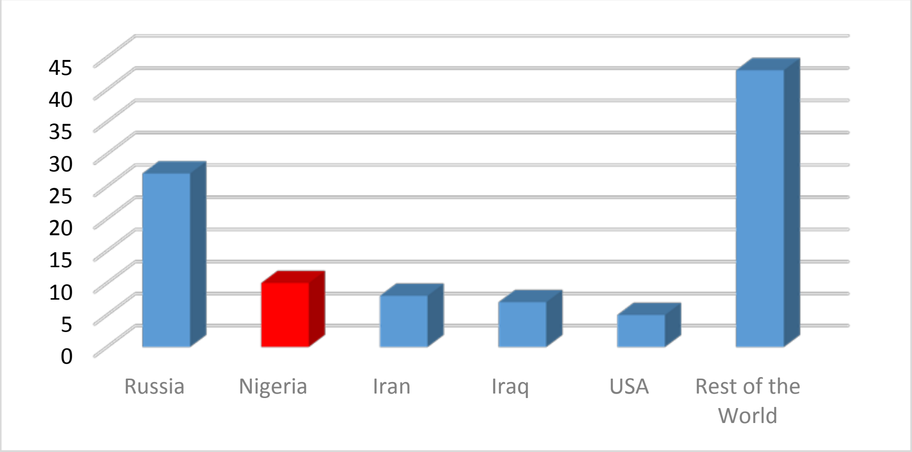
[28] EIA (2015c)

Figure 2-13: Natural gas production and consumption in Nigeria[29]



Natural gas reserves are located in the Niger Delta region of Nigeria (South-South). In the past, Nigeria flared about 73% of its gas because of poor infrastructure, which placed Nigeria second in the list of gas-flaring countries (Figure 2-14).

Figure 2-14: World's top natural gas flaring countries (2012)[30]



[29] CIA (2015a)
[30] EIA (2015f)

However, because of the efforts of the Nigerian government to reduce gas flaring through the financing and provision of relevant infrastructure to use the previously flared gas, Nigeria is now 365th on the list (Ibitoye, 2014). Infrastructure that uses the previously flared gas includes the power sector, which accounts for 80% of the total domestic consumption (Table 2-3, Figure 2-15) and generates 81% of the total electricity supply in Nigeria.

Table 2-3: Current and planned power plants in Nigeria and locations[31]

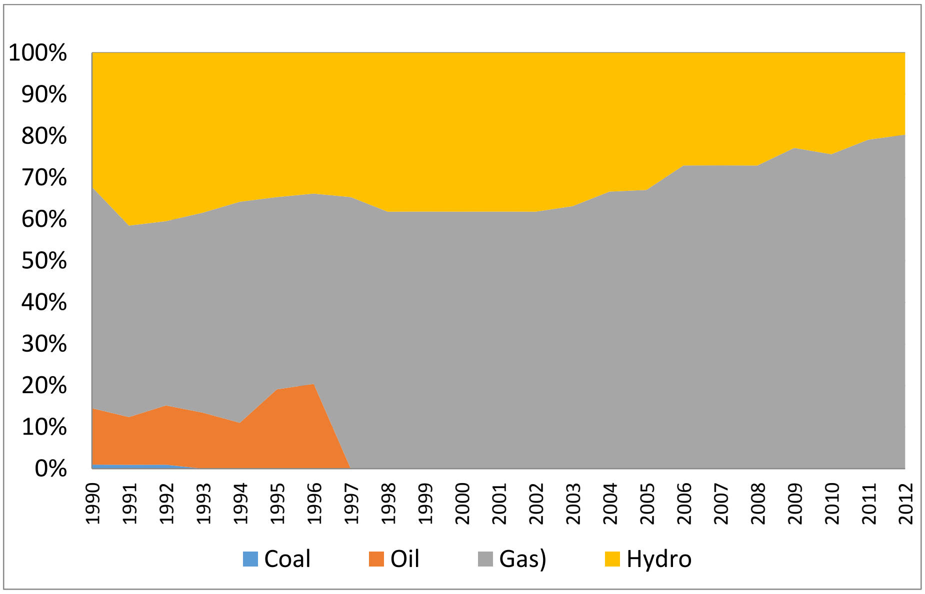
(Source: Emodi & Yusuf, 2015a)

Power Station	**Location**	**Type**	**Installed Capacity (MW)**	**Year Completed**
AES Barge	Egbin	SCGT	270	2001
Aba	Aba, Abia State	SCGT	140	2012
Afam IV-V	Afam, Rivers State	SCGT	726	1982
Afam VI	Afam, Rivers State	CCGT	624	2009
Alaoji (NIPP)	Abia State	CCGT	1074	2013
Calabar (NIPP)	Cross River State	SCGT	561	2014
Egbema (NIPP)	Imo State	SCGT	338	2013
Egbin	Egbin	Gas-fired steam turbine	1320	1986
Geregu 1	Geregu, Kogi State	SCGT	414	2007
Geregu 11 (NIPP)	Geregu, Kogi State	SCGT	434	2013
Ibom (NIPP)	Ikot Abasi	SCGT	190	2009
Ihorbor (NIPP)	Benin City	SCGT	450	2013
Okpai	Okpai	CCGT	480	2005
Olorunsogo	Olorunsogo	CCGT	336	2007
Olorunsogo 11	Olorunsogo	CCGT	675	2012
Omoku	Omoku	SCGT	150	2005

[31] NIPP=National Integrated Power Project, SCGT=Single Combined Gas Turbine, CCGT=Combined Cycle Gas Turbine, CFB=Circulating Fluidized Bed

Omoku 11 (NIP P)	Omoku	SCGT	225	2013
Omotosho 1	Omotosho	SCGT	336	2005
Omotosho 11 (N IPP)	Omotosho	SCGT	450	2012
Sapele	Sapele	Gas-fired steam t urbine	1020	1981
Sapele (NIPP)	Sapele	SCGT	450	2012
Ughelli	Delta State	SCGT	900	1990
Itobe	Kogi State	CFB Technology	1200	2015-2018
Kainji	Niger State	Reservoir	800	1968
Jebba	Niger State	Reservoir	540	1985
Shiroro	Kaduna State	Reservoir	600	1990
Zamfara (Planne d)	Zamfara State	Reservoir	100	2012
Kano (Planned)	Kano State	Reservoir	100	2015
Kiri (Planned)	Benue State	Reservoir	35	2016
Mambilla (Plann ed)	Taraba State	Reservoir	3050	2018

Figure 2-15: Electricity production by fuel type (%). (Source: Power Holding Company of Nigeria [PHCN], 2010)



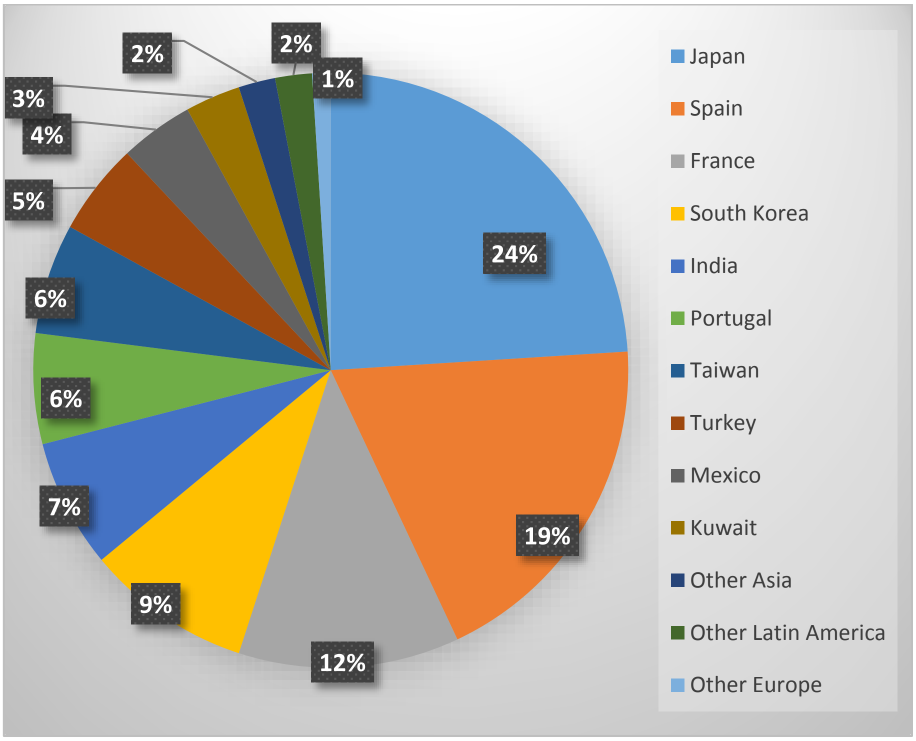
Based on the current amount of gas remaining in the natural gas reserves, it is expected that they will last for about 88 years (Kennedy-Darling et al., 2008). In order to improve natural gas activities, in 1988, through the NNPC, the government created a subsidiary and strategic business unit called the Nigerian Gas Company (NGC). This company is responsible for the development of policies for the transmission, distribution, marketing, and pricing of natural gas and all its derivatives to the market within Nigeria and West Africa (National planning Commission [NPC], 2009).

This implies that a monopoly exists in the Nigerian gas market, which also includes state and private companies such as the electricity companies and multinational companies (known as International Oil Companies; IOCs) including Shell, Chevron, and ExxonMobil who supply natural gas to the NGC (Tallapragada, 2009).

Natural gas consumption in Nigeria has been increasing since its discovery (Figure 2-13) and reached its peak in 2008 when a disruption in gas supply occurred. One of the IOCs (Shell) shut down their plants in order to repair damage to pipelines connected to the Soku plant. This damage was the result of pipeline vandalisation performed by local groups that were siphoning condensate. After five months, the plants re-opened but then closed again in 2009 because of operational problems. The Soku plant provides a substantial amount of gas to the NGC's liquefied natural gas (LNG) facility and, because of the supply disruption, a decline in gas production occurred (The Encyclopedia of Earth, 2015).

Nigeria's exports of natural gas (in the form of LNG) in 2012 are shown in Figure 2-16. Europe has reduced its LNG imports from Nigeria since 2012, whereas the US has completely stopped importing from Nigeria because of increasing domestic production. However, imports have increased in Asian countries such as Japan, South Korea, and India, while France, Spain, Portugal, Taiwan, and Turkey still maintain their LNG imports from Nigeria. In 2013, there was some supply disruption and a temporary blockade on Nigeria's LNG shipments, which led to a fall in its production and export; however, this did not affect domestic consumption.

Figure 2-16: Nigeria's LNG exports (2012)[32]



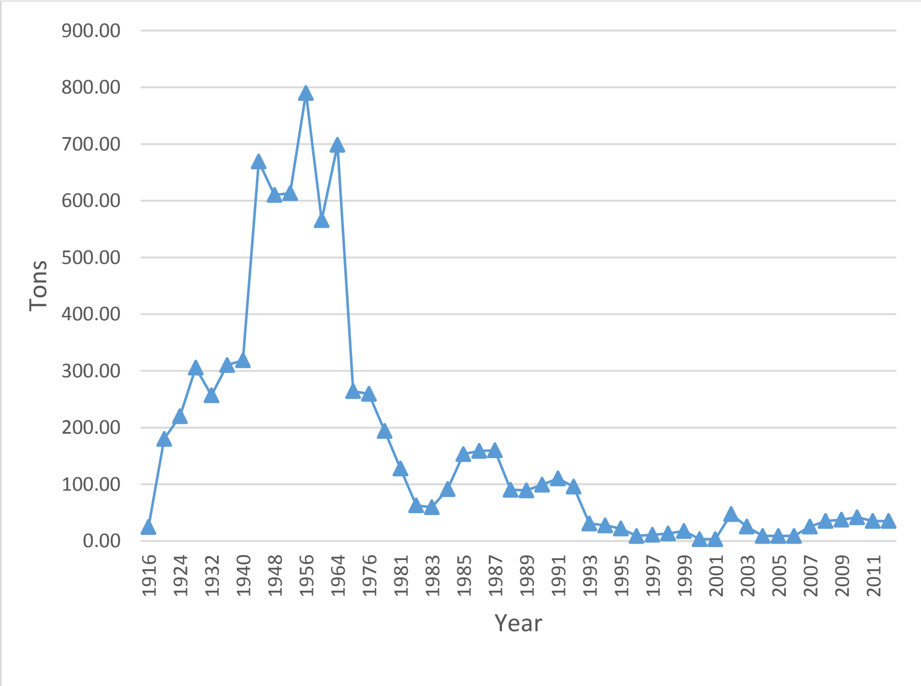
2.2.1.3 Coal

[32] EIA (2015g)

Coal was the first conventional fuel to be discovered and used in Nigeria. It was discovered in Enugu State, in the south-eastern region of Nigeria in 1909. The first coal mine, the Ogbete drift mine, was opened in 1916 with an output of 24,500 t. Its operation was merged with that of others within the country in 1950 following the formation of a new corporation known as the Nigerian Coal Corporation (NCC). The responsibility of the NCC in holding a monopoly on coal production (including coke mining) and sales was to exploit coal resources. The Polish firm KOPEX was in charge of its management from the NCC's formation until its collapse after the Nigerian Civil War in 1970 (Nwaobi et al., 2005).

Coal production reached a peak of 790,030 tons (Figure 2-17) in 1956 and about 70% of this quantity contributed to Nigeria's energy generation. Production began to decline when oil was discovered in 1956 at Oloibiri in the Niger Delta by Shell-BP, which was the sole concessionaire at that time (NNPC, 2015b). The Nigerian Railway Corporation was the largest consumer of coal in the country. The corporation began to convert their railway engines from coal to diesel and gas in 1955. By 1982, production of coal had fallen to 62,830 tons (TOPFORGE, 2015). Another set-back in coal production was the conversion of power plants from coal to oil by the National Electric Power Authority (NEPA) (now defunct) and only one coal-fired power plant was left.

Figure 2-17: Coal production in Nigeria (Tons). Source: CIA (2015b)



Following the discovery of coal in commercial quantities (1916–1980), the total cumulative production was about 25.3 million metric tons. By 1980, oil contributed 70% to electricity generation, compared with 25% and just 1% for gas and coal, respectively. In terms of coal consumption, about 95% of the coal produced in Nigeria was consumed by the Nigerian Railway Corporation, NEPA, and cement companies for heating cements. Coal consumption by the Nigerian Railway Corporation fell to 60% in 1958, less than 30% in 1966, and to an insignificant level by 1986. NEPA's coal consumption fell from 30% in 1966 to an insignificant level in 1970, and the last remaining coal plant was shut down in 1992 (Figure 2-15) (Enibe & Odukwe, 1990).

Because of the loss of its largest consumers, the NCC began to export its desirable low-sulphur-content coal to the United Kingdom and Italy. In 1999, the NCC lost its monopoly over the Nigerian Coal Industry (NCI) following the implementation of the federal government's privatization policy by the then civilian head of state (i.e. President Olusegun Obasanjo). In 2002, work stopped at all NCC-operated mines and the government established a technical advisory committee to revive the NCI (Odesola et al., 2013).

Current coal reserves in Nigeria are estimated to be 2.75 billion metric tons and the nation's proven reserves stand at 639 million tons. The locations of the coal deposits in Nigeria are mostly in eastern parts of the country, as shown in Table 2-4.

However, the coal reserves have not been fully explored or even marginally developed despite the long history of the coal industry. They are mostly lignite and sub-bituminous, although some are high-volatility bituminous deposits (Akubo et al., 2013).

Table 2-4: Coal reserves in Nigeria (Source: Essien & Igweonu, 2014)

Mine location	**State**	**Coal type**	**Estimated reserves (Million tonn)**	**Proven reserves (Million tonne)**	**Borehole record**	**Coal outcrop and seam thickness (m)**	**Coal depth (m)**	**Mining approach**	**Current status**
Okpara Mine	Enugu	Sub-Bituminous	100	24	20	Many	180	Under-ground	Functional
Onyeama mine	Enugu	Sub-Bituminous	150	40	Many	Many	180	Under-ground	Functional
Ezimo	Enugu	Sub-Bituminous	156	56	4	10 (0.6 –2.0)	30-45	Under-ground	
Inyi	Enugu	Sub-Bituminous	50	20	4	(0.9-2.0)	25-48	Open cast, Under-ground	
Amansiodo	Enugu	Bituminous (cokeable)	1000	NA	3	NA	563	Under-ground	
Ogugu/Awgu	Enugu	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	
Okaba	Kogi	Sub-Bituminous	250	73	Many	(0.8-2.3)	20-100	Open cast, Under-ground	Functional
Ogboyoga	Kogi	Sub-Bituminous	427	107	31	17 (0.8-2.3)	20-100	Open cast, Under-ground	
Ogwashi- Uku/Azagba/Obomkpa	Delta	Lignite	250	63	7	4 (3.5)	15-100	Open cast, Under-ground	
Oba/Nnew	Anambra	Lignite	30	NA	2	14 (0.3-4.5)	18-38	Underground	
Ihioma	Imo	Lignite	40	NA	Nil	Many	20-80	Open cast	
Lafia/Obi	Nasarawa	Bituminous	156	21.42	123	-1.3	80	Under-ground	

		(cokeable)							
Owukpa	Benue	Sub-Bituminous	75	57	Many	(0.8-2.3)	20-100	Open cast, Under-ground	Functional
Afikpo/Okigwe	Abia	Sub-Bituminous	50	NA	Nil	NA	20-100	Under-ground	
Afuze	Edo	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	
Ute	Ondo	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	
Lamja	Adamawa	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	
Gandi-Akwati	Plateau	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	
Jamata-Koji	Kwara	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	
Doho	Gombe	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	
KurumuPindiae	Gombe	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	
GarinMaiganga	Gombe	Sub-Bituminous	NA	NA	Nil	NA	NA	Under-ground	

2.2.2 Non-conventional Energy Resources (Renewable Energy)

Renewable energy plays a vital role in meeting the needs of both rural and urban areas of the country in terms of sustainable development (Hui, 1997). The development and proper use of renewable energy should be given high priority, especially now that the issues of climate change and global warming are among the most critical issues discussed by the various governments of the world. Developed and developing countries are now adopting renewables in order to achieve energy sustainability (Oyedepo, 2012).

Nigeria is blessed with an abundance of renewable energy resources that must be fully harnessed, developed, and properly used. However, the development of renewable energy has so far been slow, and the desperate situation of the energy sector in Nigeria can only be resolved if adequate policies are implemented to attract investors in renewable energy to Nigeria. Nigeria's renewable energy resources are presented in Table 2-5 and discussed in detail below.

2.2.2.1 Biomass Energy

Biomass energy refers to energy that is developed from organic materials like scrap lumber, forest debris, crops, manure, and some types of waste residue. Biomass is an indirect form of solar energy because it arises from the process of photosynthesis. Biomass resources found in Nigeria include wood, shrubs, and forage grasses, and waste from animals, forestry, agriculture, industry, and municipal areas. Nigeria's biomass resources have been estimated at 88 × 102 MJ[33]. Biomass energy from plants could be used as fuel for small-scale industries or fermented by anaerobic bacteria to produce cheap and versatile biogas (Garba & Bashir, 2002).

Fuel wood is the most common form of biomass in Nigeria, with about 80 million m3 used annually for cooking and various other domestic purposes (Sambo, 2005). The energy content of this fuel wood is 6.0 × 109 MJ, out of which only 5% and 12% are used for cooking and other domestic uses, respectively (Lawal, 2007). In addition, increasing demand for wood by the furniture and construction industries is causing a rapid depletion of the biomass resources in Nigeria.

Shrubs and forage grasses have been estimated to produce 200 million tons of dry biomass that could release up to 2.28 × 106 MJ of energy (Vincent & Yusuf, 2014). Because of the high dependence on fuel woods for cooking and heating by rural dwellers in Nigeria, 350,000 ha of forest and vegetation are lost annually, although this is much lower than the afforestation rate of 50,000 ha per annum (Sambo, 2009a).

However, soil erosion and desert encroachment will result from these activities if the situation is not properly controlled. This could be achieved by discouraging the use of firewood through the introduction of affordable solar stoves. The introduction of a three-stone stove with an efficiency as low as 15%, which was developed locally by the ECN through its energy research centers at the University of Nigeria in Nsukka and Usman Dan Fodio University in Sokoto, will ensure the reduction of fuel wood consumption

[33] Nadabo (2010)

(Sambo, 2009a).

Table 2-5: Renewable energy resources in Nigeria and their potential

(Source: ECN, 2009)

Resource type	**Reserves**		**Production**	**Domestic utilization (natural units)**
	Natural units	**Energy units (Btoe)**		
Small Hydro-power	3500 MW	0.34 (over 40 years)	30 MW	30 MW
Large Hydro-power	11,250 MW	0.8 (over 40 years)	1938 MW	1938 MW
Wind	2–4 m/s at 10 m height (main land)	0.0003 (4 m/s @ 12% probability, 70 m height, 20 m rotor, 0.1% land area, 40 years	–	–
Solar Radiation	3.5–7.0 $kWh/m^2/day$ (4.2 million MWh/day using 0.1% land area)	5.2 (40 years and 0.1% land area)	6 MWh/day	6 MWh/day
Biomass Fuel wood	11 million hectares of Forest and wood land Excess of 1.2 m ton/day	–	0.120 million ton/day	0.120 million ton/day

Animal waste	211 million assorted animals	–	0.781 million ton of waste/day	None
Energy crops and agricultural residue	28.2 million hectares of arable land (= 30% of total land)	–	0.256 million ton of assorted crops/day	None

Biomass is an important renewable energy source, but the sustainability of its production needs to be clearly understood. Nigeria should use its wood, municipal waste, oil palm product, sugar cane, and rice husk resources sustainably for biogas energy production. As has been practiced in South Africa and Malaysia, sugar mill companies in Nigeria could make use of their cane residues and waste, while paper and packaging mills could use their waste biomass to generate process steam (Shaaban & Petinrin, 2014). Table 2-6 lists the estimated quantities and energy values of Nigeria's biomass resources.

Table 2-6: Nigeria's Biomass resources (Source: Sambo, 2009a)

Resources	**Quantity (million ton)**	**Energy value (000 MJ)**
Fuelwood	39.1	531.0
Agro-waste	11.244	147.7
Saw dust	1.8	31.433
Municipal solid waste	4.075	–

2.2.2.1.1 Biogas

Biogas is produced from the anaerobic digestion of agricultural and animal waste in the absence of air. It has an estimated combustion temperature in the range of 65°C to 750°C and it is 20% lighter than air. Biogas is similar to LPG gas because it has no color or odor and it burns with a brilliant blue flame. Its caloric value has been estimated to be about 20 MJ/m3 and it burns with an efficiency of about 55% in a conventional biogas stove. The gas contains a mixture of carbon IV oxide, hydrogen sulphide, methane, nitrogen, and water vapour (Opeh & Okezie, 2011). The raw materials for biogas production include animal dung and waste from industry, farmland, and households.

Biogas constitutes a form of energy suitable for households and the agricultural and industrial sectors of the economy. It is a useful substitute for diesel, fuel wood, charcoal, and kerosene; it reduces GHG emissions, and it has no health risks because it burns clean (Akinbami et al., 2001). In rural areas of Nigeria, suitable feed stock has been identified and is considered economically viable for the production of biogas, including cassava leaves, dung, solid waste, water hyacinth, water lettuce, agricultural residues, urban refuse, and sewage (Akinbami et al., 1996).

Studies have shown that Nigeria produces about 227,500 t of fresh animal waste daily and 20 kg of municipal solid waste per capita annually (Mshandete & Parawira , 2009; Oyedepo, 2012;).

About 0.03 m3 of gas can be produced from 1 kg of fresh animal waste; therefore, 6.8 million m3 of biogas could be produced daily in Nigeria.

Research conducted by Adeoti (1998) showed that a 6.0-m3 family-sized biogas digester could produce about 2.7 m3 of biogas per day, which would be sufficient to satisfy the cooking needs of a family of nine persons. The initial cost of the project was US$500 (i.e., NGN 80,100 in Nigeria Naira); annual expenditure was NGN 11,200, while the benefit was NGN 25,000. Although the project appears to have good economic potential, it might be too expensive for the low-income earners who reside mostly in rural areas. If measures are not taken to lower the costs or assist the low-income earners economically, low-income households might not accept the use of biogas (Garba & Bashir, 2002).

It is of great importance for Nigeria's government to establish some biogas plants to help the development of the country's energy sector, because the technology can generate energy rapidly as the raw materials needed to feed the biogas plants are relatively abundant across the country (Opeh & Okezie, 2011). In addition to the use of biogas for household consumption and electricity generation, other areas such as the transport sector could benefit from this renewable option. The production of biogas in Nigeria would not only develop the energy sector but also aid in the reduction of urban waste.

2.2.2.2 Hydro Energy

Hydro energy technology is dependent on the potential energy difference between the levels of water in reservoirs, dams, or lakes and their discharge tail water levels downstream. A water turbine, which converts the potential energy of the water to shaft rotation, is coupled to a suitable generator to produce the electricity (Sambo, 2005).

In Nigeria, hydro energy technology is currently the prominent commercial renewable energy technology in the country's electricity supply mix. Economy of scale has enabled the development of large-scale hydropower technology to account for a large proportion of the total commercial renewable energy resources for electricity generation under greenhouse gas (GHG) emission constraints (Balogun, 2010).

Apart from the problem of relative water levels, hydropower can supply uninterrupted power. Nigeria's total hydropower potential stands at 14,750 MW, but only 1930 MW (i.e., 14%) is currently generated at Kanji, Shiroro, and Jebba, which represents about 30% of the gross installed grid-connected generation capacity in Nigeria (CBN, 2005). This assessment is based on the type of large-scale hydropower that was in operation before the 1973 oil crisis.

Clearly, Nigeria's hydropower potential has not been fully exploited. However, small hydropower (SHP) has recently received considerable global attention. This attention is because of the inherent advantages of SHP in reducing environmental impact, minimizing civil works, and offering the possibility of combining power generation with flood prevention, irrigation, and the development of fisheries. Nigeria's current SHP generation is estimated at 3500 MW, which represents about 23% of the entire national hydro potential, as shown in Table 2.5.

A study undertaken in 12 states and 4 river basins revealed over 278 unexploited SHP sites with a total potential of 734.2 MW (Aliyu & Elegba, 1990). Three of the states surveyed, Kano, Sokoto, and Plateau, had installed operating SHP generators with a total capacity of 30 MW. The Nigerian Electricity Supply Company (NESCO) is currently generating 21 MW from six other sites in Plateau state. Currently, about 5% of the available SHP capacity is exploited, while other SHP sites have been set aside for future development. However, out of the total potential of 734.2 MW, only 32 MW have been developed. Table 2-7 shows the SHP potential in Nigeria, Table 2-8 presents the existing SHP schemes (Sambo, 2009b), and Figure 2-18 shows the various water ways within the country.

Table 2-7: Small hydropower potentials in Nigeria

(Source: Sambo, 2009b)

State (Pre 1980)	**River basin**	**Total sites**	**Hydropower potential**		
			Developed (MW)	**Undeveloped (MW)**	**Total capacity (MW)**
Sokoto	Sokoto-Rima	22	8.0	22.6	30.6
Katsina	Sokoto-Rima	11		8.0	8.0
Niger	Niger	30		117.6	117.6
Kaduna	Niger	19		59.2	59.2
Kwara	Niger	12		38.8	38.8
Kano	Hadeija–Jamaare	28	6.0	40.2	46.2
Borno	Chad	28		20.8	20.8
Bauchi	Upper Benue	20		42.6	42.6
Gongola	Upper Benue	38		162.7	162.7

Plateau	Lower Benue	32	18.0	92.4	110.4
Benue	Lower Benue	19		69.2	69.2
Cross Rivers	Cross Rivers	18		28.1	28.1
Total		**277**	**32**	**702.2**	**734.2**

Table 2-8: Small hydropower schemes in Existence in Nigeria

(Source: Sambo, 2009b)

River	State	Installed Capacity (MW)
Bagel I	Plateau	1
Bagel II	Plateau	2
Ouree	Plateau	2
Kuna	Plateau	8
Lere	Plateau	4
Lere	Plateau	4
Bakalori	Sokoto	3
Tiga	Plateau	6
Total		30

Figure 2-18: Nigerian water ways. (Source: Safty4sea, 2014)

2.2.2.3 Solar Energy

Solar energy is the most promising renewable energy source because of its apparent limitless potential. The sun radiates energy at the rate of about 3.8 × 1023 kW/s. Most of this energy is transmitted radially as electromagnetic radiation, reaching the boundary of Earth's atmosphere at about 1.5 kW/m2. After traversing the atmosphere, a square meter of Earth's surface can receive as much as 1 kW of solar power, or about 0.5 kW on average during daylight hours. This huge energy resource is available for about 26% of the day (Muhammad, 2012).

Solar energy can provide cheap and abundant energy for communities whose connection to the utility grid might not be economical because they are located too far from the nearest grid-connection point. Solar energy is therefore a very good alternative source of energy in the rural areas of Nigeria. It could aid the rapid development of small-scale industries and reduce rural–urban migration (Ojosu, 1990).

Nigeria is located within a high sunshine belt and solar radiation is well distributed. The annual average total solar radiation varies from about 25.2 MJ/m2/day (7.0 kWh/m2/day) in northern regions to about 12.6 MJ/m2/day (3.5 kWh/m2/day) in southern parts. Assuming an average of 18.9 MJ/m2/day (5.3 kWh/m2/day), Nigeria has an estimated 17,459,215.2 million MJ/day (17.439 TJ/day) of solar energy arriving over its 923,768 km2 land area. The annual average intensity is 6898.5 MJ/m2/year or 1934.5 kWh/m2/year (Vincent & Yusuf, 2014).

As the average sunshine per day is 6.5 h, the annual solar energy available is about 27 times that of the country's total fossil fuel resource, and it is over 115,000 times the electrical power generated (Augustine & Nnabuchi, 2009). This implies that about 3.7% of the land area in Nigeria could collect an amount of solar energy equivalent to the conventional energy reserves within the country (Shaaban & Petinrin, 2014). This is in agreement with a study by Oji et al., (2012), considered that the minimum harnessing of solar power in some parts of Nigeria would be more than enough to power an average three-bedroom flat and two-room apartment that use low-power appliances. The monthly averages of daily solar radiation for 28 states in Nigeria over 25 years are presented in Table 2-9, and the annual average daily sun in Nigeria is illustrated in Figure 2-19.

Figure 2-19: Yearly average of solar radiation in Nigeria. (Source: Nwoko, 2015b)

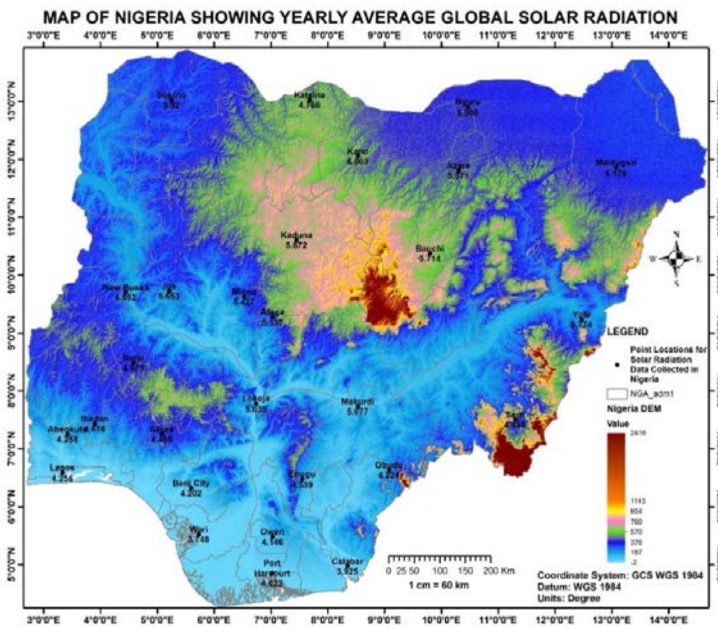


Table 2-9: Max/Minimum yearly solar radiation (kWh/m^2/day)[34]

(Source: Okoro et al., 2007)

Stations	Location Lat. 1N	Location Long 1E	Altitude (m)	Max[a]	Min[b]	Monthly Average
Abeokuta	7.25	3.42	150	4.819	3.474	4.258
Abuja	9.27	7.03	305	5.899	4.359	5.337
Akure	7.25	5.08	295	5.172	3.811	4.485
Azare	11.8	10.3	380	6.028	5.022	5.571
Bauchi	10.37	9.8	666.5	6.134	4.886	5.714
Beni City	6.32	5.6	77.52	4.615	3.616	4.202
Calabar	4.97	8.35	6.314	4.545	3.324	3.925
Enugu	6.47	7.55	141.5	5.085	3.974	4.539
Ibadan	7.43	3.9	227.23	5.185	3.622	4.616
Ilorin	8.48	4.58	307.3	5.544	4.096	4.979
Jos	9.87	4.97	1285.5	6.536	4.539	5.653
Kaduna	10.6	7.45	645.38	6.107	4.446	5.672
Kano	12.05	8.53	472.14	6.391	5.563	6.003
Katsina	13.02	7.68	517.2	5.855	3.656	4.766
Lagos	6.58	3.33	39.35	5.013	3.771	4.256
Lokoja	7.78	6.74	151.4	5.639	4.68	5.035
Maiduguri	11.85	13.08	383.8	6.754	5.426	6.176
Makurdi	7.73	8.53	112.85	5.656	4.41	5.077
Minna	9.62	6.53	258.64	5.897	4.41	5.427
New	9.7	4.48	152	5.533	4.15	4.952
Nguru	12.9	10.47	342	8.004	6.326	6.966
Obudu	6.63	9.08	305	5.151	3.375	4.224
Oweri	5.48	7.03	120	4.649	3.684	4.146
Port Harcourt	4.85	7.02	19.55	4.576	3.543	4.023

34 a= average for the months of March, April and May, b= average for the months of July and August

Serti	7.5	11.3	610	4.727	3.972	4.488
Sokoto	13.02	5.25	350.75	6.29	5.221	5.92
Wari	5.52	5.73	6.1	4.237	3.261	3.748
Yola	9.23	12.47	186.05	6.371	4.974	5.774

The levels of solar energy awareness and acceptance have already gained ground in northern parts of Nigeria, as presented in a survey performed by Shehu (2012). Other studies, surveys, and pilot projects have been undertaken by the Sokoto Energy Research Centre and the National Centre for Energy Research and Development under the supervision of the ECN. They have implemented solar PV water pumping and electrification, and solar thermal installations such as solar cooking stoves, crop drying facilities, incubators, and chick-brooding systems. However, solar technology has not penetrated into the deep rural areas, especially the off-grid areas, where candles and kerosene lamps are still used for lighting homes at night. An effective policy should be created to foster the development of solar energy across Nigeria to help reduce poverty in rural areas of the country.

2.2.2.4 Wind Energy

Wind is a natural phenomenon related to the movement of air masses caused primarily by differential solar heating of the earth’s surface. The seasonal variation in the energy received from the sun affects the strength and direction of the wind. The ease with which aero-turbines transform the energy of moving air into rotary mechanical energy lends itself to the conversion of wind energy to electricity. For many years, wind energy has been used for pumping water and milling grain (Sambo, 1981).

Wind energy generation has gained worldwide recognition and it is the fastest growing renewable energy market in the world. The global cumulative installed capacity of wind power has increased steadily from 6100 MW in 1996 to 158,505 MW in 2009, and was expected to be over 238 GW by the end of 2014, a target that will aid the reduction of GHG emissions (World Wind Energy Association [WWE], 2008). Currently, 82 countries generate electricity from wind energy, 49 of which have increased their installed capacity since 2009.

In 2009, Africa, Egypt, Morocco, and Tunisia were the leading countries for wind energy with installed capacities of 430, 253, and 54 MW, respectively (Adaramola & Oyewola, 2011). In Nigeria, wind measurements at 10-m height show that some sites have wind speeds between 1.0 and 5.1 m/s. These wind speeds can be classified into four regimes: >4.0 m/s, 3.1–4.0 m/s, 2.1–3.0 m/s, and 1.0–2.0 m/s. Therefore, Nigeria is located within a moderate wind[35] regime. The wind speed in southern Nigeria is relatively low, except for coastal regions and offshore, where the high wind speeds indicate great potential for exploiting wind energy (Vincent & Yusuf, 2014).

A study undertaken by the ECN revealed that the total exploitable wind energy reserves at 10-m height might vary from 8 MWh/yr in Yola to 51

[35] Moderate wind or breeze according to the Beaufort wind force scale gives the sea condition as small waves with breaking crests, fairly frequent whitecaps and land condition as dust, loose paper raised, small trees branches begin to move (See National Meteorological Library and Archive fact Sheet 6- The Beaufort Scale-PDF).

MWh/yr in the mountainous area of Jos, and possibly even as high as 97 MWh/yr in Sokoto (Sambo, 1981). In addition to the study performed by the ECN, many indigenous researchers (Adekoya & Adewale, 1992; Fagbenle & Karayiannis, 1994; Ngala et al., 2007; Mnse & Ojo, 2009; Felix et al., 2012) have analyzed wind data from various parts of the country and these data include wind speeds and power flux densities. Furthermore, the wind energy potential and the conditions that must be met before a wind turbine can be connected to the utility grid have also been studied in the literature (Adekoya & Adewale, 1992; Felix et al. 2012; Shaaban & Petinrin, 2014).

Adekoya and Adewale (1992) produced estimates of potential wind speeds at 10 selected sites within the country. The results were compared with wind speeds calculated by the Mainz climate model, which revealed a discrepancy of –4.3% to 4.1%, which is within acceptable error limits. The results, presented in Tables 2-10 and 2-11, list the estimated gross energy yield, while Table 2-12 presents the estimated wind energy potential of some selected states in Nigeria. Figure 2-20 shows the potential of wind energy locations in Nigeria.

Table 2-10: Summary of the measured data of annual wind speeds

(Source: Adekoya & Adewale, 1992; Felix et al.2012)

Site	Land-use Type	Altitude (m a.s.l)	Height (m)	Wind Speed (m/s) Measured	Wind Speed (m/s) KLIMM	Differences (%)
Enugu	Complex landscape	466	30	4.6	4.4	– 4.3
Jos	Complex landscape	1344	30	5.2	5.1	– 1.9
Pankshin	Complex landscape	1355	40	4.9	4.7	– 4.1
Sokoto	Plain surface	352	30	5.4	5.2	– 3.7
Kano	Plain surface	340	30	4.9	5.1	4.1
Gumel	Plain surface	393	30	4.1	4.2	2.4
Maiduguri	Plain surface	373	30	4.7	4.6	– 3
Ibi	River valley	300	30	3.6	3.3	– 8.3
Gembu	Highly complex landscape	1800	40	5	5.2	1
Lagos	Coastal area	2	30	4.7	4.9	4.3

Table 2-11: Estimated gross energy yield

(Source: Adekoya & Adewale, 1992; Felix et al.2012)

Site	Gross energy yield measurement (MWh)		
	Model FL 100, 100/20 Rotor dia. 21.0 m Hub height 34.5 m 100/20	Model FL250, 250/50 Rotor dia. 29.5 m Hub height 42.0 m 250/50	Model V52, 850/52 Rotor dia. 52.0m Hub height 44.0m
Enugu	92.9	217.9	734.20
Jos	129.6	299	1025.80

Pankshin	117.1	272.1	936.60
Sokoto	153.5	358.8	1235.80
Kano	116.3	281.2	963.60
Gumel	73.4	197.2	681.40
Maiduguri	102.7	262.2	906.10
Ibi	49.8	141.3	481.20
Gembu	112.9	253.9	855.30
Lagos	129.3	386.1	1402.80

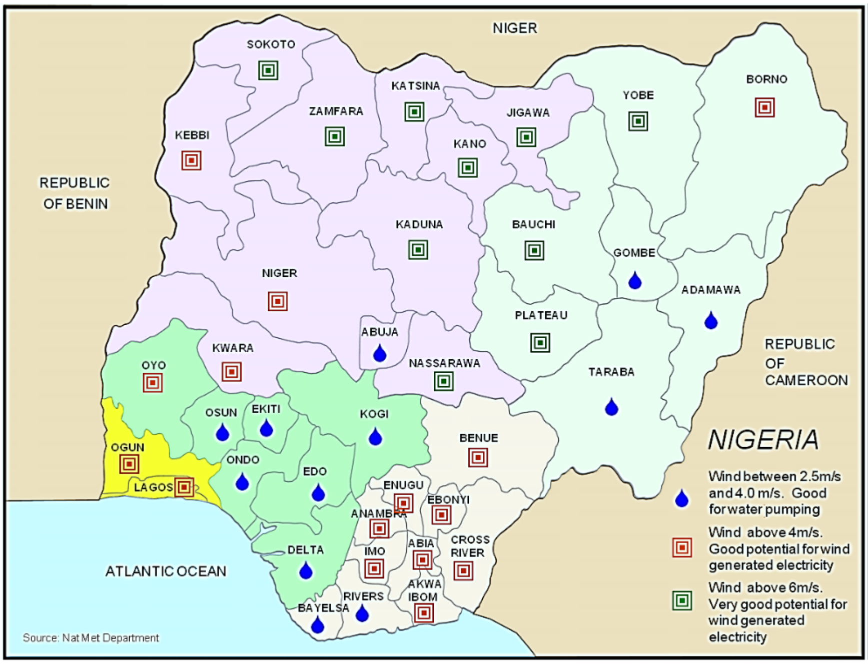
Table 2-12: Estimated wind energy potentials

(Source: Adekoya & Adewale, 1992; Felix et al.2012)

Selected State	**Area (km2)**	**Wind Area (%)**	**Effective Wind Area (km2)**	**1% Area (km2)**	**Potential Capacity (MW)**	**Potential Generation (MWh/yr)**
Adamawa	37,957	45	170,80	171	854	2244
Bauchi	48,197	50	24,098	241	1204	3166
Borno	72,767	100	72,767	728	3638	9561
Gombe	17,428	100	17,428	174	871	2290
Jigawa	23,415	100	23,415	234	1170	3076
Kaduna	44,217	60	26,530	265	1326	3486
Kano	20,389	90	18,350	184	917	2411
Katsina	23,822	100	23,822	238	1191	3130
Kebbi	36,320	25	9080	91	454	1193
Plateau	26,539	90	23,885	239	1194	3138
Sokoto	32,146	90	28,931	289	1446	3801
Taraba	58,180	40	23,672	237	1183	3110
Yobe	44,880	100	44,880	449	2244	5897
Zamfara	33,667	80	26,933	269	1346	3539
Total				**3809**	**19,043**	**50,046**

Figure 2-20: Wind energy potentials and locations in Nigeria.

(Source: Nee Nigeria, 2015)



According to Shaaban and Petinrin (2014), assuming a medium generation capacity of 5 MWh/km2 with (a) a 30% capacity factor and (b) using only 1% of the effective wind area of the selected states, Nigeria has the potential to generate about 50,046 MWh/yr of electricity. The detailed potentials and wind energy densities at 25-m height for 22 selected states in Nigeria are presented in Table 2.13.

Table 2-13: Wind energy estimates at 25m height

(Source: Adekoya & Adewale, 1992; Felix et al.2012)

Site	Mean wind Speed at 25m level (m/s)	Monthly Mean Wind Energy (KWh)	Annual Wind Energy (KWh)	Annual Wind Energy From a Wind Turbine (KWh)	
				10m blade diameter	25m blade diameter
Benin City	2.135	2.32	27.86	2,18.81	13,673.78
Calabar	1.702	1.12	13.42	1.053.69	6587.53
Enugu	3.372	7.83	93.91	7375.75	46,097.96
Ibadan	2.62	4.15	49.78	3909.70	24,436.19
Ilorin	2.078	1.23	14.73	1157.06	7230.57
Jos	4.43	16.05	192.64	15,129.60	94,559.98
Kaduna	3.605	9.91	188.88	936.81	58,355.08
Kano	3.516	8.57	102.86	8078.61	50,491.28
Lagos (Ikeja)	2.671	4.36	52.32	4099.78	25,682.52
Lokoja	2.235	2.6	31.21	4451.23	15,320.17
Maiduguri	3.486	8.42	101.01	7933.61	49,583.17
Mina	1.589	1.05	12.60	989.60	6185.01
Makurdi	2.689	4.44	53.27	4183.51	26,148.85
Nguru	4.259	14.48	173.74	14,645.19	85,284.42
Oshogbo	1.625	1.07	12.81	1006.60	6288.09
Port Harcourt	2.64	4.17	49.98	3925.48	24,533.88
Potiskum	3.636	9.44	113.25	8894.35	55,591.46
Sokoto	4.476	16.47	197.68	15,525.75	97,035.94
Warri	2.027	2.02	24.20	19,00.66	11,879.15
Yelwa	3.36	7.76	93.13	7314.88	45,714.59
Yola	1.824	1.45	17.34	1.361.88	8511.75
Zaria	2.891	5.32	63.88	5,017.26	31,357.02
Total		134.23	1680.50	120,078.90	790,548.39

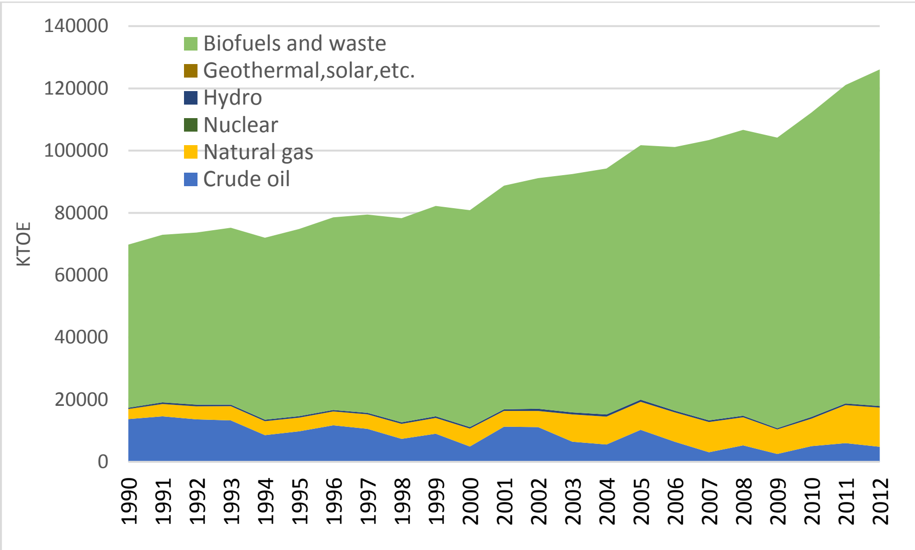
Currently, no commercial wind power plants are connected to the national grid in Nigeria. The few power plants that exist are those installed in the 1960s in five northern states and the 5-kW wind electricity conversion system installed in Sayyan Gidan Gada in Sokoto state. However, the latest development in wind energy generation in Nigeria is the ongoing installation of wind turbines in Katsina state, which is expected to generate 20 MW of electricity on completion. The progress of harnessing the potential of wind energy is too slow. Most communities in northern parts of the country are not connected to the electricity grid and therefore, the federal government must do more regarding the exploitation of wind power, especially in these northern areas where the wind speed is high.

2.3 Primary Energy Supply in Nigeria

According to the International Energy Agency, Nigeria's total primary energy supply for 2012 was 126,097 ktoe (excluding electricity trade and oil product import), and this was almost double the amount in 1990 (i.e. 69810 ktoe). In the primary energy supply mix, biofuels and waste had a percentage share of 85.8%, while crude oil, natural gas and hydro had 3.8%, 10% and 0.4% respectively. Crude oil exported out of the country in the same year (however, 2012) was 126,413 ktoe, natural gas was 21,032 ktoe, while oil products was 755ktoe. Oil products of about 8440 ktoe were also imported, so as to augment supply and meet the grow demand for petroleum products.

As previously stated, Nigeria is among the world largest oil and gas producers, but heavily depends on the importation of oil products due to the low production capacity of the nation's crude oil refineries. However, with the abundant energy resources available in Nigeria, the largest energy consumption has been biofuels and waste, of which fuel wood or firewood is the primary biofuel source. This is shown in Figure 2-21, where biofuels and waste has been the main fuel for energy supply since 1990 till 2012. The primary energy supply has been on the decrease, while natural gas have gradually been increasing. This may be due to the price of oil which was higher than natural gas, hence the increase in gas supply. Also, with the increasing construction of gas power plants in Nigeria, the supply of natural gas is expected to increase more than the 2012 values (i.e. 126,097 KTOE).

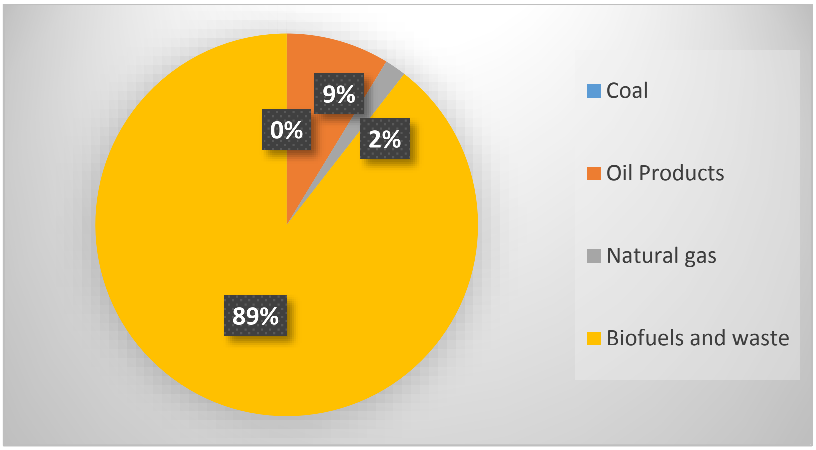
Figure 2-21 Nigeria's total primary energy supply (1990-2012). (Source: IEA, 2015a)



2.4 Primary Energy Consumption

Among the primary energy consumption in Nigeria, biofuels and waste has about 89% of the total primary energy consumption in 2012 alone, while oil products which are mainly imported and natural gas are 9% and 2% respectively (Figure 2-22). The continuous utilization of biofuels (especially firewood) has been the single most important factor for the increase in deforestation and increase in desert encroachment in most part of Nigeria. The rate of forest tree replacement is lower than fuel wood (from forest trees) consumption in Nigeria. This will be on the increase as the rate of population in the rural part of Nigeria tends to increase, as the total number of Nigeria's population is forecasted to increase to about 400 million by 2050 (See figure 2-4).

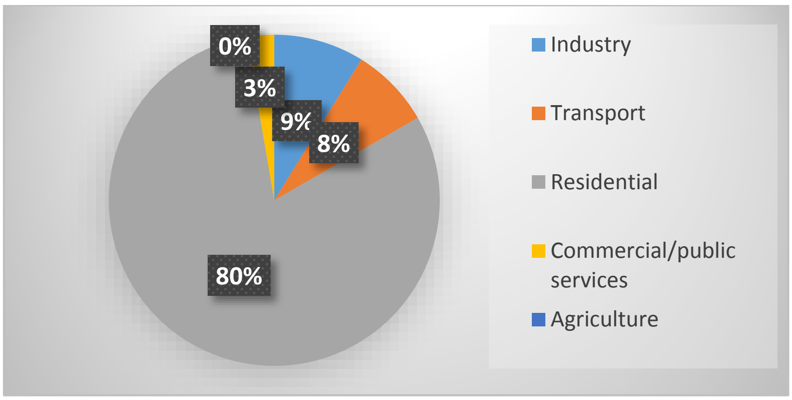
Figure 2-22: Primary energy consumption in Nigeria by fuel (2012).
(Source: IEA, 2015b)



According to the study by Zaku et al. (2013), the increase in firewood consumption can be attributed to the increase in poverty, as firewood is usually free, sometimes affordable and easily accessible to the rural dwellers. However, some studies such as Naibbi and Healey (2013), Mandelli et al., (2014), Eludoyin (2015) and Oladimeji et al., (2015) believes that firewood consumption is higher in the northern part of Nigeria, while the southern part diversify energy consumption.

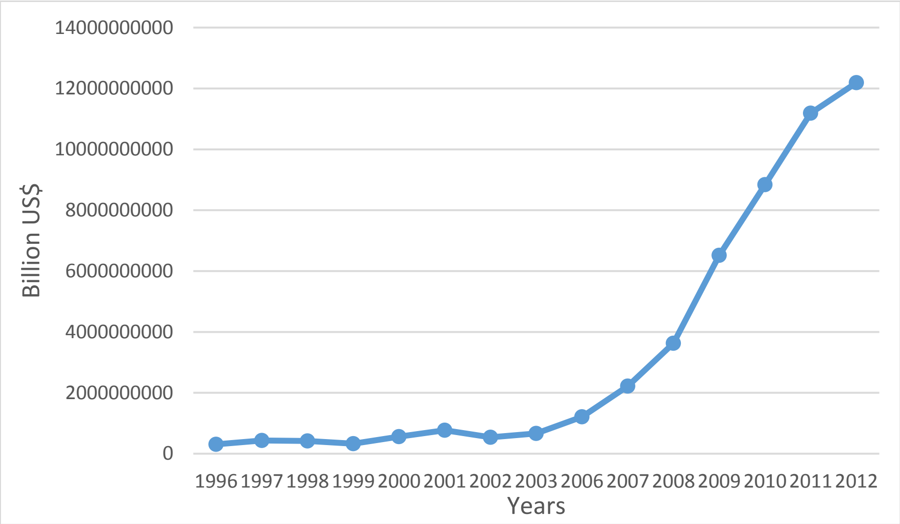
Other studies such as Audu (2013) who used descriptive and comparative methods to analyze the fuel consumption in Nigeria and desertification, shows that in Nigeria, firewood is mostly the only source of domestic fire in the desert-prone states leading to desertification. This is also the case in Al-Amin (2014) study as it extends the issue to other part of the country and suggest an immediate action by the Nigerian Government. The total primary energy consumption in Nigeria by sector is shown in Figure 2-23.

Figure 2-23: Total primary energy consumption in Nigeria by sector.
(Source: IEA, 2015b)



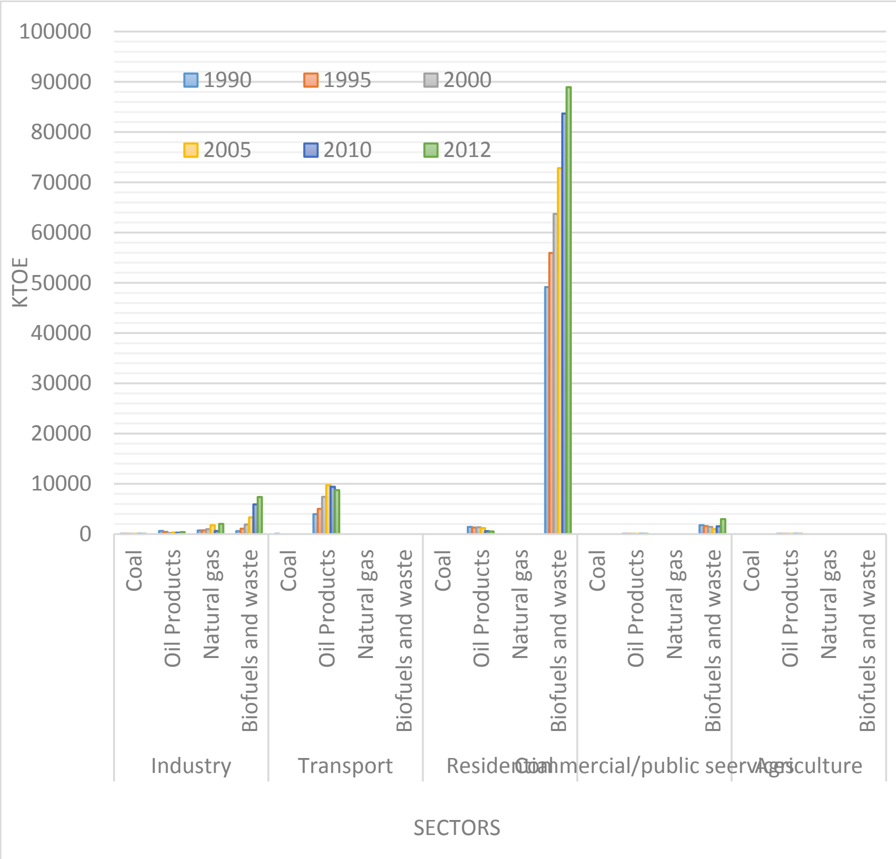
As shown in Figure 2-23, the most of the finial energy consumption in the various sectors in Nigeria is the residential sector with 80%, while the industrial and agricultural sector account for 9% and 8% respectively. With the rapidly increasing numbers of vehicle import in Nigeria (see Figure 2-24), the rate of energy consumption is expected to increase in the transportation sector just as in other sectors of the economy. This grows with the number of imported vehicles as was on the increase from 2006 (about US$1.2 billion) to 2012 (about US$12.2 billion).

Figure 2-24: Automobile import in Nigeria. (Source: NCS, 2015)



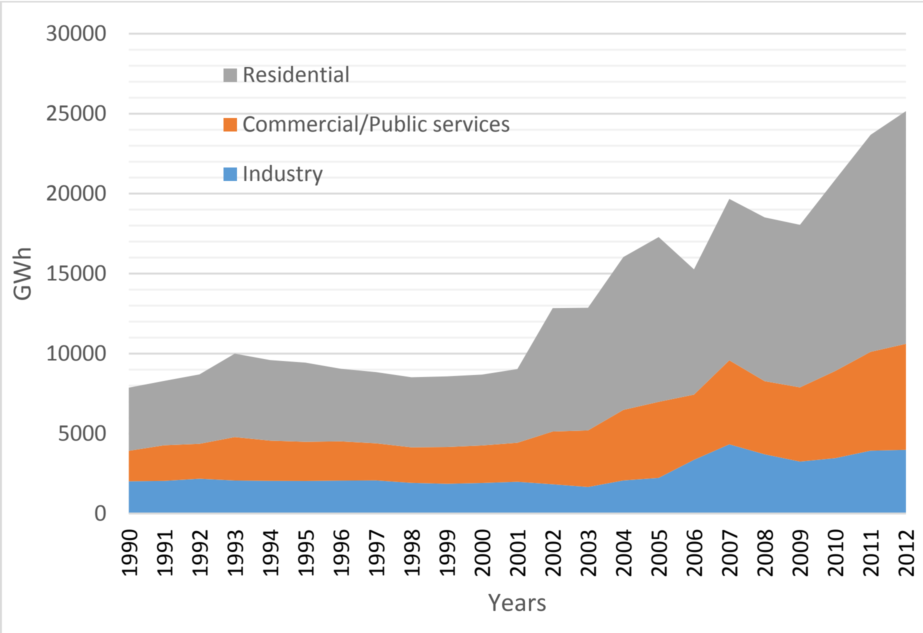
The rate of utilization of oil products such as petrol and diesel in the transportation sector is the highest in the total energy consumption as compared to other sectors such as the industry, commercial/public services and residential sectors which mainly use diesel for electricity generation. This is observed in Figure 2-25, which shows the combination of primary energy consumption by both fuel and sectors.

Figure 2-25: Total primary Energy Consumption by Fuel and Sector. (Source: IEA, 2015b)



To address the issue of desertification in Nigeria, the Nigerian Government prepared the National Report titled, "Combating Desertification and Mitigating the Effects of Drought in Nigeria", which contains various strategic policies (FRN, 1999). A more recent strategic plan by the Nigerian Government was the "National Strategic Action Plan" which was developed in 2012 by the Ministry of Environment (FME, 2012). These documents as developed by policy makers, face some implementation challenges such as; the provision of alternative source of fuel other than firewood, since the population of the rural area is expected to rise. Also the issue of urbanization as rural dwellers will migrate to urban areas when there is no longer firewood and diesel is readily available in the urban areas.

Figure 2-26: Electricity consumption by sector. (Source: IEA, 2015c)



On electricity consumption in Nigeria (Figure 2-26), the growing trend of energy consumption rate is also observed for electricity consumption in the residential sector, from 3,949 GWh in 1990 to 14549 in 2012. The commercial/public services electricity consumption was 6,627 GWh in 2012, while the industrial electricity consumption was 3,983 GWh. From Figure 2-

26, electricity consumption in the industrial sector have not increased much in 2012, as compared to 1990. This low electricity has forced most industries to depend on private generators to run their operations and business (Emodi & Boo, 2015a). The South African mobile phone company MTN who operates the largest mobile phone company in Nigeria is estimated to have installed 6,000 generators to supply its base stations for up to 19 hours a day. This cost the company $5.5 million a month on diesel in order to run the generators (Lawal, 2007).

2.5 Relevant Government Ministries, Parastatals and Agencies in the Nigerian Energy Sector and their Roles

The relevant government ministries, parastatals and agencies are presented as follows.

2.5.1 The Energy Commission of Nigeria (ECN)

The Energy Commission of Nigeria (ECN) was established according to Act No. 62, as amended by Act No.32 of 1988 and Act No.19 of 1989. It commenced operation in 1989 and is in charge of the energy sector planning and policy implementation. The ECN promotes the use of renewables and alternative energies in the country's energy mix, as well as fulfil the role of strategic overall planning, coordination and effective direction of Nigeria's national energy policies and strategies. The commission (i.e. ECN) has the following responsibilities and they include (ECN, 2015);

- To serve as a center for gathering and dissemination of information relating to national policy in the field of energy;
- To serve as a center for solving any inter-related technical problems that may arise in the implementation of any policy relating to the field of energy;
- To advise the government of the Federation or a State on questions relating to such aspect of Energy as the Government of the Federation or a State may from time to time refer to it;
- To prepare after consultation with such agencies of government whose functions relate to the field of Energy development or supply as the Commission considered appropriate, periodic master plans for the balanced and coordinated development of energy in Nigeria and such plans include:
    - Recommendations for the exploitation of new sources of energy as when considered necessary, and
    - Such other recommendations to the Government of the Federation relating to its functions under this Decree as the Commission may consider to be in the national interest;
- To lay down guidelines on the utilization of energy types for specific purposes;

- To inquire into and advise the Government of the Federation or of the State on the adequate funding of the energy sector including research and development, production and distribution;
- To collate, analyze and publish information relating to the field of energy;
- To carry out such other activities as are conclusive to the discharge of its functions under this Decree;
- To monitor the performance of the Energy sector in the execution of government policies on energy;
- To promoting training and manpower development in Energy sector;
- To liaise with all international organizations in Energy matters.

2.5.2 Federal Ministry of Environment (FME)

The Federal Ministry of Environment (FME) was established in 1999 by the Federal Government of Nigeria with the statutory responsibility of protecting the natural environment against pollution, degradation and conservation of natural resources. The Ministry (i.e. FME) is officially charged with environmental responsibilities and also with coordinating all climate change matters under its Special Unit Climate Change (SUCC). The unit also represents the Ministry at international climate negotiations. The Special Unit on Renewable Energy (SURE) acts as the voice of the ministry regarding renewable energy and energy efficiency issues. The objective of the unit is to develop and implement strategies that will achieve clean, reliable energy supply mechanisms in order to develop the sector based on international best practices and in order to showcase viability for private sector participation. The official mandate of the FME are presented as follows (FME, 2015);

- To prepare a comprehensive National Policy for the protection of the environment and conservation of natural resources, including procedure for environmental impact assessment of all developing projects.
- To prepare in accordance with the National Policy on Environment, periodic master plans for redevelopment of environmental science and technology and advise the Federal Government on the financial requirements for the implementation of such plans.
- To advise the Federal Government on National Environmental Policies and priorities, the conservation of natural resources and sustainable development and scientific and technological activities affecting the environment and natural resources.
- To promote cooperation in environmental science and conservation technology with similar bodies in other countries and with international bodies connected with the protection of the environment and the conservation of natural resources.
- To cooperate with Federal and State Ministries, Local Government, statutory bodies and research agencies on matters and facilities relating to the protection of the environment and the conservation of natural resources.
- To prescribe standards for and make regulations on water quality, effluent limitations, air quality, atmospheric protection, ozone protection, and

- To monitor and enforce environmental protection measures.

2.5.3 Federal Ministry of Lands, Housing and Urban Development (FMLHUD)

The Federal Ministry of Lands Housing and Urban Development (FMLHUD) is an important arm of the Nigerian government that is charged with the implementation of all policies and regulations relating to lands, housing and urban development in the country. The FMLHUD has the mandate to enforce regulations in buildings in all the sectors of the economy. This involves the ministry's strategic role in energy efficiency in the residential, industrial, as well as commercial/ services sectors. This is carried out under the Architectural Services under the FMLHUD and the inclusion of energy efficiency is under the newly developed building code. Other mandates of the FMLHUD are; the establishment of sustainable housing delivery system which ensures easy access to home ownership and rental schemes by the Nigerian populace in an environment where basic physical and social amenities are available (FMLHUD, 2015).

2.5.4 Federal Ministry of Power (FMP)

The Federal Ministry of Power has the official responsibility of ensuring a robust power sector that fully supports the socio-economic needs of the nation. The main goal of the ministry is directed at initiating, formulating, coordinating and implementing broad policies and programmes on the development of electricity generation from all sources of energy. FMP is also charged with the responsibility of developing and deploying electricity-related renewable energy policies in Nigeria. The FMP also ensures that Nigeria is provided with adequate and reliable power supply by implementing generation, transmission and distribution projects in the sector and facilitate the emergence of a private sector led competitive and efficient power industry. In a view to diversify the nation's energy mix, the FMP encourage the utilization of renewable energy for power generation in both the urban and rural areas (FMP, 2015).

2.5.5 Federal Ministry of Water Resources (FMWR)

The Federal Ministry of Water Resources (FMWR) was created in its current form in April 2010 with the responsibility of providing sustainable access to safe and sufficient water to meet the socio-economic needs of all Nigerians. This is achieved through efficient water resources management for basic human needs, irrigated agriculture, hydropower generation and the promotion of healthy population while maintaining the integrity of fresh water bodies. The FMWR is involved in numerous renewable energy and rural electrification activities through its Department of Dams and Reservoir Operations. To increase energy supply in order to meet the nation's energy demands as mandated by the government, FMWR is collaborating with the FMP on the aspect of handling the area of power generation component, while the ministry handles the aspect of civil works in all the dam projects with hydropower potential. Small hydropower schemes have been integrated into some dam projects across the country in order to increase the energy supply of the nation (FMWR, 2015).

2.5.6 National Power Training Institute of Nigeria (NAPTIN)

The National Power Training Institute of Nigeria (NAPTIN) was established on 23rd March 2009 and commenced full operation in September, 2009. The primary purpose for its establishment is to provide training for power sector personnel and coordinate training activities in the sector. In pursuit of this mandate, NAPTIN has taken over the management of existing seven regional training centers of PHCN. NAPTIN reports directly to the FMP and it’s supervised by a board of directors appointed by them (NAPTIN, 2015).

2.5.7 Nigerian Bulk Electricity Trading Plc. (NBET)

In 2001, the Federal Government, in a bid to address the deficiency in power sector supply, adopted the National Electric Power Policy for the reform of the sector. Following suit, the Electric Power Sector Reform Act (EPSRA), was passed into law in March 2005. A key thrust of the sector reform is the transfer of the control and operations of the industry from public sector to private sector. In furtherance of this goal, the Act saw the creation of the Power Holding Company Nigeria (PHCN) which assumed the assets, liabilities and employees of the erstwhile Nigeria Electricity Power Authority (NEPA); the subsequent unbundling of PHCN into 18 successor companies, the establishment of the Nigerian Electricity Regulatory Commission

(NERC); the establishment of the Rural Electrification Agency (REA) and the provision for the establishment of two special purpose vehicles (SPVs) to undertake electric power trading and management of extant liabilities respectively.

In line with the "Road-map to Power Sector Reform" of August 2010, and, in fulfillment of the requirements of EPSRA, the Nigerian Bulk Electricity Trading Plc., (NBET) aka the Bulk Trader, was incorporated on July 29 2010 as the SPV for carrying out, under license from National Electricity Regulatory Commission (NERC), the bulk purchase and resale function contemplated by the EPSRA. As such NBET has been set up to "engage in the purchase and resale of electric power and ancillary services from independent power producers and from the successor generation companies" (NBET, 2015).

2.5.8 Nigerian Electricity Regulatory Commission (NERC)

The Nigerian Electricity Regulatory Commission was established as an independent regulatory agency in 2005 under the EPSR Act 2005. Its mandate is to monitor and regulate the electricity industry of Nigeria, and ensure compliance with market rules and operating guidelines. NERC is responsible for assessing applications for licenses to operate an independent power plant larger than 1 MW, and thus approves eligibility of prospective companies to negotiate a power purchase agreement with the central off-taker in the current transitional market, the NBET. The NERC also play a crucial role consumer protection by ensuring the development of customer service standards, fair pricing rules and the provision of dispute resolution if a situation arise (NERC, 2015).

2.5.9 Nigerian National Petroleum Corporation (NNPC)

The Nigerian National Petroleum Corporation (NNPC) is the oil corporation through which the federal government of Nigeria regulates and participates in the country's petroleum industry. NNPC was established on April 1, 1977 as a merger of the Nigerian National Oil Corporation and the Federal Ministry of Mines and Steel. NNPC by law manages the joint venture between the Nigerian federal government and a number of foreign multinational corporations, which include Royal Dutch Shell, Agip, ExxonMobil, Chevron, and Texaco (now merged with Chevron). Through collaboration with these companies, the Nigerian government conducts petroleum exploration and production.

NNPC has sole responsibility for upstream and downstream developments, and is also charged with regulating and supervising the oil industry on behalf of the Nigerian Government. In 1988, the corporation was commercialized into 11 strategic business units, covering the entire spectrum of oil industry operations: exploration and production, gas development, refining, distribution, petrochemicals, engineering, and commercial investments (The Economist, 2007; NNPC, 2015c). The NNPC is also exploring the biofuel option for the transportation sector and this include mainly ethanol and biodiesel which is mixed with conventional fuel.

2.5.10 Presidential Taskforce on Power (PTFP)

The Presidential Task Force on Power (PTFP) was established in June 2010, to drive the implementation of the reform of Nigeria's power sector. It brings together all the agencies that have a role to play in removing legal and regulatory obstacles to private sector investment in the power industry. It also has the mandate to monitor the planning and execution of various short-term projects in generation, transmission, distribution and fuel-to-power that are critical to meeting the stated service delivery targets of the power reform roadmap (PTFP, 2015).

The PTFP collaborates closely with various ministries and agencies that have specific contributions to the reform process, including the Federal Ministry of Power (FMP), the Federal Ministry of Finance (FMF), Ministry of Petroleum Resources (MPR), the Bureau of Public Enterprises (BPE), the Nigerian Electricity Regulatory Commission (NERC), the Nigerian National Petroleum Corporation (NNPC), the Bureau of Public Procurement, National Gas Company Limited (NGC) and the Power Holding Company of Nigeria (PHCN).

2.5.11 Rural Electrification Agency of Nigeria (REA)

The Rural Electrification Agency (REA) was established in 2006 under section 88 (I) of the Electric Power Sector Reform Act (EPSRA), 2005. Its vision was to mobilize capital for sustainable private sector driven investment in rural electricity development in Nigeria dedicated the goal of improving the living conditions in rural areas through enhancing agriculture, commercial, industrial and domestic activities. The core functions of the REA is to promote and coordinate rural electrification projects, implement and manage the Rural Electrification Fund and regulation of rural electrical sector. The REA projects center on grid expansion to rural areas via funding from the federal government's annual budgetary allocation; most recently it has broadened its ambit to include the deployment of off-grid and mini-grid renewable energy generating systems to accelerate the pace of improvement (REA, 2015).

2.5.12 Standards Organization of Nigeria (SON)

Established by the Federal Government by the Act. No.56 of the 1971, the Standards Organization of Nigeria (SON) is entrusted with the responsibility to ensure imported and manufactured products in Nigeria are kept at stipulated standards (SON, 2015). Other functions of the SON includes the follow;

- To ensure the compliance of designated and approved standards by the Council;
- undertake investigations as necessary into the quality of facilities, materials and products in Nigeria, and establish a quality assurance system including certification of factories, products and laboratories;
- To provide reference standards for calibration and verification of metering and metering equipment ;
- To compile an inventory of products requiring standardization;

- To prepare Nigeria Industrial Standards;
- To foster interest in the recommendation and maintenance of acceptable standards by industry and the general public;
- To develop methods for testing of materials, supplies and equipment;
- To register and regulate standard marks and specification.

Some renewable energy and energy efficiency standards have recently been developed and adopted by the SON. This includes among others, a code of practice for the deployment of outdoor solar lighting, design qualification and type approval of PV modules, safety standards for use of PV power converters, etc. (Ley et al. 2014).

2.5.13 Council for Renewable Energy in Nigeria (CREN)

The Council For Renewable Energy Nigeria is a not for profit, multi-stakeholder association, which promotes the appropriate use of renewable energy technology in Nigeria and the reduction of greenhouse gases through reduced consumption of fossil fuels. CREN aims to bring together the professional sector, government and civil servants, academics, associations, industry, financial institutions and services, the not for profit sector and end-users to act as a forum where they can work together for efficient, appropriate renewable energy implementation and to develop a comprehensive sustainable energy strategy for Nigeria.

The Council works with all stakeholders to address the challenges of awareness, availability, cost and appropriate implementation of renewable energy technologies in Nigeria. Also, CREN creates public awareness and foster the emerging availability of reliable, economically viable renewable energy systems by supporting policy information and implementation, research, development and use of such systems (CREN, 2015).

2.5.14 Green Building Council of Nigeria (GBCN)

Although Nigeria is a prospective member of the World Green Building Council, the Green Building Council of Nigeria (GBCN) will aid in the development of green building rating system in Nigeria. The council will also provide a single useful metric for the establishment of green building actions and address the issue of climate change in Nigeria (WGBC, 2015). Some rating systems that would be adopted include the following;

- BEREEAM (Building Research Establishment's Environment Assessment Method)
- CASBEE (Comprehensive Assessment System for Building Environmental Efficiency)
- SBTool (Sustainable Building Tool)
- Green Globes
- LEED (Leadership in Energy and Environmental Design)

2.6 Nigerian Energy Policies and Strategies

The Nigerian energy policies and strategies are summarized in this section from the earliest to the latest.

2.6.1 National Electric Power Policy (NEPP), 2001

The National Electric Power Policy (NEPP) was the first of its kind in the wake of reform in the Nigerian power sector. Its development was due to the recommendations of the Electrical power implementation Committee (EPIC), which was the body in charge of reforms and transformation of the power sector in 1999. The NEPP was created in March 2001[36], and presented three bold steps in achieving the goal of reforming the power sector. The first step was to privatize NEPA which was state owned and introduce Integrated Power Producers (IPPs) of electricity. The next step was to increase competition between participants in the market, gradually remove subsidies and sale excess power to the DISCOs. In the last step, it was expected that the market and competition would have been more intense and allow for full cost pricing of supply, and liberalization of the electricity market would have been complete (Maduekwe, 2011). The NEPP had the following as critical objectives for Nigeria's electric power sector:

- Ensure that the power sector attracts private investment both from Nigeria and from overseas
- Drafting of a new Electricity law to provide the legal framework for the reform Agenda
- Establishment of an independent regulatory agency
- Development of a wholesale electricity market

[36] See www.nigeriaelectricityprivatisation.com/?page_id=2

- Establishment of a consumer assistance fund to ensure the efficient and targeted application of subsidies to less privileged Nigerians
- Establishment of a Rural Electrification Agency ("REA") to manage the rural electrification fund.

2.6.2 National Energy Policy (NEP), 2003, 2006, 2013

Before the Federal Government of Nigeria approved the energy policy in the year 2003, there was no comprehensive energy policy. The established energy policy was called the National Energy Policy (NEP) which was developed by the Energy Commission of Nigeria (ECN).The National Energy Policy (NEP) sets out government policy on the production, supply and consumption of energy reflecting the perspective of its overall needs and options.

The main goal of the policy is to create energy security through a robust energy supply mix by diversifying the energy supply and energy carriers based on the principle of "an energy economy in which modern renewable energy increases its share of energy consumed and provides affordable access to energy throughout Nigeria, thus contributing to sustainable development and environmental conservation". Importantly, the national policy already outlines the key elements for development and application of renewable energy as:

- To promote decentralized energy supply, especially in rural areas, based on RE resources

- To develop, promote and harness Renewable Energy (RE) resources of the country and incorporate all viable ones into the national energy mix
- To promote efficient methods in the use of biomass energy resources
- To de-emphasize and discourage the use of wood as fuel
- To keep abreast of international developments in RE technologies and applications.

The NEP has first revised in 2006 to incorporate some changes and improvement, while the last draft revised edition was done in 2013. The 2013 draft revised edition includes; environmental and climate change policy, policy on other energy issues such as R&D, bilateral, regional and international cooperation, local content, manpower development and training, and Gender issues. Other areas included are policy on energy financing, planning and policy implementation (see NEP, 2003; NEP, 2006; NEP, 2013).

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

The National Economic Empowerment and Development Strategy (NEEDS) was developed by the National Planning Commission (NPA) in 2004 and was intended to develop and alleviate poverty in the country. This involves the action of human resources on the natural resources to produce goods necessary to satisfy the economic needs of the community[37]. On infrastructure, NEEDS promotes the privatization of government

[37] www.omojuwa.com/2014/06/national-economic-empowerment-and-development-strategy-needs%E2%80%8F-ayorinsola-obisanya/

infrastructure and was one of the key instrument in achieving a revamped service delivery.

The Nigerian government will however, fund projects that have very low attractiveness and high investment cost to investors such as those in rural areas. Furthermore, the increased share of renewables in the national energy mix was further encouraged in the NEEDS. This involves the suggestion for the creation of renewable energy agency and technologies which will be funded under the National Power Sector Reform Act. This was the milestone towards the adoption of renewables in the power sector and its utilization for rural electrification (NEEDS, 2004; Marcellus, 2009).

2.6.4 National Power Sector Reform Act (EPSRA), 2005

The National Power Sector Reform Act established in 2005 ensured the liberalization of the Nigerian power sector. The Act was due to the NEPP developed in 2001 and made provision for new legal and regulatory framework for the power sector.[38] The Act gave way to unbundling and privatization of the power sector, which intends to introduce competition in the electricity market, enhance rural electrification, while protecting consumer rights and developing performance standards in the power sector.[39] The main provisions of the Act include the following:

- Creation of the initial Holding Company (PHCN) to assume the assets, liabilities and employees of NEPA.

[38] www.reegle.info/policy-and-regulatory-overviews/ng
[39] www.nigeriapowerreform.org/index.php?option=com_content&view=article&id=79:policy-framework&catid=41&Itemid=304

- Unbundling of PHCN into successor companies and ensuring greater operational autonomy.
- Market development.
- Privatization of successor companies which empowers the Bureau to undertake this responsibility.
- Establishment of the Nigeria Electricity Regulatory Commission (NERC).
- Establishment of the Rural Electrification Agency and Fund to provide access to electricity to the rural areas as well as fund rural electrification projects, respectively.
- Power Consumer assistance fund to bridge the funding gaps for the low income earners.

The Act also provides for an investment-friendly environment for potential investors in the power sector by transforming the integrated structure of the sector (as in the period of NEPA) into vertically unbundled segments: Generation, Transmission and Distribution (Ajumogobia & Okeke, 2015). The Act ensured a transition in the reform process, providing a necessary criteria for the advancement of power generation reforms. As part of the process in the Act, a wider mandate for power market regulation was established (Ayanruoh, 2012).

2.6.5 Renewable Electricity Policy Guidelines (REPG), 2006

Developed by the federal Ministry of Power and Steel in December, 2006, the Renewable Electricity Policy Guidelines (REPG) mandated the Nigerian government on the expansion of electricity generation[40] from renewables to at least 5% of the total electricity generated and a minimum of 5 TWh of electricity generation in the country (REPG, 2006). This policy document presents the Nigerian government's plans, policies, strategies and objectives for the promotion of renewables in the power sector (Iwayemi et al., 2014). The policy goals and strategies of the REPG are as follows;

- Expansion of the market for renewable electricity to at least five percent of total electricity generating capacity and a minimum of 5 TWh of electric power production;
- Establishment of stable and long-term favorable pricing mechanisms and ensuring of unhindered access to the grid with guaranteed purchase and transmission of all electricity produced by renewable electricity producers and obliging the grid operators upgrade the system accordingly;
- Construction of independent renewable electricity systems in areas not covered by the electricity grid;
- Development of innovative, cost-effective and practical measures to accelerate access to electricity services in rural areas through renewable sources;
- Setting up of a Renewable Electricity Trust Fund to be governed by the Rural Electrification Fund.
- Creation of a multi-stakeholder partnership for the delivery of renewable electricity to meet national development goals;

[40] www.businessdayonline.com/2015/02/reviewing-the-legal-framework-for-renewable-energy-projects-in-nigeria/

- Broadening international cooperation in expanding the role of renewable electricity for meeting national development goals and contributing to global efforts in addressing climate change.

2.6.6 Renewable Electricity Action Programme (REAP), 2006

Developed in relation to the REPG by the Federal Ministry of Power and Steel in 2006, the Renewable Electricity Action Programme (REAP) set out a roadmap for the implementation of the REPG. The document presents an overview of the Nigerian electricity sector and relates it to renewable energy development. The documents also reviews government targets and provides strategies for renewable energy development such as; leveling the playing field for renewable electricity producers, multi-sector partnerships, demonstration projects, supply chain initiatives, etc. The study also made provision for financing renewable programs and explored the roles of government ministries and agencies, then concludes with a risk assessment, monitoring and evaluation (REAP, 2006). The Ministry of Power and Steel has however been restructured to the Ministry of Power and this programme may have been abandoned.

2.6.7 Nigerian Biofuel Policy and Incentives (NBPI), 2007

The aim of this policy was to develop and promote the domestic fuel ethanol industry through the utilization of agricultural products. This was in line with the government's directive on an Automotive Biomass Programme for Nigeria in August 2005. The NNPC was mandated to create an environment for the take-off of the ethanol industry. The policy further aimed at the gradual reduction of the nation's dependence on imported gasoline, reduction in environmental pollution, while at the same time creating a commercially viable industry that can precipitate sustainable domestic jobs. The benefits of this policy was to create additional tax revenue, provision of jobs to reduce poverty, boost economic development and empower those in the rural areas, improve agricultural activities, energy and environmental benefits through the reduction of fossil fuel related GHGs in the transport sector.

The targets of the NBPI are as follows:

- To ensure the contribution of all biofuels companies with 0.25% of their revenue towards funding research into feedstock production, local technology development and improved farming practice
- To develop an import duty waiver for biofuels granted by for 10 years will be required
- An exemption from taxation, withholding tax and capital gains tax imposed in respect of interest on foreign loans, dividends, services rendered from outside Nigeria to biofuel companies by foreigners.
- To launch of a special kind of loan for investors in the biofuel industry to aid the development of large-scale Schemes and large scale integrated operation including a plantation, a plant and within-the gate collocated power generating plants.

- To achieve the blending of up to 10% of fuel ethanol with gasoline to achieve a blend to be known as E-10 during the seeding phase of the programme
- To achieve 100% domestic production of biofuels consumed in the country by 2020.
- Ensure an off-take agreement by NNPC for biofuels as buyer of last resort.

The implementation of the NBPI was set to be undertaken in two phases. The first phase is called seeding the market which involves the importation of cargoes of fuel ethanol until the domestic market is matured. The seeding phase was expected to begin with initial penetration of selected cities during the first 3 years, while the nationwide roll-out is expected within 5-10 years. The phase 2 which is called bio-fuel production programme, will begin concurrently with the seeding programme. It was the core agriculture integration programme and ensure the establishment of plantations and the construction of a bio-fuel distillers and plants (NBPI, 2007).

2.6.8 Nigerian Gas Master Plan (NGMP), 2008

In line with the Nigerian government's plan to become a major international player in the international gas market as well as to lay a solid framework gas infrastructure expansion within the domestic market, the Nigerian Gas Master Plan (NGMP) was developed and approved on the 13th of February, 2008[41]. The NGMP envisages a wholesale transition to decentralized privately held electricity generation gas plants from the erstwhile public power utility. The plan also aims to stem the huge waste associated with gas flaring and to put to more productive use the nation's large gas reserves. What the Gas Master Plan does not clearly mention is that the utilization of Compressed Natural Gas (CNG) can play a major role in transforming the nation's transportation sector if adopted on a large scale (Emodi & Boo, 2015c).

2.6.9 Roadmap for Power Sector Reform (A Customer-Driven Sector-Wide Plan to Achieve Stable power Supply, 2010) and (Revision 1, 2013)

The first Roadmap for Power Sector reform was developed by the Presidential Task Force on Power (PTFP) in 2010 and based on it, the Revision was carried out and presented on the 30th of August 2013. This document includes review and strategic plans by the government to finalize the reforms in the power sector, while setting the nation on a steady path clean electricity generation at a competitive rates. The Roadmap is not in itself a policy document but a set of strategies to fast-track the achievement of the NEP (2003) as stated in the EPSRA of 2005. The Roadmap explores some key aspects of the power sector and development such as generation, transmission, distribution, NIPP and fuel supply to power plants (see RPSR,

[41] See www.nercng.org/index.php/myto-2

2010; RPSR, 2013). Some recommendations and proposals of the reforms are given below;

- An improvement of collection efficiency and returns to the market during the pre-Transitional Electricity Market (TEM) declaration stage;
- The commencement and conclusion of all labor negotiations, settlement of liabilities, rationalization and eventual winding down of the Power Holding Company of Nigeria (PHCN).
- The continuation of the clear and firm political will to resist efforts that could undermine privatization and the reform.
- The development of an optimal transmission capacity expansion plan and funding strategy to provide a reliable highway for wheeling generated power;
- The acceleration of the management and operational efficiency levels of the Transmission Company of Nigeria (TCN);
- More commitment to deliver the gas development and transportation infrastructure projects earmarked for gas-to-power alignment.
- The prevention of frequent acts of vandalism to pipelines such as the Trans-Forcados and Trans-Niger crude oil lines, and the Escravos Lagos Pipeline Systems (ELPS) gas pipelines.
- The clarity on the interim operation and maintenance of the National Integrated Power Projects (NIPP) generation assets;

- More firm commitment from NIPP to deliver its critical transmission projects scheduled for 2013 as well as the Omoku, Gbarain and Alaoji power plants to come on stream without further delay;
- To meeting of the conditions precedent to the declaration of TEM, before the handing over the successor companies to the new owners.
- The positioning a well-capitalized Nigerian Electricity Liability Management Company (NELMCO) to address post hand-over fall outs from creditors.
- To secure a minimum, transitional service-delivery level through project and process optimization.

2.6.10 Renewable Energy Master Plan (REMP) 2005 and 2012

The Renewable Energy Master Plan (REMP) was developed by the Energy Commission of Nigeria (ECN), in collaboration with the United Nations Development Programme (UNDP) in 2005 and was later reviewed in 2012 (see REMP, 2005; REMP, 2012). The REMP expresses Nigeria's vision and sets out a road map for increasing the role of renewable energy in achieving sustainable development. The REMP is anchored on the mounting convergence of values, principles and targets as embedded in the National Economic Empowerment and Development Strategy (NEEDS), National Energy Policy, National Policy on Integrated Rural Development, the Millennium Development Goals (MDGs) and international conventions to reduce poverty and reverse global environmental change (REMP, 2012).

The REMP stress the need for the integration of renewables in buildings, electricity grids and for off-grid electrical systems. Further, the importance of solar power in the country's energy mix was also highlighted in the policy document. According to the REMP, Nigeria intends to increase the supply of renewable electricity from 13% of total electricity generation in 2015 to 23% in 2025 and 36% by 2030. Renewable electricity would then account for 10% of Nigeria's total energy consumption by 2025. However, the REMP have not been approved by the National Assembly to be passed into law.

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

The National Renewable Energy and Energy Efficiency Policy (NREEEP) outlines the global thrust of the policies and measures for the promotion of renewable energy and energy efficiency. The FMP developed the NREEEP in 2014 and is awaiting the approval of the Federal Executive Council. The objectives of the NREEEP are presented as follows (NREEEP, 2014);

- To set out a framework for action to address Nigerians' challenge of inclusive access to modern and clean energy resources, improved energy security and climate objectives;
- To recognize the national significance of renewable electricity generation activities by providing for the development, operation and maintenance,

and upgrading of new and existing renewable electricity generation activities;

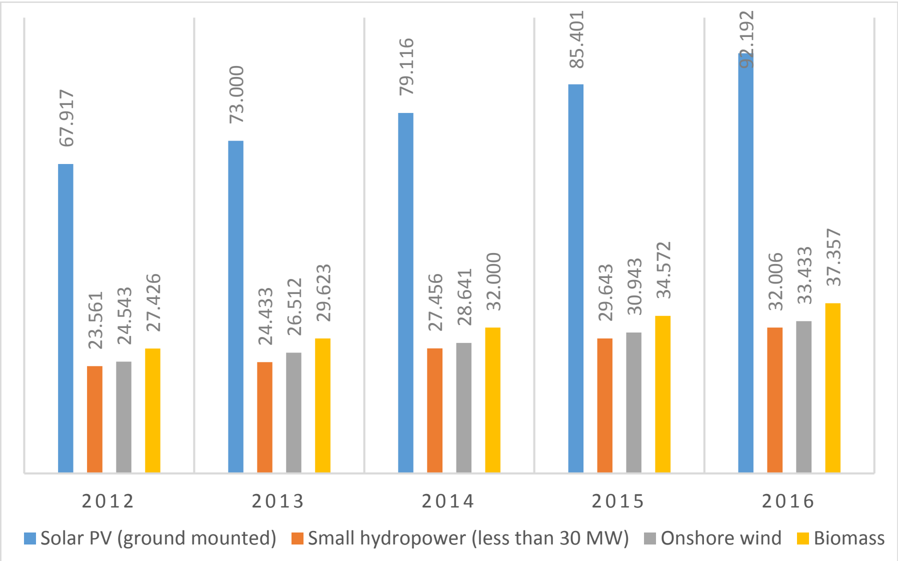
- To declare that the proportion of Nigeria's electricity generated from renewable energy sources shall increase to a level that meets or exceeds the ECOWAS regional policy targets for renewable electricity generation and energy efficiency for 2020 and beyond;
- To declare energy efficiency to be a major, low-cost, and under-utilized Nigerian energy resource offering savings on energy bills, opportunities for more jobs, improving industrial competitiveness, and lowering air pollution;
- To recognize that poverty mitigation and environmental protection are hindered by the continued predominance and inefficient use of oil and natural gas in meeting our energy needs;
- To take a step in the right direction and broaden the definition of energy security to include renewable energy and energy efficiency as equally important indigenous sources of energy, in addition to oil and gas;
- To incorporate provisions for renewable energy and energy efficiency generation activities into government policy statements and plans, and recognizes the importance of enabling framework conditions for private investment in renewable energy and energy efficiency;
- To set national targets for achievements in electricity from renewable energy and energy efficiency capacity addition by 2020 and beyond;

- To require the preparation of a national action plan for renewable energy and for energy efficiency and set a time frame within which implementation is required;
- To recommend that the signatory parties to this policy should collaborate in preparation of the action plans and work together in achievement of the final mandatory targets;
- To make it mandatory for the Ministry of Power to facilitate the development of an integrated resource plan (IRP) and ensure the continuous monitoring and review of the implementation and effectiveness of the action plans prescribed under the national policy statement;
- To take steps away from the overheated rhetoric that Nigeria's future energy independence be secured by ever more gas and oil consumption; and
- To facilitate the establishment of a framework for sustainable financing of renewable energy and energy efficiency projects and programmes in Nigeria.

2.6.12 Multi-Year Tariff Order (MYTO), 2008 and 2012

In 2008, a 15-year roadmap towards cost reflective tariffs called the Multi-Year Tariff Order (MYTO 1) was developed by the Nigerian Electricity Regulatory Commission (NERC). The first two phases, 2008-200 and 2012-2017 were designed to keep consumer prices relatively low, through still affecting the price increases in a gradual manner. The final regime is intended to provide the necessary incentives for power producers and investors to operate and maintain electricity infrastructure (Emodi and Yusuf, 2015). The NERC has released the Multi-Year Tariff Order 2 (MYTO 2), which has similar features to MYTO 1 but includes some improvements, and will be effective from 1st June 2012 to 31st May 2017. The retail tariff in MYTO 2 will be reviewed bi-annually and changes may be made for all electricity generated at wholesale contract prices, adjusted for the Nigerian inflation rate, US$ exchange rate, daily generation capacity, and accompanying actual CapEx and OpEx requirements that will vary from those used in the tariff calculation. Figure 2-27 shows the MYTO 2 feed-in tariffs from 2012 to 2016 in Nigeria (Nigerian Naira per MWh (N/MWh) and the dollar equivalent)[42].

Figure 2-27: Nigeria's MYTO 2 FiTs for 2012-2016 (Naira/Per MWh)



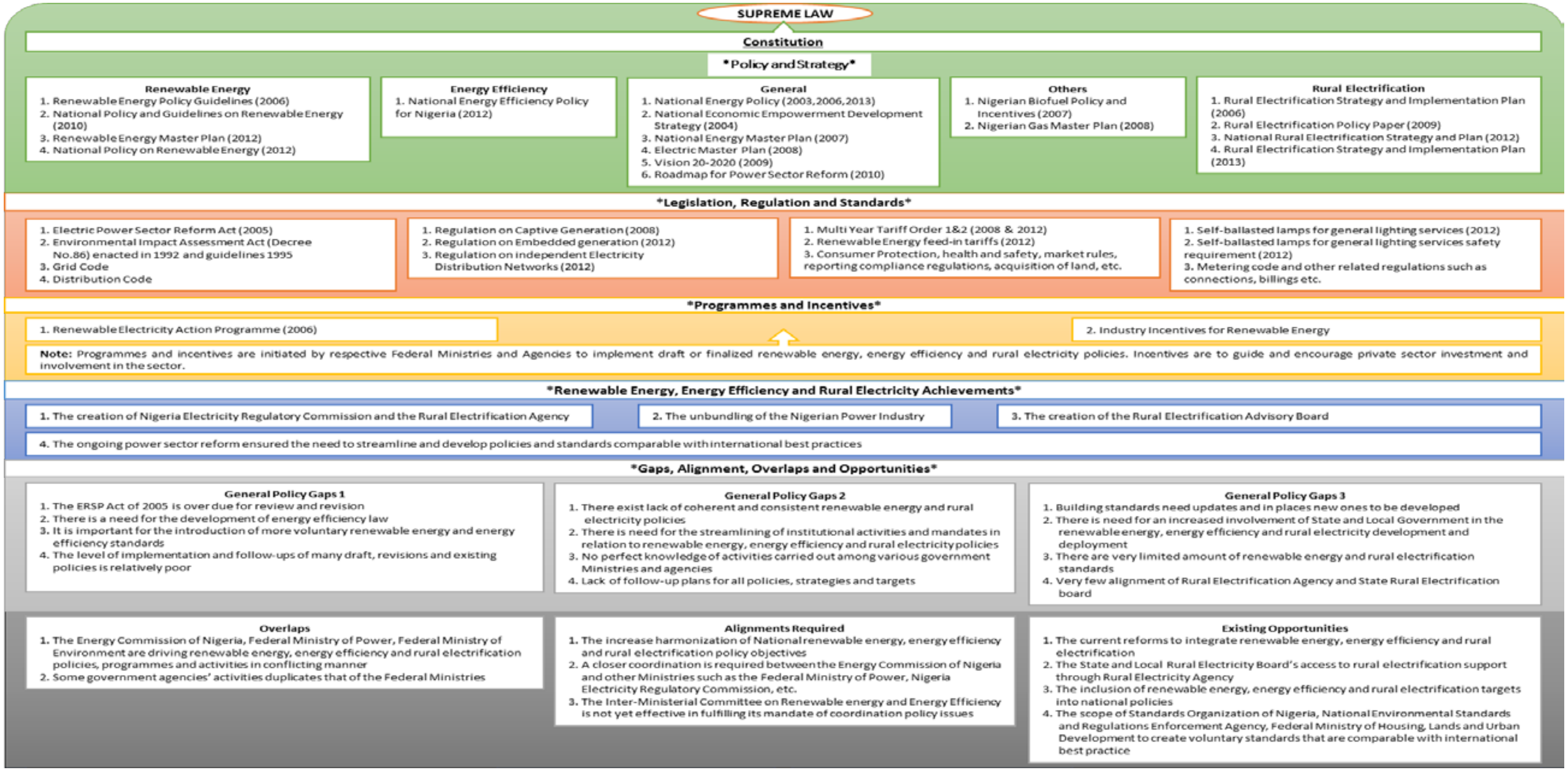
[42] www.nercng.org/index.php/myto-2

The review of all inputs to the tariff calculation is expected to begin by 2016 as the basis of a new Multi-Year Tariff Order (MYTO) designed to kick-start the next five years starting from 1st June 2017. The MYTO 2 contains a 15-year tariff pathway for electricity generated from RE, with bi-annual minor reviews and major reviews every five years. The MYTO 2 tariffs are negotiable if a generator can prove to the NERC that their costs for electricity generation from renewables are not in-line with the assumptions of the MYTO 2 (Emodi & Boo, 2015c).

2.6.13 Draft Rural Electrification Strategy and Implementation Plan (RESIP), 2014

The Power Sector Reform team initially prepared the Rural Electrification Strategy and Implementation Plan in 2006 (RESIP, 2006). However, a committee involved in the power sector reviewed and redrafted the RESIP in 2014. It was expected to establish a clear institutional step-up for the sector and set a roadmap which will result in the development of an enabling framework for rural electrification in Nigeria. The primary objective of the RESIP is to expand access to electricity as rapidly as can be afforded in a cost-effective manner. This includes the use of on-grid and off-grid means of electricity supply. The draft is ready and awaiting approval from the government. A general overview of the various Nigerian energy policies, legislations, regulations, standards, programmes and incentives, their achievements, gaps, alignment, overlaps and opportunities are presented in Figure2-28.

Figure 2-28: An Overview of the Nigerian Energy Policies (Source: Ley et al. 2014; Energypedia (2015)



Chapter 3. Literature Review

This chapter is divided into two sections where the first presents an insight into the various energy forecasting models, their approach and classification. The second section presents some scholarly contributions in the economics literature which applied the LEAP model on various sectors in different countries of the world. The review in the second section is limited to the application area, findings, results and synthesis in relation to the present study.

3.1 Review of Energy Forecasting Models

The increasing availability of computers in the 1970s and the raise in environmental awareness due to climate change and oil crises saw the introduction of energy models (Kempton, 1997; MacCracken, 2004; Weart, 2008). The models initially built were mostly for industrialized countries, and as such, its application to developing countries were based on assumption in relation to the developed country situation (Shukla, 1995). Furthermore, it was assumed that the future developmental projections would be similar to the historical projections of developed countries, in which in reality was not the same. Although, Urban et al., (2007) argued that the pre-2007 energy models were biased towards the real situation in developing countries, subsequent energy models have been upgraded to suit the needs of developing countries.

Most energy forecasting models use economic activity (GDP per capita, representing living standards) as driving force for energy related issues. When internationally comparing to economic activity, the local currencies are expressed in a commonly known currencies such as the US dollars (Van Ruijven et al., 2008). They are developed specific to a nation or utility depending on the economic and market conditions prevailing (Suganthi & Samuel, 2012). Forecasting using energy models are done through either backcasting[43] or forecasting[44].

Some energy forecasting models are available and can be categorized under broad headings as briefly explained below;

- Time series models: are the most simplest of all energy models which uses time series trend analysis for extrapolating the future energy requirement. Time series models have been used in various energy economic studies to investigate the interrelations between energy-economic-environment variables for some time periods which are usually 25 years and above (Hamilton, 1994).
- Regression models: are employed in such a way to test theories that the current values of one or more independent time series affect the current value of another time series[45]. They are used to forecast coal, oil, gas and

[43] Backcasting usually refers to the process of exploring the past events given the information known to date. It usually starts by defining a desirable future and then works backwards to identify policies and programs that will connect the future to the presents (Brandes & Brooks, 2005).

[44] Forecasting is the process of exploring the future events that have not been observed or determined and is based on current trend analysis (Holmberg & Robert, 2000)

[45] Regression time series differ from the time series analysis previously mentioned, which focuses on comparing values of a single time series or multiple dependent times series at

electricity requirements, GDP projections as well as electric load forecasting. Much of the studies applying regression models are well established in the literature.

- Econometric models: are tools used by economist to forecast future developments in an economy (Hymans, 2002). They are statistical models which specifies the relationship that is believed to exist between the various economic quantities pertaining to a particular economic phenomenon under study. They are usually derived from a deterministic economic model by allowing for uncertainty, or from an economic model which itself is stochastic (Wooldridge, 2012). Studies [46] applying econometric models includes those dealing with energy demand and supply under some scenarios, projections of the total energy demand as a function of previous year's energy demand, price of energy, real income and heating day.
- Decomposition models: is a technique used in research methodology to decompose an aggregated indicator, using either energy use or CO_2 emission, into its drivers (Sun & Ang, 2000). Various studies such as Ang, (1995a; 1995b; 1996) have applied the decomposition method to investigate the changes in industrial energy consumption. Other studies have investigated the changes in other sectors as available in energy economics literature.

different point in time (Imdadullah, 2013).

[46] Some studies include; Suganthi and Jagadeesan (1992), Rao and Parikh (1996), Suganthi and Williams (2000), Iniyan et al., (2006), and Roming and Leimbach (2015),

- Unit root test and cointegration models: unit root tests are used to tests whether a time series variable is non-stationary using an autoregressive model. Two know type of test include the augmented Dickey-Fuller test and the Phillips-Perron test, and they use the existence of a unit root as the null hypothesis. The cointegration tests which are preceded by various unit root test are used to test the cointegration or long run relationships between two variables.
- Input-output models: are used to assess how social and economic changes will affect energy requirements in a country. They specifically show how industries are linked together through supplying inputs for the output of an economy[47].
- Computable general equilibrium models: are a standard tool of empirical analysis that use economic data to estimate how an economy might react to changes in policy, technology, climate change, subsidy, different tax and quota (Wing, 2004).
- Bottom up models: this includes partial equilibrium models (e.g. POLES, WEM, PRIMES), optimization models (LEAP, MARKAL, TIMES, MESSAGE), simulation models (NEMS-RSDM, MURE, REEPS, LEAP, MAED, NIA)[48]. These models project energy demand for appliances and equipment in the residential, commercial and industrial sectors, as well as other technologies in the sectors analyzed (MacNeil, 2013). Some of these models will be further described in the subsequent subsections.

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[47] www.sjsu.edu/faculty/watkins/inputoutput.htm

[48] See Herbst et al., (2012) for more on this energy models.

3.1.1 Approach to Energy Modeling

Energy models have two types of approach and they are; the top-down and bottom-up approaches. These are the two basic approaches to examine the linkages between the economy and specific GHG emitting sectors such as the energy system. Top down models evaluate the system from aggregate economic variables and they come from the way the energy modeler apply macroeconomic theory and econometric techniques to historical data on energy consumption, prices, income to model the final demand for goods and services, and supply it to the main sector (Pachauri et al., 2014).

On the other hand, bottom-up models work at a disaggregated level, and thus require extensive databases of empirical data to be able to build up the desired energy model (Kavgic et al., 2010). However, the application of the bottom-up model results in a more inclusive assessment and analysis of the energy technologies, policies, fuel mix, energy mix and the entire energy system (Lkhagva, 2014). Table 3-1 shows the comparison between the top-down and bottom-up models.

Table 3-1: Comparison between Top-down/Bottom-up Models
(Source: Van Beeck, 1999)

Top-down Models	**Bottom-up Models**
Use an economic approach	Use an engineering approach
Give pessimistic estimates on best performance	Give optimistic estimates on the best performance
Cannot explicitly represent technologies	Allow for detailed descriptions of technologies
Reflect the available technologies adopted by the market	Reflect the technical potential

The most efficient technologies are given by the production frontier (which is set by the market behavior)	The efficient technologies can lie beyond the economic production frontier suggested by the market behavior
Use aggregated data for predicting purposes	Use disaggregated data for exploring purposes
Are based on the observed market behavior	Are independent of the observed market value
Disregard the technically most efficient technologies available, thus underestimating the potential for efficiency improvement	Disregard the market thresholds (hidden costs and other constraints), thus overestimating the potential for efficiency improvement
Determine the energy demand through aggregated economic indices (GNP, price elasticity), but vary in addressing the energy supply	Represent the supply technologies in detail using disaggregated data, but vary in addressing the energy consumption
Endogenize behavioral relationships	Assess the costs of the technological options directly
Assume that there are no discontinuities in historical trends	Assume that the interactions between the energy sector and the other sectors are negligible

From Table 3.1, it can be observed that the bottom-up models presents a better approach in analyzing an energy system provided the complex data for the modeling are available. According to Andersen and Termansen (2013) "*bottom-up models presents a comparative strength in their ability to investigate the impacts of energy policy on the portfolio of technologies that make up the supply and demand components of the energy system, in order to identify low-cost opportunities or design technology-based taxes, subsides or standards. The comparative strength of the top-down model is its ability to assess the macroeconomic costs of a policy shock and its economy-wide feedbacks on prices, commodity and factor substitution, income and economic welfare*". This leads to further clarifications on the bottom-up and top-down models as the next subsection describes the classification of these models.

3.1.2 Classification of Existing Bottom-up and Top-down Energy Models

In this subsection, the classification of ten popular bottom-up and top-down energy models are carried out in nine classification pattern which includes; (i) purposes of the energy models, (ii) model structure (internal and external assumptions), (iii) the analytical approach, (iv) underlying methodology, (v) mathematical approach, (vi) geographic coverage, (vii) sectorial coverage, (viii) time horizon and (ix) data requirement. This is shown in Table 3-2. This thesis employed the LEAP model in energy demand and supply forecasting along with their GHG emission using a scenario base approach. The LEAP model and the reason for the selection of the model are presented in the next chapter.

Table 3-2: Classification of Popular Bottom-up/Top-down Models (Source: Van Beeck (modified), 1999)

	Developers	Purposes		Assumptions	Top-down vs. Bottom-up	Methodology	Mathematical Approach	Level	Sectorial Coverage	The Time Horizon	Data Requirements
		General	Specific								
EFOM-ENV	European Commission DDG-XII F/1, Belgium	Exploring	Energy supply, Energy and environment policy analysis and planning, Emission reduction	Endogenous analysis of generation expansion. Input needed: demand projections/ scenarios, supply costs, (environmental) constraints	Bottom-Up	Optimization	Linear Programming/ Dynamic Programming	National	Energy producing and consuming sectors	Medium to long term	Quantitative, monetary, disaggregated
ENERPLAN	Tokyo Energy Analysis Group, Japan	Forecasting or exploring (depending on mode)	Energy supply, energy demand, matching demand and supply	Depends on mode	Top-Down	Econometrics and simulation	Not available	National	Energy sector	Short to medium	Quantitative
ENPEP	International Atomic Energy Agency (IAEA), Autstria	Forecasting, exploring	Energy demand, supply, matching demand and supply, environmental impacts	Demand: high degree endogenization Supply: detailed description of end-uses and (renewable) technologies	Hybrid. Top-down for demand analysis and bottom-up for supply	Macro-economic for demand, economic equilibrium for total energy system	Not available	Local, National	Entire economy	Short (1-3 yrs), medium, long (max 50 yrs)	Quantitative, monetary, aggregated and disaggregated
LEAP	Stockholm Environmental Institute Boston, USA	Exploring, forecasting	Demand, supply, environmental impacts. energy policy analysis, environmental	Demand: rather high degree of endogenization and description of all sectors in economy Supply: simple	Demand: top-down, supply: bottom-up	Demand: econometric or macro-economic. Supply: simulation	Not available	Local, national, regional, global	All sectors	Medium, long term	Quantitative, monetary, aggregated/ disaggregated

			policy analysis, biomass- and land-use assessment, preinvestment project analysis, integrated energy planning, full fuel cycle analysis	description of end-uses and supply technologies, including some renewable							
MARKAL	International Energy Agency (IEA)/ ETSAP	Exploring	Energy supply with constraints. The objective includes target-oriented integrated energy analysis and planning through a least cost approach	Low degree of endogenization, focuses only on the energy sector, detailed description of end uses and (renewable) energy technologies possible	Bottom-up	Toolbox/ Optimization	Linear programming, dynamic programming	Local, national	Energy sector only	Medium, long term	Quantitative, monetary, disaggregated
MARKAL-MACRO	Brookhaven National Laboratory, USA	Exploring	Demand, supply, environmental impacts. Economy-energy-environmental analysis and planning	Neo-classical growth model with nested substitution (CES) between capital/ labor aggregate and energy	MACRO part is top-down, MARKAL part is bottom-up	Macro-economic for MACRO and partial equilibrium through optimization for matching demand and supply in MARKAL	Dynamic programming (non-linear)	Local, National	All sectors	Medium, long term	Qualitative, monetary, aggregated, disaggregated
MESAP	IER, University of Stuttgart,	Exploring, forecasting	Modular package. Demand,	Depends on module	Top-down (demand) and bottom-	Econometric (demand), simulation or	(among others) linear programming,	Local, national	All sectors through PLANET/	Medium, long term	Quantitative, monetary, aggregated,

	Germany		supply, environmental through different modules		up (supply)	linear programmin g (supply)	dynamic programming		MADE		disaggregated
MESSAGE-III	International Institute for Applied System Analysis (IIASA), Austria	Exploring	Energy demand and supply, environmental impacts. generation expansion planning, end-use analysis, environmental policy analysis, investment policy	Detailed description of energy end-uses and (renewable) energy technologies	Bottom-up	Optimization	Dynamic programming	Local, national	Energy sector	Short, medium, long term	Quantitative, monetary, disaggregated
MICRO-MELODIE	CEA, France	Exploring	Energy demand, supply, environment. analysis of macro-economic energy and environment linkages	Multi-sectorial analysis with a description of conventional energy technologies only, in particular for the electricity sector.	Top-down with a detailed description of the energy sector	Macro-economic based on price equilibrium	Not available	National	All sectors, with a detailed description of the energy sector	Medium, long term	Quantitative, monetary, aggregated, disaggregated
RETscreen	CEDRL/Natural Resources Canada	Exploring	Energy supply. Specially designed for renewable energy technologies	Detailed description of supply technologies for generation expansion	Bottom-up	Spreadsheet/ Toolbox	Not available	Local, national	Energy Sector	Not available	Quantitative, monetary, disaggregated

3.1 Literature Review and Synthesis

3.1.1 Literature Review

The LEAP model have been applied to a large number of scholarly articles and have been used by various government bodies and agencies for energy related studies. Most studies include Bose (1996), who simulated the passenger transport sector for the capital city of India namely New Delhi city for various scenarios including Business-As-Usual (BAU), improvement in vehicular speed, increased share of public transport buses, introduction of mass rapid transport system (MRTS) and a combination of other scenarios from a medium and long term perspective. Shin et al., (2005) analyzed the impact of expand landfill gas (LFG) method of electricity generation on cost of electricity generated as well as amount of greenhouse gas emissions using LEAP model for Korea by considering various different situations viz. a viz. business as usual scenario of existing power plants. It has been found that adopting expand landfill gas (LFG) complemented with further forms of energy consumption would help in dwindling global warming potential up-to 75% in comparison with spontaneous release of CH_4 gas. The result of the study suggests that expand landfill gas (LFG) method of electricity generation in Korea would prove to be a good alternative for CO_2 dislocation from medium-term perspective and would result in supplementary energy earnings.

An environmental and economic assessment was performed by Song et al., (2007) for Korea using the LEAP model. The study was based on energy policy changes particularly for climate change agreement and enhancement of CO2 lessening expertise, scenario investigation via operating data for the CO2 chemical absorption pilot plant which was installed in Seoul coal steam power plant (capacity of 2 Ton/day). The chief focus was on impact of chemical absorption progression on energy and environmental scheme. The findings of the study shows that CO2 separation pilot plant in coal steam power plants had significance and there was inevitability of further investment and technology development for CO2 mitigation technology in Korea. Dementjeva and Siirde (2010) modeled scenarios for energy sector of Estonia by extenuating the environmental impacts of electricity generation and by means of a new, lesser amount of environment destructive technology using the Long-range Energy Alternatives Planning system (LEAP) framework. The result of the study gives insights to policymakers about energy modeling results from the perspective of Estonia wishing to adhere to the European Union's severe technological and environmental requirements.

The study by Huang et al., (2011) elucidated the importance of long-term forecasting of supply and demand of energy from Taiwan's perspective highlighting the fact of lack of natural resources in the country, profound reliance on energy imports by Taiwan and the off-late stride of the country towards sustainable development. The study provides a glimpse of energy requirement and supply scenario in Taiwan and energy policies adopted over a period of time. The key objective of the study is application of the LEAP model for Taiwan's energy sector with an objective of comparing future energy requirement and supply trends including greenhouse gas emissions by considering alternative scenarios of energy policy and its impact for the evolving energy segment of Taiwan. The authors present outcome for different scenarios of implementation of energy policies considering the scenarios such as ‘‘business-as-usual” and aggressive energy-efficiency improvement policies. The authors have painstakingly considered the case of on-schedule retirement of existing nuclear plants (three in number) and have compared its impact with assumptions of lower economic growth on Taiwan’s energy sector. The outcome of the study offers key insights for policy makers related to adoption and implementation of future energy and climate policies in case of Taiwan.

In Taoa et al., (2011) study, they predicted scenarios which may act as an imperative indication for Chinese government to work towards having a low-carbon economy by considering four critical factors namely: Per capita GDP of China, energy structure in China, energy consumption in China and CO2 emissions for measuring and quantifying the level of low-carbon economic development of China. By adopting the LEAP model, the authors’ successfully model for: a) base scenario; b) low-carbon scenario; and c) frustrated low-carbon scenario in-order to suggest China’s low-carbon economic development (possible) levels for 2050. The results of the study elucidates that for China, the total terminal energy requirement (of coal) could be 6.095 billion tons (base scenario), 5.236 billion tons (low-carbon scenario) and 6.239 billion tons in 2050 (for frustrated low-carbon scenario). The study furthermore suggests that the main contributor for decrease in CO2 emissions in China could be attributed to improved energy concentration. Auxiliary infiltration of renewable energy and fuel switching seems to have contributed for decrease in CO2 emissions and conclude that these improvements would contribute significantly to achieve the goal of low-carbon economy ably coupled and complemented by clean coal technology and energy efficiency in China.

The possible potential trends of energy demand, energy structure and carbon emission was analyzed considering Beijing as a case study using LEAP model. The authors (Feng & Zhang, 2012) used 2007 as the base year up-to 2030 for three different scenarios namely: a) Business-As-Usual (BAU); b) Basic-Policy (BP) and c) Low-Carbon (LC) scenario. The results of the study shows that energy demand for Beijing under Low-Carbon (LC) scenario would be 88.61 million Mtce in 2030 which would be 55.82% lesser than BAU scenario and 32.72% lesser than BP scenario. Total Carbon emissions for Beijing under Low-Carbon (LC) scenario in 2030 would be 62.22% lesser than BAU scenario and 36.75% lesser than BP scenario. The results suggest that industrial sector in 2030 will account for largest proportion for BP and LC scenarios compared to BAU scenario and it has been found that building and transportation sector would play a major role in Beijing for effective control of energy-consumption and carbon emissions for decades to come.

Household energy requirements for most of the developing countries is majorly sufficed from non-commercial fuels (example: animal dung, wood, crop residues) which have often resulted in human health deterioration as well as environmental hazards. Ibitoye (2013) study focused on energy requirements for households in Nigeria under the framework that Nigeria would have access to clean affordable energy which is under United Nation's (UN's) Millennium Development Goals (MDGs) by estimating energy requirements between 2005 to 2020 and having a base/reference period. For UN's MDG's to be achieved, the authors estimated that household electricity utilization in Nigeria would increase by 41% and the use of contemporary fuels would more than double. This exodus to the use of contemporary fuels for cooking would result in diminution of overall fuel-wood consumption. Senshaw (2014) developed alternative scenarios (business-as-usual (BAU) and alternative scenario) for energy requirement of Ethiopia up-to 2050 using the LEAP model. The results of the study provide crucial insights for Ethiopian policy makers while framing policies towards sustainable energy and development for decades to come.

A study similar to Bose (1996), was Bitos and Kiartzis (2014) who analyzed the energy demands and pollutant emissions for a variety of potential scenarios and policies using the LEAP software for Greek road transport sector by considering 2010 as base year and extrapolating till 2035 under By making estimations for: a) business-as-usual (BAU) scenario; b) Substituting conventional fuels with alternate fuels leading to better fuel economy; c) Adoption of alternate technologies; d) better efficiency in-order to make possible predictions from policy perspective. The results of the study suggests that execution and adoption of enhanced fuel economy vehicles complemented by usage of alternative fuels and technologies would play a major role in reducing energy demand and alleviate pollutant emissions for Greek transportation sector in decades to come.

Mahumane and Mulder (2015) study estimated aggregate trends in energy supply and demand due to projected gush in natural resources exploration in Mozambique, the energy infrastructure and economic growth by using the LEAP framework and using elasticities of GDP with respect to biomass consumption, structure of the sector and vehicle ownership. The authors developed various scenarios and found that by 2030 primary energy production in Mozambique is expected to increase six times and majority of this would contribute to energy exports. With Mozambique all set to become a major energy player in decades to come, it has to strike a judicious balance between local and International export needs.

3.1.2 Synthesis of the Literature

From the literature review in the last sub-section, a synthesis is carried out to bring out the essence of the previous studies in terms of application of Long-Range Energy Alternatives Planning System (LEAP) framework and mitigation of GHG emissions under various scenarios for different countries world-wide and in the process highlight the importance of our study from Nigeria's Long term Energy Policy perspective.

Several studies in literature have focused on mitigation of GHG emission by shifting the energy utilization in demand side, while maximizing the potentials of diversification of the energy supply mix (Ghanadan & Koomey, 2005 for California; Lin et al., 2010; Cai et al., 2008; and He & Chen, 2013 for China; Papagiannis et al., 2008 for Greece; Giatrakos et al., 2009 for Crete; Davoudpour & Ahadi, 2006 for Iran; Phdungsilp, 2010 for Thailand (Bangkok); Kadian et al., 2007 for India; Fadel et al., 2001 for Lebanon; Mondal et al., 2010 for Bangladesh; Mustonen, 2010 for Lao). Other Studies have focused on GHG mitigation by shifting the energy carter in supply side (Zhang et al., 2010 for China; Islas et al., 2007 for Mexico; Takase & Suzuki, 2011 for Japan; Kalashnikov et al., 2011 for Russia; Huang & Lee, 2009 for Taiwan; Shin et al., 2005; and Lee et al., 2008 for Korea; Flores et al., 2011 for Central America - Honduras; Fadel et al., 2003 for Lebanon; Mulugetta et al., 2007 for Thailand).

This thesis falls into category where it intends to lessen GHG emissions by imposing policies in both supply and demand side for Nigeria energy system, by using the Long-Range Energy Alternatives Planning System (LEAP) framework and simulating scenarios (Similar studies include Dhakal, 2003 for Nepal; Shabbir & Ahmad, 2010 for Pakistan; Cai et al., 2008 and Wang et al., 2010 for China; Bose, 1996 and 1998 for India). Based on the findings and synthesis of literature, the future energy demand and supply in Nigeria was modeled using the LEAP model, as well as GHG emission. In this thesis, emphasize is placed on a) Primary energy supply mix (i.e. coal, hydro, natural gas, crude oil, biomass and other renewable). b) Transformation in the form of bio-fuel, charcoal, compressed natural gas, diesel, electricity, firewood, kerosene, liquefied petroleum gas and petrol. c) Final energy consumption from the perspective of household, transport, industry, commercial/service as well as agriculture sector. d) GHG emission reductions potentials in Nigeria. e) Least cost energy technology for Nigeria.

Based on the synthesis of previous findings and studies we model and develop four scenarios which include: a) Reference scenario; b) Low Carbon Moderate scenario; c) Low Carbon Advance; and d) Green Optimistic scenario.

Chapter 4. Methodology, Data and Scenario Development

This Chapter is divided into three sections, the first section presents model used in this thesis, the reason for the selection of the model and the algorithm of the LEAP model. The second section describes the LEAP data requirement, explains the data collection process and presents the datasets used in the development of the Nigeria LEAP Model. The last subsection explains the scenario development techniques, processes and then extensively discussed on each scenario developed.

4.1 The Model

This research will apply the Long-range Energy Alternatives Planning system[49] (LEAP) which is a scenario-based energy analysis and climate change assessment modeling tool, developed by Stockholm Environment Institute (SEI LEAP, 2008). It designs different scenarios of future energy demand and environmental impact based on how energy is consumed, converted, and produced in a given region or economy under a range of values for parameters such as population increase, economic development, technology utilization and inflation (Cai et al., 2008) . With a flexible data structure, LEAP is user-friendly and rich in technical specifications and end-

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[49] **LEAP citation:** Heaps, C.G., 2012. Long-range Energy Alternatives Planning (LEAP) system. [Software version 2015.0.4] Stockholm Environment Institute. Somerville, MA, USA. www.energycommunity.org

use details (Stockholm Environment Institute [SEI], 2008). The model has been extensively used at the local, national, and global scales to project energy supply and demand, predict environmental impact of energy policies, and identify potential problem.

4.1.1 Reason for the Selection of the LEAP Model

The LEAP model has some advantages compared to other models mentioned in the last chapter (Chapter 3) and these were the basis for the selection of the LEAP model presented below.

- Work scope: the LEAP model is able to work its way up from energy extractions, processing, conversion, transmission, up to end-use consumption by demand devices, under a range of assumptions.
- Data characteristics: the LEAP uses a flexible data structure which can be a Top-Down or Bottom-Up approach depending on the data available, or even decoupling approach.
- Policy analysis: with LEAP, an energy policy analysts can develop and evaluate alternative scenarios by comparing the energy requirement, social costs and benefits, and their environmental impacts.
- Technology and Environmental Data (TED): the LEAP model is integrated with TED databases which gives users information regarding technical characteristics, cost, and environmental effects of energy technologies.

- Graphical interface: the LEAP's interface is user-friendly, rich in technical specifications and end-use details.

4.1.2 The Algorithm of the LEAP Model

The LEAP uses a framework for calculating energy consumption, transformation (Electricity generation, oil refinery, charcoal production, coal mining), and carbon emissions and this are presented as follows.

4.1.2.1 Energy consumption

The total final energy consumption is calculated as follows[50]:

$$EC_n = \sum_i \sum_j AL_{n,j,i} \times EI_{n,j,i} \qquad (4-1)$$

Where *EC* is the aggregate energy consumption of a given sector, *AL* is the activity level, *EI* is the energy intensity, *n* is the fuel type, *i* is the sector, and *j* is the device.

The net energy consumption for transformation is calculated as follows:

$$ET_s = \sum_m \sum_t ETP_{t,m} \times \left(\frac{1}{f_{t,m,s}} - 1\right) \qquad (4-2)$$

[50] Feng and Zhang, 2012

Where *ET* is the net energy consumption for transformation, *ETP* is the energy transformation product, *f* is the energy transformation efficiency, *s* is the type of primary energy, *m* is the equipment, and *t* is the type of secondary energy.

The transport stock turnover is calculated as follows:

$$EV_n = \sum_c s \times \frac{m}{fe} \qquad (4-3)$$

Where *EV* is the energy consumption in the transport sector, *s* is the number of vehicles (stock), *m* is the vehicle distance, *fe* is the fuel economy, *n* is the fuel type, and *c* is the vehicle type.

4.1.2.2 Transformation

The transmission and distribution module calculations take the domestic fuel requirement faced by the module and map those corresponds to the output fuels directly to the module input fuels. The total domestic requirements are then decreased by the outputs of the module and increased by the inputs to the module[51]. For each process *p*:

$$INPUT_P = \frac{OUTPUT_P}{EFFICIENCY_P} \qquad (4-4)$$

[51] Lazarus, Heaps and Raskin (1997)

For a Transmission and Distribution module:

$$EFFICIENCY_P = 1 - LOSSES_P \qquad (4-5)$$

Where INPUT is the fuel or feedstock, OUTPUT is the electricity generated or the refinery/production output, EFFICIENCY is the efficiency of the power plants or refinery plants.

4.1.2.3 Carbon emission

The carbon emission from final energy consumption is calculated as follows[52]:

$$CEC = \sum_i \sum_j \sum_n AL_{n,j,i} \times EI_{n,j,i} \times EF_{n,j,i} \qquad (4-6)$$

Where *CEC* is the carbon emission, *AL* is the activity level, *EI* is the energy intensity, and $E_{n,j,i}$ is the carbon emission factor from fuel type *n* for equipment *j* from sector *i*.

The carbon emission from energy transformation is calculated as follows:

$$CET = \sum_s \sum_m \sum_t ETP_{t,m} \times \frac{1}{f_{t,m,s}} \times EF_{t,m,s} \qquad (4-7)$$

[52] Feng and Zhang (2012)

Where *CET* is the carbon emission, *ETP* is the energy transformation product, f is the energy transformation efficiency, and $EF_{t,m,s}$ is the emission factor from one unit of primary fuel type *s* consumed for producing secondary fuel type *t* through equipment *m*.

4.1.2.4 Costs

The total cost of sector is calculated as follows[53];

$$C = \sum_i \sum_j \left\{ \left[\sum_n \left(e_{n,j,k} ep_n \right) + \sum_k \left(m_{k,j,i} mp_k \right) + fc_{j,i} \right] p_{j,i} \right\} \qquad (4-8)$$

Where *C* is the total cost of sector including equipment fixed costs and variable costs for raw materials and fuels, ep_n is the unit price of fuel type *n*, $mk,_{j,i}$ is the demand for raw material *k* per unit of production used in equipment *j* within production process *i*, mp_k is the unit price of raw material *k*, and $fc_{j,i}$ is the fixed cost per unit production through equipment *j* (within production process *i*).

4.1.2.5 Cost-Benefit Analysis

The cost-benefit analysis in LEAP calculates the costs of each part of the energy system such as the capital and operating maintenance costs of purchasing and using the technologies in the Demand and Transformation systems; the costs of extracting primary resources and importing fuels and the

[53] Webmeets (2015)

benefits from exporting fuels. Additionally, one can also optionally broaden the scope of the cost-benefit calculations to examine environmental externalities, by assigning costs to the emission of pollutants and any other direct social and environmental impacts of the energy system. LEAP performs cost-benefit calculations from a societal perspective by counting up all of the costs in the energy system and then comparing the costs of any two scenarios. LEAP can include all of the following cost elements[54]:

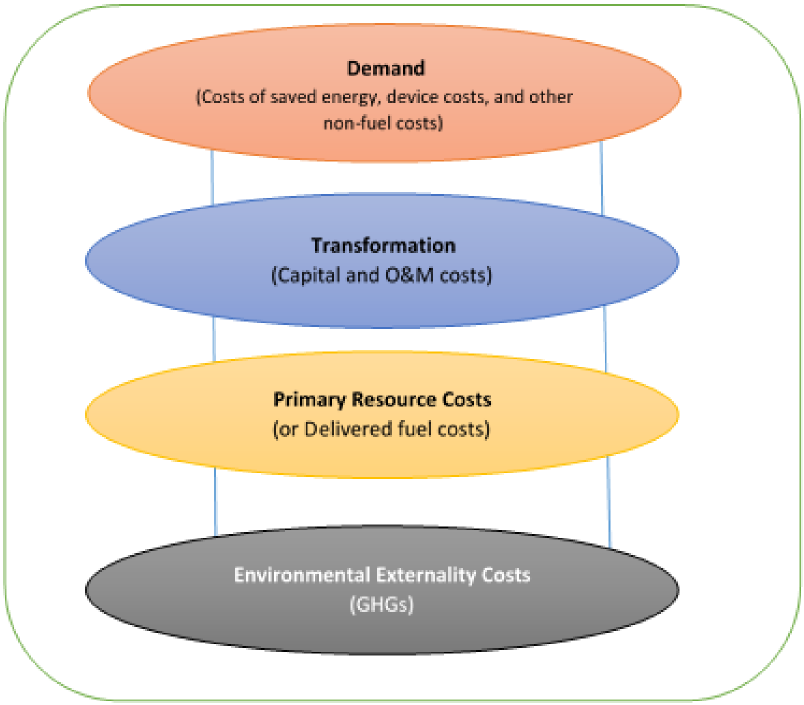
- Demand costs (expressed as total costs, costs per activity, or costs of saving energy relative to some scenario).
- Transformation capital costs
- Transformation fixed and variable operating and maintenance costs.
- Costs of indigenous resources
- Costs of imported fuels
- Benefits of exported fuels
- Externality costs from emissions of pollutants
- Other miscellaneous user-defined costs such as the costs of administering an efficiency program.

When setting-up costing in LEAP, it is very important to draw a consistent boundary around the system, so that LEAP will not double count costs and benefits. For example, if one counts the cost of fuels used to generate electricity it should not also count the cost of the electricity in an overall cost-

[54] Webmeets, 2015

benefit calculation. Figure 4-1 shows the costs required at different stages in LEAP's cost-benefit analysis.

Figure 4-1: Required costs of a Cost-Benefit Analysis in LEAP model



4.1.2.6 Least-Cost Electricity Generation[55]

The least-cost electricity generation is calculated using the LEAP's optimization model called OSeMOSYS[56] to investigate a range of different technologies for generating electricity. The objective of this model is to estimate the lowest net present value (NPV) cost of an energy system to meet

[55] See Howells (2009) and Howells et al., (2012) for more detailed explanation on least-cost electricity generation using the OSeMOSYS functions.

[56] Open Source Energy Modeling System

a given demand for energy or energy services. The optimization model is calculated as follows:

4.1.2.6.1 Least-Cost Electricity Generation Equations

Objective Function[57]

The total discounted cost of each technology over each year is summed and minimized to the following (Howells, 2009);

$$\sum_{y}\sum_{t} TotalDiscCost_{y,t} \qquad (4-9)$$

Where *y* represents Year and *t* represents Technology, while *TotalDiscCost* represents the total discounted cost as will be further described in Equation (4-10).

Total Discounted Costs[58]

The total Net Present value (NPV) of each technology for each year is calculated as follows (Howells, 2009);

[57] The model is set up so that all costs incurred are attributed to a technology. Later, cost penalties will be introduced for under production (cost of energy not served) or over production of either energy or a commodity such as an emission.

[58] In order to derive the total costs incurred by each technology, the net present value operating, capital and salvage costs are summed by year for each technology. These values are stored in the variable: $TotalDiscCost_{y,t}$.

$$TotalDiscCost_{y,t} = DiscOperatingCost_{y,t} + DiscCapitalInvestment_{y,t} - SalvageValue_{y,t} \qquad (4-10)$$

Where y represents Year and t represents Technology, while *DiscOperatingCost* represents the operating cost, *DiscCapitalInvestment* represents the discounted capital investment, and the *SalvageValue* represents the salvage value. The equation 4-10 is further described as follows.

Operating Costs[59]

The total NPV operating cost for each technology for each year is calculated as follows (Howells, 2009);

$$DiscOperatingCost_{y,t} = OperatingCost_{y,t} \times DiscountFactor_{y,t} \qquad (4-11)$$

Thus,

$$OperatingCost_{y,t} = TotCapAnn_{y,t} \times FixedCost_{y,t} + \sum_{l}(Activity_{y,l,t} \times VariableCost_{y,t} \times YearSplit_{y,t}) \qquad (4-12)$$

[59] Operating costs are calculated by summing the variable and fixed operating costs. The variable costs are a function of the technology's activity level during a time slice and the length of that time slice. These costs associated with each load region are summed to give an annual operating cost. The fixed cost is determined by the capacity of technology in the system. These costs are calculated for each technology, for each year. These values are stored in the variable: *DiscOperatingCost*$_{y,t}$.

Where y represents Year and t represents Technology, while l represents the Time Slice[60]. *OpertingCost* represents operating cost, *DiscountFactor* represents the discount factor[61]. From equation (4-12), *TotCapAnn* represents the total installed capacity of the power plant. *FixedCost* represents the fixed cost, *VariableCost* represents the variable cost, and *YearSplit* represents the Year Split (the fraction of a year).

Capital Costs[62]

The total NPV capital expenditure for each year and each technology is calculated as follows (Howells, 2009);

$$DiscCapitalInvestment_{y,t} = CapitalCost_{y,t} \times NewCap_{y,t} \times DiscountFactor_{y,t} \qquad (4-13)$$

Where y represents Year and t represents Technology. *CapitalCost* represents capital cost, *NewCap* represents new capacity, and *DiscountFactor* represents discounted factor.

Salvage Value[63]

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[60] Annual demand is 'sliced' into representative fractions of the year, and this is necessary to assess times of the year when demand is high separately from times when demand is low, so that fuels that are expensive can be stored.

[61] The discount factor is the factor by which the future investment is multiplied in order to obtain the present value of the technology investment.

[62] The capital costs are calculated by multiplying capacity requirements by their respective capital costs. They are then discounted. These costs are recorded for each technology type as well as for the year in which the investment took place. These values are stored in the variable: $DiscCapitalInvestment_{y,t}$.

The value of each technologies remaining at the end of the modeling period is calculated as follows (Howells, 2009);

$$SalvageValue_{y,t} = CapitalCost_{y,t} \times NewCap_{y,t} \times SalvageFactor_{y,t} \qquad (4-14)$$

Where y represents Year and t represents Technology. *CapitalCost* represents capital cost, *NewCap* represents new capacity, and *SalvageFactor* represents the salvage factor.

Fuel Production Constraints[64]

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[63] At the end of the modeling period, the stock of equipment which was invested in during the period has value which could be salvaged. This is dependent on (amongst other things) how it is depreciated, the life and the time in which it is invested. (The NPV salvage value is calculated, and for simplicity is accounted for (by technology) in the year in which the new investment took place – rather than in the last year of the modeling period.) These values are stored in the variable: $SalvageValue_{y,t}$.

[64] There are several possible variations on this constraint which is the "main driver" of the model. For simplicity one is considered now. To start with, for each fuel an exogenous demand can be specified in terms of power consumed per time slice (e.g. In GJ/year or kW/year). This demand can be met from the activity of a technology. A technology's fuel production is related to its activity by an "output activity ratio". If a technology's activity, and output activity ratio for a given fuel is greater than zero it produces that fuel. Similarly, the consumption or use of a fuel by a technology is related by its "input activity ratio". The model is constrained to produce more fuel than is used by energy technologies plus fuel that is exogenously demanded. The flexibility that comes with defining an input and output activity ratio allows the user to relate the capacities and activity in terms of the input of fuel (using an input activity ratio of 1, and an output activity ratio equal to the technology's efficiency (if only one fuel is produced)). The capacity may be related to the technology's output (by having an output activity ratio of 1 and an input activity ratio equal to the reciprocal of the efficiency [if only one fuel is production]). Note that how this is defined in turn determines how the costing parameters (capital and O&M) are quantified. Until "guided" by an interface, the user must be consistent. (The user may also define capacity in terms of kW, for example, but relate that to an activity in GJ/year by multiplying those ratios by 31.5 etc.).

Fuel Production during each time slice and year must be greater than or equal to its use (consumption) by technologies plus any exogenous demand for that fuel, thus;

$$Production_{y,l,f} \geq Demand_{y,l,f} + Consumption_{y,l,f} \qquad (4-15)$$

Where:

$$Production_{y,l,f} = \sum_{t} (Activity_{y,l,t} \times OtptActvtyRatio_{y,t,f} \times YearSplit_{y,l})$$

$$and$$

$$Consumption_{y,l,f} = \sum_{t} Activity_{y,l,t} \times InptActvtyRatio_{y,l,f} \times YearSplit_{y,t}) \qquad (4-16)$$

Where *y* represents Year and *t* represents Technology, while *l* represents the Time Slice and *f* represents the Fuel. *OtptActvtyRatio* represents the output activity ratio, *InptActvtyRatio* represents the input activity ratio, while *YearSplit* represents the year split (the fraction of a year).

Capacity Constraints[65]

[65] Each technology is able to accommodate an activity which uses, produces or both uses and produces energy. This activity (currently measured in terms of power, such as kW/year or

The capacity of each technology must be greater than its activity for each load region, thus (Howells, 2009);

$$Activity_{y,l,t} \leq TotalInstalledCapacity_{y,t} \times CapacityFactor_{y,t} \quad (4-17)$$

Where *y* represents Year and *t* represents Technology, while *l* represents the load region.

Activity Constraints[66]

The activity of each technology is limited by its annual availability, thus;

$$\sum_{l} Activity_{y,l,t} \times YearSplit_{y,l} \leq TotCapAnn_{y,t} \times AvailabilityFactor_{y,t} \times CapacityFactor_{y,t} \quad (4-18)$$

Where *y* represents Year and *t* represents Technology. *YearSplit* represents year split (the fraction of a year), *TotCapAnn* represents the total installed

GJ/year) should be less than the de-rated capacity of that technology. The technology capacity is de-rated by a capacity factor. (If the capacity factor is kept at 1 there is no de-rating.) The total capacity of a technology is the sum of new investments made during the modeling period (which have not been retired) plus the any residual capacity left over from before the modeling period. In order to account for stations, invested in during the modeling period, which may be retired during the modeling period the notion of a station's “investment year” is introduced.

[66] In these constraints the activity of a technology is limited to a fraction of what its output would otherwise be – were it limited only by the capacity of the technology. Therefore it may run at the maximum level (de-rated by the capacity factor) for some time slices, but for other time slices its output would be below this. (This serves to approximate planned outage in a facility such as a power station for example. The model determines when the most economic time for this to happen.) This constraint is implemented by considering the activity rate for each load region and the length of the load region, the activity's annual availability as well as the total capacity of the technology in which the activity occurs. The total capacity determines the maximum potential activity during a load region (time slice).

capacity of the power plant. *AvailabilityFactor* represents the availability factor which is *1 – M* (*M* is the fraction of the year in during which planned maintenance takes place), *CapacityFactor* represents capacity factor.

4.1.2.6.2 Least-Cost Electricity Generation Model Sets, Variables, and Parameters

Model Sets:

All model sets contain entries which are used as indexes to parameters and variables. The sets includes the following (Howells, 2009);

- Year: this set contains years over which the model is solved. Almost all variables and parameters are indexed by the model year for which it is solved.
- Investment year: this set is used to track the years in which investments are made. Investment years are identical in number to model years. It is separate from the model year set as it will be used to index investments by their "investment year" over the modeling period.
- Technology: this is the set of all technologies represented in the application.
- TimeSlice: this set contains the time slices per year. At this point, the same number of time slices are carried through for each year. The number of slices are also limitless.

- Fuels – this set contains the fuels used in the model. The model is constrained so that fuel production should be larger than the specified exogenous demand and technology fuel use.
- (OpFlows: this is to be added and will include all “flows” that the user will relate to operation – this could include emissions for example)
- (ConFlows: this is to be added and will include all “flows” that the user will relate to construction – this could include demands for materials for example)

Model Variables

The model variables used are presented as follows (Howells, 2009);

- NewCap: new investment in capacity by the model year in which the investment was made, for each technology.
- TotCapAnn: this gives the total capacity available by technology for each year. It consists of the sum of the capacities of different vintages which are available for the given model year as well as any residual capacity from previous years
- Activity: this variable represents the “activity” of the technology. It's unit is in terms of power – of energy out per year. Where the energy out, is related by an output to activity ratio. (Conversely the energy used is related to the activity by an input to activity ratio) Activity is calculated for each technology, for each year, for each time slice. To convert activity

from power to energy, it is multiplied by the length of the time-slice over which it is active.

- Production: gives the total output of each fuel from all technologies for each time slice
- Use: as with the production variable, this gives the total consumption – or use - of each fuel from each technology.
- CapitalInvestment: for each model year and each technology this variable is derived by multiplying new capacity investment (NewCap) with the capital cost of each technology.
- DiscCapitalInvestment: for each model year and each technology, this variable gives discounted capital investment
- SalvageValue: this is the discounted salvage value of calculated by the technologies remaining at the end of the model period
- OperatingCost: this is the total annual operating cost for each technology. It includes both the variable and fixed costs.
- DiscOperatingCost: this is the discounted total annual operating cost for each technology
- VarOpCost: the variable operating cost is calculated for each time slice, each technology for each year.
- AnnVarOpCost: for each technology and year the variable operating cost is calculated. This is calculated by summing the variable operating costs incurred for each load region in each year.
- TotalDiscCost: for each technology and for each year, the NPV capital, operating and salvage costs are summed in this variable.

Model parameters

The model parameters presented below are those connected to the LEAP model used in this thesis, and they are as follows (Howells, 2009);

- Capacity Factor: this is defined for each year and each technology. It is used to convert annual capacity to available capacity for each time slice
- Availability Factor: this is defined for each year and each technology. It is used to simulate "planned outages" and indicates the maximum the technology may run for the whole year
- Vintage Matrix: this is defined for each model year, for each technology vintage and each technology and is used to construct the total installed capacity variable. It is a function of the technology life, as well as when that technology was investment was made.
- Salvage Factor: this is the (discounted) salvage value of a technology at the end of the modeling period, represented as a fraction of the initial per unit capital cost. It is determined for each model year as well as each technology. It is calculated by estimating the depreciated value of the technology at end of the modeling period. (In the optimization, this is required to determine the full NPV costs of technology investment. At present, flexibility is left to the user as to how to calculate this.)
- Residual Capacity: this is defined for each model year and each technology. It is the capacity left over from a period prior to the modeling period.

- Output Activity Ratio: gives the output of fuel as a ratio to the activity of the technology. It is defined by year (as the technology could degrade), by technology, by time slice and for the fuel which is produced.
- Input Activity Ratio: gives the input (use) of fuel as a ratio to the activity of the technology. It is defined by year (as the technology could degrade), by technology, by time slice and for the fuel which is used.
- Capital Cost: The capital cost of each technology is given as a function of the technology as well as the year in which the technology was invested. The cost is the NPV cost for a new power station (presently calculations to determine the NPV cost as a function of the station's build profile are undertaken in the Excel mock-up interface.)
- Variable Cost – The variable cost is defined for each technology in each year and is the cost per unit of activity of that technology.
- Fixed Cost – The fixed cost, also a function of technology as well as the model year, is the cost per unit of capital stock (or installed capacity) of a particular technology.

4.2 The LEAP Data Requirement[67]

The LEAP as a general purpose software tool typically used to build a wide variety of energy models, it may be difficult to definitively provide its data requirement (Heaps, 2006). A key benefit of LEAP is its low initial data

[67] Please note that the data requirement in this section is quite different from those required by the **Least-Cost Electricity Generation in Subsection 4.1.2.4**, because the data have already been described there.

requirements[68] which depends on the type of energy modeling being carried out (i.e. bottom-up or top-down approach). However, the LEAP model requires a comprehensive knowledge on data collection, understanding of the energy system and time-consuming efforts especially in the data collection and input period. The type of data required for analysis on the LEAP model is described below and can be found in Heaps (2006).

4.2.1 Demographic Data

This is usually the general data of a country of which includes; national population data, rates of urbanization, average household sizes, household growth rate, population growth rate, and urbanization growth rates. In some modeling, population by region, male/ female population and age structure of population may be required. All this are entered into the "Key Assumption" of the data tree in the LEAP model.

4.2.2 Economic Data

The economic data include GDP/GNP data, value added by sector/subsector, average income levels, and interest rates. Other data include production of energy-intensive materials (output in tons or US$ per steel), transport needs (passenger-km, tonne-km, vehicle-km), income distribution.

4.2.3 General Energy Data

[68] www.energycommunity.org/default.asp?action=47#LowDataRequirements

These are usually found in the National energy balances with data on energy consumption and production by sector or subsector in an economy. Most of these data are found in National statistical bodies or agencies or Energy related agencies as the country case may be. If the data are not available in the country, they may be available from the International Energy Agency (IEA) published energy statistics. Other data includes; National energy policies and plans, annual statistical reports with information on production, consumption, etc., of oil, natural gas, coal, charcoal, LPG, CNG, and other relevant fuel.

4.2.4 Demand Data

- Activity Levels: In LEAP's demand analysis, works by forecasting future energy consumption as the product of two factors: activity levels and energy intensities. Activity levels are simply a measure of the economic activity in a sector, and you can choose what data to use for this purpose. For example, in the household sector the user may choose to use the number of households as the activity level, in the cement industry you might use tonnes of cement production, and in the transport sectors you may choose to use tonne-kms (for freight transport) and passenger-kms (for passenger transport). The user will need to collect data describing the current, historical and future projections of whatever data the user choose to use for his/her Activity Level variables. The user may need to consult national statistical reports or contact governmental or academic organizations working in specific sectors (industry, commerce, transport, households, etc.)

- Energy intensity data is often very hard to come by. If the user is preparing an aggregate analysis he/she will likely be able to use combine their activity level data with national energy consumption statistics and energy balances to calculate historical energy intensity values by sector and by fuel. In other words, for historical data, *energy intensity = total energy consumption/activity level*. For your forward looking scenarios you will instead use LEAP to calculate the total energy consumption by projecting the energy intensity and activity level. That is: *total energy consumption = energy intensity x activity level.*
- Other useful sources of energy demand data include recent social surveys or energy consumption surveys that analyze how energy is consumed in different sectors of the economy, and reports from utilities and private companies on sales of different energy forms (electricity, natural gas, oil products). If possible, the user should try to get data disaggregated by sector and by consumer category.
- If the user is creating a more detailed analysis, he/she will likely also need information on the stocks, technical characteristics (efficiency, specific fuel consumption), costs and environmental loadings of major energy consuming devices in different sectors. For example, if the user want to focus on road transport energy use you would need data describing the stocks and sales of vehicles; there fuel economy, and some estimate of their average on-road life expectancy.

4.2.5 Transformation data

In a general case, transformation analysis requires that the user prepare a complete picture of how energy is extracted, converted and transported in the modeled energy system. This requires data on the flows of energy into and out of major processes, as well as information on the efficiency, costs (capital, operating and maintenance and fuel costs) and environmental loadings associated with each major process.

- Electric sector: Generally, the user will need data describing the current and historical installed capacities (MW), efficiencies, costs (capital, operating and maintenance and fuel costs) and actual dispatch (MW-HR) of the various types of electric generating plants in your country. The user will also need information on the seasonal load shape for his/her country's electric system and the maximum availability and dispatch priority of each different type of power plant. Capacity expansion plans, if they exist, can be very useful for establishing forecasts of how the electric system is likely to evolve in the future. In addition to collecting data on generation, you should also collect data describing transmission and distribution losses including both technical and non-technical losses. The user may wish to analyze this sector separately from the dedicated electric generation sector. For this sector, the user's data should include the production efficiencies of both electricity and heat. In many countries, rural electrification is a key issue, so you may wish to collect relevant data describing rural electrification rates for different geographic regions.

- Oil Refining: If oil refining is an important sector in the model development, the user will need to collect data on the different products produced by your refineries, the efficiency and the capacity of the refineries.
- Extraction sectors: If extraction sectors such as coal mining or oil and gas production are important, the user will need data describing the efficiency and capacity of these sectors as well as information on the fuels produced and the energy consumed during extraction.
- Renewables: Renewable energy is becoming increasingly important in many countries and may be an important focus of any GHG mitigation analysis. Collect data describing the current installed capacities, efficiencies, costs and expansion plans for any relevant renewables such as wind, geothermal, municipal solid waste, solar, etc.
- Biomass: If wood or other biomass fuels are important in the country, the user will have to collect whatever data is available on the consumption and production of those fuels. Wood fuel (or firewood or fuel wood) surveys can be an important source of data for estimating the sustainability of production of wood fuels.
- Other Sectors: Other conversion sectors that may be important include charcoal making, ethanol production and synthetic fuel production from coal.

4.2.6 Environmental Data

For a first cut GHG mitigation assessment, the user may be able to rely on the basic “Tier 1” emission factors published by the IPCC (and included in LEAP). However, as the user refine his/her analysis, they may wish to collect local emission factors estimates that reflect the fuel and technology characteristics of devices used in the country. For example, cars in the country may have particular emissions characteristics. It is particularly important to have data on the chemical composition of the fuels used in the country as this can be used to refine the emission factor estimates from different devices. The IPCC’s online EFDB database is a key source of data on emission factors[69].

4.2.7 Fuel Data

LEAP includes a good default list of fuel and their characteristics (energy content, chemical composition) that should meet the needs of most studies. However, the user should be sure to adjust the energy, carbon and sulfur contents in this list to reflect the characteristics of the fuels used in the country analyzed. In particular, the characteristics of coal and biomass fuels vary greatly between (and even within) countries and uses. In addition to their physical characteristics, the user will also require data describing the production costs of any primary fuels produced in the country and the import and export costs of any relevant fuels.

[69] This is available at: http://www.ipcc-nggip.iges.or.jp/EFDB/main.php

4.2.8 Data Collection Process

The Nigerian LEAP model was developed to forecast the future energy demand, supply, and GHG emission under the Reference scenario and alternative scenarios (explained in later subsections). The data collected for the Nigerian LEAP model were from many sources which includes the National Bureau of Statistics in Nigeria (NBS) (primary data source), Energy Commission of Nigeria (ECN) (for national policies, some primary data and plans), National Control Center, Osogbo in Nigeria (NCC) (power plants data), the Petroleum Products Pricing Regulatory Agency in Nigeria (PPPRA), the World Bank, International Energy Agency (IEA), the United States Energy Information Administration (EIA), the International Association of Public Transport (UITP) and African Association of Public Transport (UATP), National Surveys by bodies and independent researchers, credible research articles, newspaper and website articles and publications. The datasets used in this thesis can be provided on request to the researcher[70]. However, the source of each data set used in this thesis is presented in Appendix B (i.e. Appendix B1 – B29)

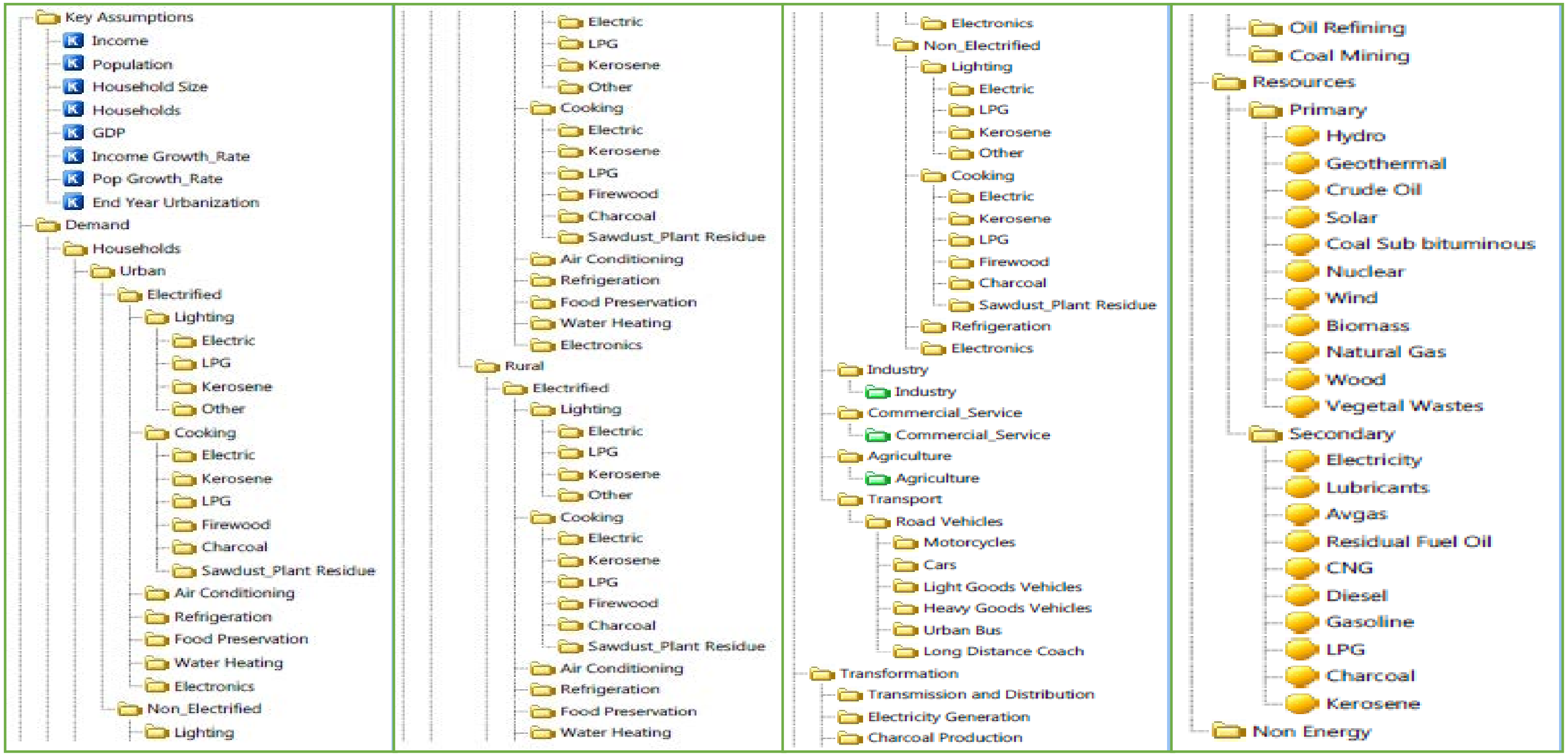
The Nigerian LEAP dataset were vast but carefully divided into five subsectors of energy demand of which includes; households, industry, transport, commercial/service and agriculture. The household sectors was split into two main branches and two sub-branches under the main branches: the urban household was divided into electrified and non-electrified, while the rural household were divided into rural electrified and non-electrified. This is

[70] A request can be sent to the researcher’s email: icecube4ever2000@gmail.com.

shown in Figure 4-2 which is the Nigerian LEAP model data branches.

In the industry branch, energy use is divided into shares of energy use (i.e. gas, coal, electricity, biomass), and this is due to the data availability. These is also the situation in the commercial/service and agriculture sectors. The transport branch is divided into six branches: motorcycles, cars, light goods vehicles, heavy goods vehicles, urban bus and long distance coach. The transformation branch is divided into five branches: transmission and distribution, electricity generation, charcoal production, oil refinery and coal mining. The final resource branch is the branch which includes the primary and secondary energy resources.

Figure 4-2: The Nigerian LEAP Model data branches



4.1 Scenario Development

The scenarios were developed using the Reference scenario (REF), from which three other alternative scenarios were developed to provide a low carbon-green growth development in Nigeria. The alternative scenarios developed are; Low Carbon Moderate (LCM), Low Carbon Advance (LCA) and Green Optimistic (GO) scenario. In the development of these scenarios, the REF scenario assumed that the energy policy goals of the Nigerian government through its policy documents (National Energy Master Plan [NEMP], 2014; National Energy policy [NEP], 2013; National Renewable Energy and Energy Efficiency Policy [NREEEP], 2014), will be achieved by the end of 2040 from 2010.

Thus, the Nigeria LEAP model was developed from 2010 which is the base year, to 2040 which is the target/ end year. The alternative scenarios (i.e. LCM, LCA and GO) were developed from the same base year and target year period (30 years), and inherited the characteristic features of the base year from the REF scenario. However, three different policy pathways were followed in the three alternative scenarios, of which their individual goals was to use a low carbon approach to match energy demand with supply at the least cost until 2040. The scenarios are outlined and discussed below, while the key assumption parameters for the Nigerian LEAP model is shown in Table 4-1 and a summary of the features of each scenario is presented in Tables 4-2.

Table 4-1: Key assumption parameters for the Nigerian LEAP model

*denotes Billion, **the figures in the REF scenario are based on the NEMP (2014)

Key assumption	**REF****		**LCM**		**LCA**		**GO**	
	2010	2040	2010	2040	2010	2040	2010	2040
GDP (million USD)	369	1255*	369	1476*	369	1587*	369	2177*
GDP growth rate (%)	8		10		11		13	
Income (Thousand USD)	2310	5705	2310	5914	2310	6329	2310	6676
Income growth rate (%)	4.9		5.2		5.8		6.3	
Population (Million)	160	304	160	318	160	328	160	337
Population growth rate (%)	2.55	3	2.55	3.30	2.55	2.40	2.55	3.70
Households (Million)	37	72	37	80	37	84	37	87
Household size (people)	5							
Household growth rate (%)	3.16		3.9		4.2		4.5	
Urbanization rate (%)	44	70	44	75	44	80	44	73
Industry growth rate (%)	6	6.5	6	7.1	6	7.5	6	7.7
Commercial/ Services growth rate (%)	12	12.5	12	13.2	12	13.6	12	13.9
Agriculture growth rate (%)	6	6.5	6	7.3	6	7.4	6	7.8

Table 4-2: Summary of the Features in each Scenario

	REF	LCM	LCA	GO
Driving philosophy	Follows the Government's most-likely-developmental-pathways for the energy system	Driven by cheaper capital, cost, readily available fuels to improve power supply, and moderately reduce energy demand	Motivated by a cleaner fossil fuel power technologies and an aggressive reduction in energy demand	Based on a low-carbon-green growth economy in view of mitigating global climate change, reduce energy poverty, and ensure energy sustainability.
Scenario characteristic	• Current trend of energy consumption continues in all sectors • No supply side diversification of energy source (BAU case)	• Moderate improvement in energy efficiency in all sectors • CFL bulbs to replace 85% incandescent bulbs • Increase in gas power plants, small share of renewables • Introduction biofuel in transport sector • Moderate reduction in electricity T&D and natural gas loss	• Aggressive improvement in energy efficiency in all sectors • LED bulbs to replace 70% in candescent bulbs • Increased capacity of efficient low carbon fossil fuel power plants, increased share of renewables • Introduction of LPG fuel options in addition to biofuel to complement conventional fuels in the transport sector • Improved reduction in electrical and natural gas losses	• Provision of Energy efficiency and solar PV systems for the demand side • Phase-out incandescent bulbs and replace with CFL 60% and LED 4 0% • Reduction in the share of fossil fuel plant capacity and the increase share of renewables on the supply side • CNG, LPG and biofuel options with a reduced share of conventional fuels • Reduction in electrical and natural gas losses to the barest minimum
General assumptions	Increased electricity access to 100% by 2030			

Scenario-specific assumptions	Demand side: Business-as-usual case in all sectors Supply side: Installed capacity by 2040 = 155283 MW Estimated share of fuel type: Fossil fuel = 90% Renewables = 10%	Demand side: CFL introduction, moderate energy efficiency in appliances Supply side: Installed capacity by 2040 = 170500 MW Estimated share of fuel type: Fossil fuel = 80% Renewables = 20%	Demand side: LED introduction, aggressive energy efficiency in all sectors Supply side: Installed capacity by 2040 = 180500 MW Estimated share of fuel type: Fossil fuel = 60% Renewables = 40%	Demand side: introduction of both CFL and LED with reduction in incandescent bulbs, advance approach towards energy efficiency in all sectors Supply side: Installed capacity by 2040 = 181000 MW Estimated share of fuel type: Fossil fuel = 30% Renewables = 70%

4.1.1 The Base Year

In the base year (2010), Nigeria had a gross domestic growth (GDP) of US$ 369 Million which has a growth rate of 6.3%. Average income is US$ 2310 and the country's population is 160 million with a growth rate of 2.55%. According to the National Bureau of Statistics (NBS, 2015), there are 37 Million households in Nigeria with an average of 5 people per house and have a growth rate of 3.16% each year. The country's urbanization rate was 44% and access to electricity was 48% in the base year. The percentage of urban population with access to electricity was 79.80% while those in rural area with access to electricity was 34.90%.

Energy consumption for cooking has been observed to have the highest share of intensities in the household sector in Nigeria (Ibitoye, 2013; Ogwumike et al., 2014; Akinyele et al., 2014; Oteh et al., 2015). Although a large share of the households in both the rural and urban areas use kerosene for cooking, LPG and electricity has continued to play a crucial role in the choice of fuel for cooking. In the rural areas, firewood (or fuel wood) has a competitive share with kerosene, while LPG and electricity consumption is relatively small compared to other source of fuel for cooking. From the characteristics features of household cooking technologies shown in Appendix B24, the amount of stoves which use firewood and kerosene is high as well as their operating time. Other features of the household technologies, their percentage shares and intensities are shown in Appendix B11-B12.

Other sectors of the economy that were observed in the base year are industry, commercial/service, and agriculture sector. The value added for the industry sector was 80 million dollars with a growth rate of 6%, while that of the commercial/service and agriculture were 196 million and 86 million respectively. The type of energy used in the sectors and their consumptions are shown in Appendix B8. In the transport sector, six type of vehicles were used in this thesis and they include; motorcycles, cars, light goods and heavy goods vehicles, urban bus, and long-distance coach. The fuel type, fleet, vehicle activity, and fuel efficiencies are shown in Appendix B15-B16.

In the power (electricity) sector, electricity generation is mainly from thermal and hydropower stations. The thermal power stations are made up of only natural gas power plants with majority being single cycle gas turbines (SCGT), and a small share of combined cycle gas turbine and gas-fired steam turbine (GFST). The average availability of the thermal power plants are observed to be half of the installed capacity, but the hydro power plants have a higher average availability as compared with the thermal power plants. On the part of transmission and distribution for the power sector, a 20% loss rate was recorded in 2010. Details of the electricity generation are shown in Appendix B27.

On the natural resources and refinery operations recorded in the base year, the conventional energy resources observed were crude oil, natural gas and coal (sub-bituminous). The secondary energy supply which were from the conventional energy resources produced in the refinery are; gasoline, diesel, LPG, Kerosene, lubricant, avgas, CNG, residual fuel oil, charcoal and firewood (from biomass). Details of the data used for refineries of crude oil, charcoal production and coal mining in the base year are shown in Appendix B5-B7, B10, and B17-B19. From the data and characteristic features of the socio-economic activities in the base year (2010), the development of the scenarios were established following the REF scenario which will be discussed in the following subsection.

It is very **important to note** that when developing an energy model using the LEAP, energy efficiency measures can be imputed in two ways:

- By including another variable called "**efficient**" alongside the **existing** technology. If the government (the user in this case) intends to increase energy efficiency of a particular technology such as refrigerator in the household sector in 2015, the share of efficient refrigerator variable will be increased from 2015. If the government intends to have 70% share of efficient refrigerator by 2040 starting from 2015, the "**efficient refrigerator**" variable is interpolated into the technology from the reference or business-as-usual case. The results will then show for example; Demand-Household-Refrigeration-existing & efficient. This same case will be done for all technologies in the sector, including transport, industry etc.
- The other way of imputing energy efficiency measures is through the decrease in "**final energy intensity**" by end/target year. If the government intends to increase energy efficiency by a certain amount,

the existing technology's final energy intensity is then **interpolated** to a given decrease by the target year. To **interpolate**, the following command is inserted into the technology variable's final energy intensity; Demand-Household-Refrigeration-Existing-Final Energy Intensity-Interp (2040, -10) or Inerp (2020, -2, 2030, -5, 2040, -10). It however depends on how the user wants the energy efficiency target to be for a particular technology in a sector. In some situation, the final energy intensity value can be imputed directly into the LEAP model. For example, if the base year vale for household refrigerator's **final energy intensity** is 400 kilowatt-hour per household, the user can set a final energy intensity value for the particular technology to be 200 kilowatt-hour per household by 2040. To do this, the following command is imputed into the LEPA model; Demand-Household-Refrigeration-Final Energy Intensity-200 kilowatt-Hour-per Household. The results will then show for example; Demand-Household-Refrigeration-efficient-value. Either of the two ways (i.e. the Interp or Final Energy Intensity) will still produce the same results which is; Demand-Household-Refrigeration-efficient-value.

The same way of imputing energy efficiency measures was also applied in all demand sector in the Nigerian LEAP model.

4.1.2 The Reference scenario (REF)

The development of the REF scenario is in line with the concept of the most-likely-developmental-pathways of the government in the Nigerian energy system. This considers the policy directions in terms of future energy demand and supply projections carried out by the Energy Commission of Nigeria (ECN). The assumptions made in this scenario are further discussed according the Nigerian government plans for the household, commercial/ service, transport, industry, agriculture and power sector as described in the national policies (See NEMP, 2014; NEP, 2013; NREEE, 2014).

In the REF scenario, the number of households are 37 million from the base year and this is expected to grow at 3.56%. The increase in urban activities is expected to attract those in the rural areas and this will increase the urbanization rate to 50% by 2040 from the 44% in 2010. According to the NREEE (2014), the Nigerian government plans to introduce energy labelling program for households' energy consuming appliances with the intention to reduce energy intensities. Also the encouragement of the widespread use of energy saving electric lamps such as CFL[71] and LED[72], which will phase-out

[71] A compact fluorescent lamp (CFL), is designed to replace an incandescent lamp; some types fit into light fixtures formerly used for incandescent lamps. The lamps use a tube which is curved or folded to fit into the space of an incandescent bulb, and a compact electronic ballast in the base of the lamp. Compared to general-service incandescent lamps giving the same amount of visible light, CFLs use one-fifth to one-third the electric power, and last eight to fifteen times longer. A CFL has a higher purchase price than an incandescent lamp, but can save over five times its purchase price in electricity costs over the lamp's lifetime (Energy Star, 2015).

[72] An LED lamp is a light-emitting diode (LED) product that is assembled into a lamp (or light bulb) for use in lighting fixtures. LED lamps have a lifespan and electrical efficiency that is several times better than incandescent lamps, and significantly better than most fluorescent lamps, with some chips able to emit more than 100 lumens per watt. The LED lamp market is projected to grow by more than twelve-fold over the next decade, from $2 billion in the beginning of 2014 to $25 billion in 2023, a compound annual growth rate (CAGR) of 25%. The

inefficient incandescent bulbs. This policy was not however considered in the development of this scenario due to the absence of a specific target, but it was developed for the alternative scenarios which will be discussed in the next sub-sections.

The National Bureau of Statistics reports that only 67% of households in Nigeria depend on electricity supply from the national grid, the rest depends on other sources which includes private generators, rural electrification, etc. However, electricity access is expected to increase up to 75% in 2020 and 100% by 2030 as expressed in the NEMP (2014). To achieve this, the share of urban population without electricity is expected to shrink to 10% by 2030 and 0% by 2040, while rural communities will attain 80% by 2030 and 100% by 2040.

The NEMP (2014) stressed the need for the reduction of electricity use in cooking and heating, of which the government intends to supplement with cooking gas stoves and solar thermal for water heating (Muhammad, 2012; Shaaban & Petinrin, 2014; Adekunle et al., 2015). The percentage share of fuel source for lighting (see Appendix) is assumed to remain the same until 2040, except for the case of rural electrification program in the rural areas (especially in non-electrified rural areas).

The transport, industry and agriculture sector will continue to grow at its current growth rate, while energy consumption also follow the status quo. No improvement in energy efficiency is observed in the sectors, although the

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efficiencies of the LED is expected to drive down the package costs (Jacques, 2014).

Nigerian government recognize the need to improve of the efficiency of other energy consuming sectors besides the household sector (Oyedepo, 2012). Improvement in electricity supply to the industrial sector was not also considered in the REF scenario due to no clear policy direction the current national energy policies. This implies that industries will continue to rely on private/ independent power generating set to support their activities.

On the power sector, the Nigerian government promoted some planning studies on the Nigerian Electricity Sector as a whole. This was done so as to present a sound understanding of the condition/ challenges of the power sector and provide solutions. The studies include among others;

- The Presidential Advisory Committee Report on Nigeria's Electricity Sector in 2006 (see PAC, 2006)
- The National Load Demand Forecast by the Power Holding Company of Nigeria Project Management Unit in 2009 (see PHCN-PMU, 2009).
- The Nigerian National Energy Demand and Power Planning Study (2000 to 2030) by the Energy Commission of Nigeria (see ECN, 2008).
- The Nigeria Vision 20:2020 Energy Report, Medium Term implementation Plan (2010 to 2013) by the National Planning Commission (see ECN, 2008).

These reports presented some vital problems facing the power sector in Nigeria of which includes the poor state of transmission and distribution network in the national grid, inadequate electricity generation capacity, hence the low power output, inadequate supply of gas for power plants, etc.

This prompted the Nigerian government to set-up the Presidential Action Committee on Power[73] (PACP) of which is chaired by the President himself, and the Presidential task Force on Power (PTFP) of which is chaired by the Advisor to the President on Power. The PACP presented a report which was titled "The Roadmap for Power Sector Reform (see FGN, 2010) and this report along with the Nigeria Vision 2020 (ECN, 2008) was the basis for the development of the future electricity supply projections in the REF scenario.

In the development of the future electricity supply mix in the REF scenario, the capacity addition will continue with the existing mix of fossil fuel and hydroelectric power for on-grid power, while diesel and gasoline power are provided for off-grid electricity generation. The fossil fuel electricity generation technologies include a large share natural gas of which single cycle power plants will have a 51% share by 2040 and CCGT will have 24%. The development is in line Nigerian government's plan to increase electricity generation from gas power plants through the improvement of natural gas supply (Tallapragada, 20009; Olugbenga et al., 2013). The Nigerian government intends to increase the prices of domestic gas supply, so as to be comparable with international gas prices (International Comparative Legal Guides [ICLG], 2015).

[73] www.nigeriapowerreform.org/index.php?option=com_content&view=article&id=337&-Itemid=318

Other electricity generating technologies such as nuclear is expected to have a 4% share by 2040. This is expected to begin with the construction of a 1,000 MW power station by 2020 in Nigeria as described by the National Atomic Energy Agency (Lowbeer-Lewis, 2010). Currently, the Nigerian government has selected two sites for the construction of a 4,800 MW nuclear power plant. The location are Geregu in Kogi State and Itu in Akwa Ibom State, and each will have 2,400 MW at an investment cost of $20 billion[74].

The minimal expansion for hydropower is expected to reach a capacity of 9,000MW, while coal steam power plants will have a capacity of 13,000 by 2040. The Nigerian government has made consultations with relevant stakeholders and made plans to revive the coal mining industry[75]. This will supply the needed coal power plants under construction in various part of the nation (Odesola et al., 2013). In 2014, the construction of 1,000MW coal power plant began in Enugu State[76], while a 500MW power plant is being built in 2015[77]. Operation of the coal power plants are expected to commence by the end of 2015[78], while other power plants will become operational in the years to come.

Renewables such as on-shore wind turbines, solar thermal and PV systems is expected to have a small share in the future electricity generation

74 www.power-technology.com/news/newsnigeria-selects-sites-for-4800mw-nuclear-power-plants-4604192

75 www.bdlive.co.za/africa/africanbusiness/2013/06/05/nigeria-seeks-to-revive-mining-to-diversify-from-oil

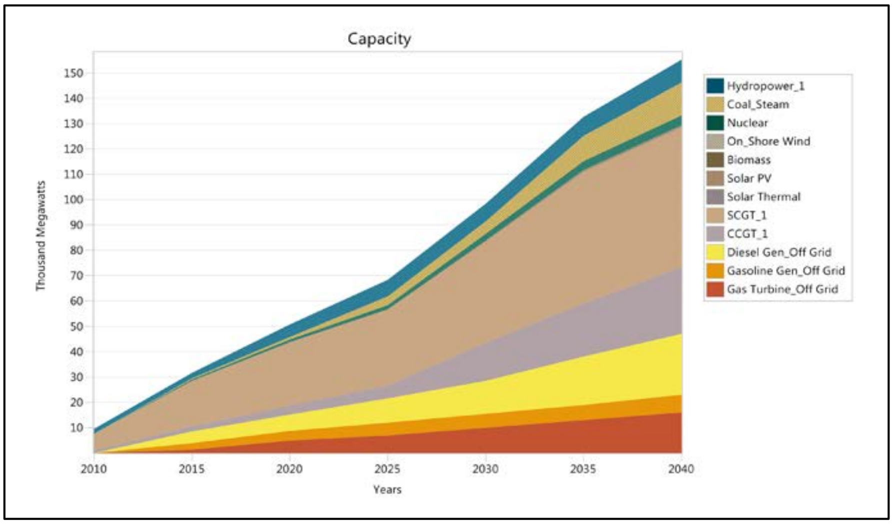
76 www.vanguardngr.com/2014/09/fg-establish-1000mw-coal-power-plant-enugu

77 www.thisdaylive.com/articles/firm-to-build-500mw-coal-power-plant-in-enugu/202562/

78 www.punchng.com/business/business-economy/coal-power-plant-to-begin-operation-in-2015/

mix. Off-grid technologies such as diesel, gasoline and small gas turbines will increase from 4300 MW in 2010 to 47000 MW in 2040 due to the availability of fuel for powering these plants in remote areas of the country. The rest of the projected electricity generation capacity in Nigeria under the REF scenario is show in Figure 4-3 and Appendix A1.

Figure 4-3: REF scenario future electricity generation capacity



Transmission and distribution loss which stands at 20% in the base year will be reduced to 10%, while natural gas losses[79] will be reduced to 20% by 2040. Charcoal production in the REF scenario is by traditional earth mound and brick kilns at 70% and 30% respectively.

[79] According to a study carried out by Achebe et al., (2012) to analyze the oil pipeline failures in the oil and gas industry, the losses were attributed to construction failures, external human material and structural accident, and incidental acts of vandalism and sabotage.

4.1.3 The Low Carbon Moderate Scenario (LCM)

This scenario takes into consideration, the need to improve power supply at a moderately reduced GHG emission as compared to the REF scenario by 2040, and moderately reduce energy demand in the sectors. In setting up the low carbon scenarios (both LCM and LCA), the resource availability was observed for the continued supply of fuel for the power plants until 2040. However, imports of fuels such as uranium for nuclear power plants will commence in before 2020 due to the construction of the nuclear power plants. The low carbon technologies in the LCM are economically competitive with those on the REF scenario. This includes energy technologies from the household sectors such as improved firewood and charcoal cooking stoves with lower intensities.

The lighting bulbs used in the household and commercial/services which are mainly incandescent lamps will be reduced to 15% by 2040, while CFL will be introduced in 2015 and reach 70% by the end year. The CFL bulbs which cost about $2.33 has a life time of 6 years[80] which is more competitive than the incandescent bulbs which is sold for $0.33 and has a life time of 4-6 months[81]. The introduction of this efficient lighting bulbs will reduce the electricity consumption in commercial/ service sector to 10%, while households will have a drop in energy intensities for lighting by 2040. The CFL (14 watts) bulbs has the capacity to reduce peak demand (which is usually during the evening from 5pm to 9pm) by 46 watts for a single bulb,

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[80] www.efi.org/factoids/cfl_faq.html
[81] www.consumerenergycenter.org/lighting/bulbs.html

which is lower than the incandescent bulb (60 watts).Refrigerators that are inefficient was replaced by efficient ones and this will increase to 70% by 2040 at the cost of $20 per refrigerator which will extend their lifetime to 14 years at a reduced intensity[82].

In the transport sector, some moderate changes were introduced into the sector. This includes the use of biofuels and biodiesel in the six categories of vehicles in the Nigerian transportation sector (Akande & Olorunfemi, 2009; Highina et al., 2011). Although there exist some challenges with the production of biofuels for commercial use as discussed in Idusuyi et al., (2012), and Balogun (2015).

These challenges[83] could be alleviated with the increased support of the Nigerian government through the National Biofuel Policy (NNPC, 2007). Biofuels which are produced from contemporary biological process from either agriculture or anaerobic digestion[84], presents a future of reduced GHG emission in Nigeria as seen in countries such as the USA and Brazil. Biodiesel can be used as a fuel for vehicles in its pure form or as a diesel additives to reduce the levels of particulates, carbon monoxides and hydrocarbons from diesel powers vehicles[85]. The shares assumed for biofuel use in the Nigerian transport sector under the LCM scenario up to 2040 are presented in Appendix A2.

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[82] www.homeguides.sfgate.com/expected-life-refrigerator-88577.html
[83] Some the challenges include feedstock availability, land availability for feedstock production, availability of domestic market, and lack of support for the development of the biofuel industry.
[84] www.businessdictionary.com/definition/biofuel.html
[85] www.userpages.umbc.edu/~copher1/ART336/wikiredesign/biofuel.html

The transmission and distribution losses in electricity sector assumes the reduction to 6% by 2040. This is in line with the current trend of low T&D loss experienced in other developing countries which are becoming more advanced. The reduction in T&D losses will be due to the improvement in the national grid network and provision of distributed generation and distribution systems (Anumaka, 2014). Natural gas losses will also be reduced to 13% in the LCM scenario, so as to ensure improved supply to all the sectors of the economy.

In order to ensure a reduction in the amount of GHG emission from electricity generation, the inclusion of renewable energy technologies were made in this scenario. Due to the high potentials for solar radiation in most part of Nigeria, the share of solar PV systems alone was assumed to be 9% by 2040 (Yohanna & Umogbai, 2010; Awogbemi & Komolafe, 2011; Ogunmodimu, 2013; Oghogho, 2014). Rural electrification with solar PV systems and small hydropower was integrated for off-grid electricity supply as unlimited potentials exist in its application (Muhammad, 2012; Shaaban & Petinrin, 2014).

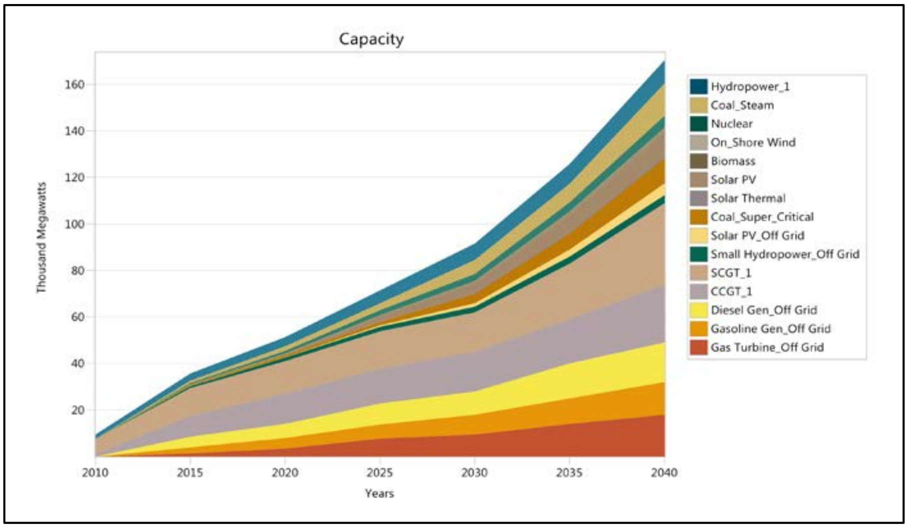
According to the study carried out by United States Environmental Protection Agency [USEPA] (2010) and United Nations Industrial Development Organization [UNIDO] (2011), a large amount of energy could be realized from biomass and small hydropower sites in Nigeria. The studies clearly showed that 250MW of biomass power plant constructed in Nigeria could generate 1,643 MWh/y of electricity in 2015 alone. This figure could go higher to 13,140 MWh/y of power supply with the installed capacity of 2000 MW on the long term. Also small hydropower with an installed capacity of 100 MW can generate 526 MWh/y of electricity in 2015, and 17,870 MWh/y on the long term.

The increase in the installed capacity of CCGT in the LCM scenario is due to the lower carbon intensity, improved efficiency, availability time and output capacity as compared to the SCGT. The share of off-grid gas plants was increased due to economical nature of gas power plants as compared to diesel and gasoline generators. Although gas supply may not get to some power plants located in remote areas of the country, diesel and gasoline maybe available but at a higher cost (Elusakin Julius et al., 2014). This was also bases for the increased capacity of small hydropower and solar PV systems in off-grid areas.

The total capacity for the LCM scenario is 170,500 MW by 2040, which is more than the REF scenario (i.e. 155,283 MW). Nuclear power plants is assumed to have an installed capacity of 5000 MW which is realizable and judging from the fact that a 4600 MW nuclear power plant is set to be constructed before 2020 (as discussed in the REF scenario). Coal power plants were of two types in the LCM scenario; the conventional coal steam turbine and the more advance coal supercritical power plant. The coal power plants had an installed capacity of 25000 MW, of which the coal steam had 14000 MW and the coal supercritical had 11000 MW by 2040.

The basis for the selection of these two coal power plants was based on the economic variability assessment carried out by Ujam and Diyoke, (2013) and the review by Essien and Igweoonu, (2014). The projected generation capacity additions by technologies in the LCM scenario are presented in Appendix A4 and Figure 4-4.

Figure 4-4: LCM scenario future electricity generation capacity



The increase in crude oil refinery and coal mining production capacity was not assumed in this scenario, hence remains the same as in the REF scenario. However, charcoal production efficiency was improved through the introduction of steel kilns (40% share) and casamance kilns (30% share), so as to boost domestic production and meet market demand (see Appendix A3).

4.1.4 The Low Carbon Advance Scenario (LCA)

In making a shift towards a more advance low carbon society in Nigeria, the LCA scenario was developed. This scenario assumes a more aggressive energy policy and strategy to reflect a higher level of economic development and commitment for climate friendly energy production and consumption than the LCM scenario. As shown in Table 4-1, the LCA scenario has more sectorial growth rate as compared to the REF and LCM scenarios. The assumption for the annual economic growth is much higher than the average annual growth rate and much higher than the projections made by the National Bureau of Statistics and the Central Bank of Nigeria.

In the household sector, the increase in income is assumed to increase the purchase of more household electrical appliances such as electronics (TV, DVD, Hi-Fi systems), air conditioners and refrigerators. With this, household energy consumption is expected to increase more than the REF scenario. To address the increase in energy demand and reduce household energy intensities for electrical appliances, energy efficiency labelling program for the Nigerian household is implemented. This includes the increase ownership of efficient refrigerators, air conditions and other household's appliances. This policy strategy is expected to bring about the reduction of household energy intensity to about half the required amount by 2040 (Momodu et al., 2012).

Efficient lighting in the household sector in the LCA scenario is expected to attain a much lower energy intensity through the introduction of LED bulbs which are more efficient than the CFL bulbs introduced in the

LCM scenario. The LED[86] bulbs consumes about 30% less energy required than the CFL bulbs and about 50% less than the incandescent bulbs. In comparing the LED, CFL and incandescent light bulbs, the LED bulbs presents a better alternative option in terms of lower annual operating cost, intensity, environmental impact, output and life span as shown in Table 4-3. Although LEDs ($4.5) cost more than the CFL and incandescent bulbs in Nigeria, the benefits as shown in Table 4-3 is expected to offset the cost on the long run.

Table 4-3: Comparison between LED/CFL and Incandescent light bulbs

(Source: www.designrecycleinc.com/led%20comp%20chart.html)

Energy Efficiency and Energy Costs			
	LED	Incandescent light bulbs	CFL
Life Span (average)	50,000 hours	1,200 hours	8,000 hours
Watts of Electricity used (equivalent to 60 watt bulb)	6 - 8 watts	60 watts	13 – 15 watts
Kilo-watts of Electricity used (30 Incandescent bulbs per year)	329 KWh/yr	3285 KWh/yr	767 KWh/yr
Annual Operating Cost (30 Incandescent bulbs per year equivalent)	$32.85/ year	$328.59/ year	$76.65/ year
Environmental Impact			
Toxic Mercury	No	No	Yes
RoHS Compliant	Yes	Yes	No
Carbon Dioxide Emissions (30 bulbs per year)	451 pounds/ year	4500 pounds/ year	1051 pounds/ year
Light Outputs			
Lumens	Watts	Watts	Watts
450	4 – 5	40	9 – 13
800	6 – 8	60	13 – 15
1,100	9 – 13	75	18 – 25
1,600	16 – 20	100	23 – 30
2,600	25 - 28	150	30 – 55
Other Facts			
Sensitivity to low	None	Some	Yes

86 www.bulbs.com/learning/ledfaq.aspx

temperatures			
Sensitive to humidity	No	Some	Yes
On/off Cycling	No effect	Some	Yes
Turns on instantly	Yes	Yes	No
Durability	Very Durable	Not very durable	Not very durable
Heat Emitted	3.4 btu's/ hour	85 btu's/ hour	30 btu's/ hour
Failure Modes	Not typical	Some	Yes

The shear of LPG for lighting and cooking was increased to 20%, while the share of kerosene was reduced to 11.70% in the LCA scenario. This is expected to be a better alternative than kerosene which has been on high demand by the household sector in Nigeria[87]. A study by Maduka, (2011) showed that the popularization of LPG among Nigerian women can help in the reduction of firewood use in Nigerian households. The challenges however remains the access to the LPG in rural areas and lack of public awareness of the use of LPG in households (Ah Julius, 2013). LPG has an important role to play in achieving a low carbon economy in Nigeria and other developing countries (Kojima, 2011; Kojima, Bacon & Zhou, 2011), hence the increase in its share was considered in the LCA scenario.

In Nonekuone (2008) thesis, the barriers to the increase in LPG use in Nigeria were identified as; affordability, pricing, government policies, safety, transportation and distribution. This challenges were assumed to be addressed by the government through the government provision of policy regulation, institutional development, safety standards and improved access to the rural areas. Besides the reduction in the share of firewood and kerosene use for

[87] www.thisdaylive.com/articles/hindering-growth-of-nigeria-s-lpg-market-with-kerosene-subsidy/157397

cooking, more policy steps were taken in improving the efficiency of firewood and kerosene cooking stoves in the rural and urban areas in the LCA scenario. These steps is expected to lower the demand for these fuels in the household sectors which is expected to have the highest consumption in the REF scenario.

Efficiency improvement through the increase use of LEDs does not only affect the household sector alone, but also the commercial/service, and industrial sector. Further improvement in energy efficiency in the industry sector was the through the replacement of inefficient electric motor, air conditioning and refrigeration systems. According to the energy audit carried out on manufacturing and processing industries in Nigeria by Olayinka and Oladele (2013), consumption by electric motors account for 40-47% of the total electricity consumed in most industries in Nigeria. Others such as boilers and heaters account for 65% of the total energy consumed. The inefficiencies in energy use were attributed to poor in-housekeeping of air conditioner, refrigeration equipment’s, weal electric motors and lack of switching off electric bulbs during the day time. These inefficiencies if addressed will resort to the reduction to about 30% of energy demand in the industrial sector.

The use of LPG which is also called autogas when used as a fuel in internal combustion engines in vehicles have been extensively used in many countries of the world (Sethiya, 2014). Countries such as Australia, Italy, Poland, South Korea, and Turkey account for half of the world autogas vehicle consumption in 2013[88]. Autogas Incentive Policies (AIP)[89] have been attributed to the success of the increase use of LPG for transportation in most countries. According to the World LP Gas Association (2014), government policies to promote alternative fuels such as autogas has been mainly through financial incentives, regulatory policies and measures. These was assumed to be in-effect in the LCA scenario and therefore ensure the penetration of LPG (or autogas) vehicles in Nigeria by 2040. The shares of LPG cars for vehicles in the transport sector under the LCA scenario is shown in Appendix A5. The assumption was made in line with penetration of LPG in other developing countries such as China as reviewed by Leung (2011), and Ou, Zhang and Chang (2010), with the scenario analysis for LPG penetration in Ghana by Biscoff et al., (2012).

The LCA scenario assumes more expansion of renewable energy technologies in both rural and urban areas in order to increase electricity supply, energy security and enhance environmental protection as compared to the LCM scenario. To meet the environmental obligation of reduced GHG emission, the LCA scenario assumes a strong political pressure to build power plants that are less polluting than those in the REF and LCM scenario. Appendix A6 and Figure 4-5 presents the projected electricity generation capacity for the LCA scenario. From the generation mix, diesel and gasoline generators in the off-grid areas are put to retirement and never expanded as in

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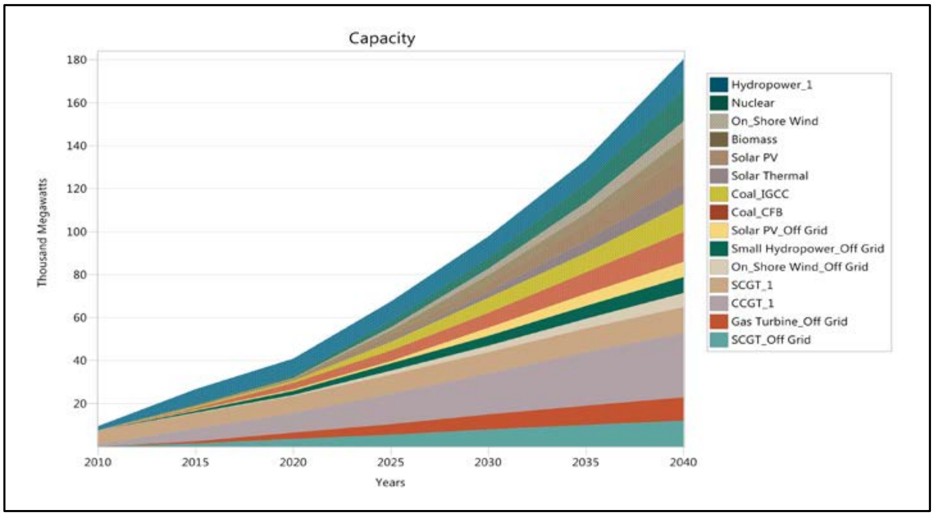
[88] See www.bpnews.com/index.php/publications/magazine/current-issue/305-world-autogas-demand-jumps-57-in-past-decade-incentives-play-key-role

[89] The AIP is promoted by the government through; lowering fuel tax vis-à-vis gasoline and diesel, lowering vehicle taxes or conversion subsidies, employing traffic measures and removing barriers (parking restrictions etc.).

the REF and LCM scenarios. They are however, replaced with more efficient gas turbine and small SCGT power plants at 25% and 27% respectively.

Renewables for off-grid electricity generation is also improved at 15%, 17% and 16% for on-shore wind, small hydropower and solar PV respectably. The share of renewables were also increased for on-grid electricity generation with solar PV and large hydropower having 10% share each. However, the more efficient CCGT power plants has 22% of the total on-grid electricity generation capacity. Nuclear power plants share was also increase 4% in the LCM scenario to 11% so as to ensure a more low carbon approach to electricity generation. According to the Nigeria Atomic Energy Commission (NAEC) and the Nigerian Nuclear Regulatory Authority (NNRA), the first nuclear power plant in Nigeria will have the capacity to produce 1,000 MW and be expanded to 4,000 MW within 10 years of establishment[90].

Figure 4-5: LCA scenario future electricity generation capacity



[90] www.punchng.com/news/nigerias-first-nuclear-power-plant-ready-in-10-years-naec

Coal power plants in the LCA scenario are circulating fluidized bed (CFB) and integrated gasification combined cycle (IGCC) which are more efficient and produce less GHGs as compared to other coal power plants. Transmission and distribution losses in electricity was reduced to 5%, while natural gas pipeline losses was reduced to 10%. For charcoal production, Mud beehive and Adam retort kilns are used with a share of 40% and 35% respectively. Oil refinery capacity was kept at 90% for all the three refineries (i.e. Kaduna, Warri and Port Harcourt Refineries).

4.1.5 The Green Optimistic Scenario (GO)

According to the National Renewable Energy and Energy Efficiency Policy (NREEEP, 2014), Nigeria's population is expected to double its amount in twenty years and the aggregate energy demand will triple. Fossil fuel energy resources alone will not be able to meet the challenges of an increasing population at affordable costs and in a flexible manner (NEP, 2013). In order to meet the rapidly growing demand for energy, and the challenges posed by climate change, there has to be a conscious effort to increase the share of renewables in the energy mix (Oyedepo, 2012; NREEEP, 2014).

Great potentials and benefits exist for renewable energy development in Nigeria of which it can create jobs such as green jobs[91] (Bowen, 2012), alleviate poverty as well as energy poverty (Emodi & Boo, 2015a), and open up market in rural areas (REP, 2015). These were the basis for the development of the GO scenario which intends to increase the share of renewables on the supply side, as well on the demand side.

On energy efficiency measures in the household and commercial/service sector, this scenario assumes that incandescent bulbs will be completely replaced by CFC and LED at 60% and 40% respectively by 2040. To ensure that the GO scenario achieve this, measures such as the "Phase out Incandescent Light Bulbs (POILB)" should be employed[92]. This measure comes as a kind of regulations effectively banning the manufacture, importation and sale of incandescent light bulbs to the public[93].

Most countries around the world have employed this policy measures and they include, China who started the ban in 2012, but extended it to 2016[94], India also started the ban on incandescent bulbs in 2012[95], Israel

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[91] The green jobs, green growth or the green revolution has been encouraged by many economies of the world and such include South Korea. The South Korean government have been on the forefront of green growth initiatives and established the National Strategy for Green Growth (NSGG) (2009-2050) and the Five-Year Plan (FYP) (2009-2013) to provide a comprehensive policy framework for green growth in both the short and long term. The long term policy impact of the NSGG aims to promote eco-friendly new growth engines, enhance peoples' quality of life and contribute to international efforts to fight climate change. The FYP outlines the government plan to spend approximately 2% of annual GDP on green growth programs and projects (see OECD, 2011).

[92] See www.energyrating.gov.au/products-themes/lighting/lighting-and-phase-out-general-information/incandescent-light-bulbs-phase-out/

[93] www.lampochki.org.ua/en/topovaja-novost-4/

[94] www.reuters.com/article/2011/11/05/us-china-light-bulbs-idUSTRE7A40MV20111105

[95] www.treehugger.com/interior-design/india-to-phase-out-400-million-incandescent-lightbulbs-by-2012-replace-with-cfls.html

phased it out since 2012[96], the United Kingdom in 2011[97], and all European Union (EU) countries have until 2016 to completely phase out incandescent before 2016[98]. Other countries include Canada who made a move in 2007[99], while most states in the United States (US) have completely phased out incandescent since 2007 and others will be in 2018[100]. Some countries implemented new energy standards and phase out incandescent bulbs, among them include Argentina in 2012[101], Mexico, Malaysia and South Korea[102] in 2014.

Other efficiency measures include the complete deployment of efficient refrigerators and air conditioners which will phase out the inefficient ones used in the Nigerian households by 2040. Since the GO scenario is renewables oriented, the share of kerosene, firewood and Charcoal stoves are reduced to half the value in the LCA scenario. This is complemented by increasing the share of LPG and introducing solar thermal and solar cookers. Agbo and Oparaku (2006) reviewed the status and prospect of solar heaters in Nigeria. They highlighted some pressing policy issue research and development (R&D), pilot and demonstration projects, institutional framework, investment promotion, incentives and protections. The GO scenario assumes that this measures are meet before 2040.

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96 www.energy.gov.il/LightBulb/Pages/GxmsMniMiniSiteLightBulb.htm
97 www.news.bbc.co.uk/2/hi/uk_news/7016020.stm
98 www.greenpeace.org.uk/blog/climate/eu-ban-inefficient-light-bulbs-eventually-sort-20081212
99 www.reuters.com/article/2007/04/25/us-lightbulbs-env-idUSN2529253520070425
100 www.leginfo.ca.gov/pub/07-08/bill/asm/ab_1101-1150/ab_1109_bill_20070223_introduced.html
101 www.lanacion.com.ar/1091978-desde-2011-no-podran-venderse-mas-lamparas-incandescentes
102 www.yonhapnews.co.kr/economy/2013/07/16/0302000000AKR20130716057151003.H-TML

Alternative source of electric lighting for households and commercial/service sector was encouraged with LPG use increased to 30%, kerosene reduced to 10%, solar lamp 10, electricity stands at 48%, other sources was 2%. Industrial efficiency improved to 40% which the same measures applied in the LCA scenario, and in addition, the introduction of electric arc blast furnace to replace the conventional ones currently in use by 2040[103]. The use of the electric arc blast furnace in the Nigerian industries will not only reduce energy/electricity consumption, but also reduce GHG emission from the industry sector. Due to the introduction of the electric arc, the share of energy consumed in the in the industrial sector is assumed to have electricity 43.94%, biomass 23.46%, natural gas 29.56%, residual oil 2.735 and coal 0.32% by 2040. For the growth rate of the industry, commercial/service and agriculture sector in the GO scenario, please refer to Table 4-1.

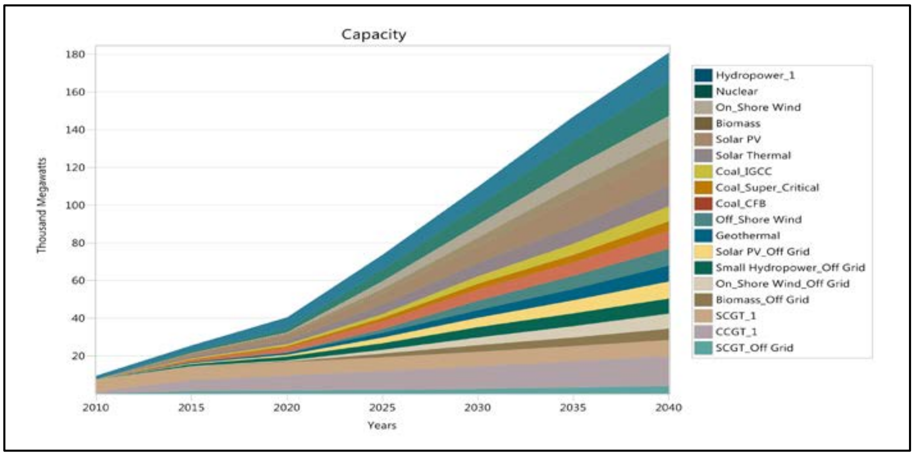
The transport sector inherit the biofuel and LPG used in the LCM and LCA scenarios, with the introduction of the CNG in all the vehicle categories apart from motorcycles. The GO scenario assumes the increase penetration of biodiesel use in motorcycles up to 50% by 2040. In order to provide various low carbon emitting fuels than conventional ones, CNG and LPG are introduce and some vehicle types have the same share, while others slightly differ. Other policies introduced include improved fuel economy and

[103] An electric arc furnace is a furnace that heats charged material by means of an electric arc. It's used for steelmaking and has various advantages over the conventional blast furnace of which includes the high efficiency in recycling of steel scrap and the efficient energy consumption of the arc.

reduction in private car ownership. The projected share of fuel mix in the transport sector under the GO scenario is presented in Appendix A7.

In the power sector under the GO scenario, the share of fossil fuel power plants were reduced in terms of installed capacity as shown in Figure 4-6 and Appendix A8, except for CCGT power plants which has 11% share in the total on-grid electricity generation mix. Nuclear power plant have about 18000 MW of installed capacity while hydropower has 11% share.

Figure 4-6: GO scenario future electricity generation capacity



As observed from Figure 4-6, the installed capacity of renewables were more than the LCA scenario, with the introduction of new renewable technologies; geothermal and off-shore wind turbine. The Nigerian energy policies (NEMP, 2014; NEP, 2014) stated the intention of the Nigerian government to investigate other source of renewables such are hydrogen and geothermal energy resources. This scenario did not consider hydrogen as an energy source, but assumed the introduction and expansion of geothermal power plant (from 2020-2040). Studies (Nwachukwu, 1976; Avbovbo, 1978; Gelnett & Gardner, 1979; Onuoha & Ekine, 1999; Nwankwo et al., 2009) have analyzed various part of Nigeria for geothermal resources[104]. Kurowaska and Krzysztof (2010) highlighted that the geothermal resources in Nigeria were enough to be exploited for power generation. This scenario takes this as a rationale for the inclusion of geothermal power plants in the future energy mix in Nigeria.

Off-shore wind was also introduced and expanded in the energy mix as a study carried out by Onyemechi et al. (2013) showed through a cost comparative assessments that it was possible and presents more advantage than other renewables. For off-grid electricity generation, the status quo of retired plants in the LCA scenario holds, including the gas turbine power plants. The SCGT was the only fossil fuel plant considered for off-grid electricity generations at a small percentage share. Renewables such as the on-shore wind, small hydropower and solar PV are to complement the retired fossil fuel power plants. The GO scenario assumes a reduction of T&D losses to 4%, while natural gas pipeline loss is reduced to 6% by 2040.

[104] Maximum temperature gradients were found in around the Niger Delta regions within the sedimentary Basins, the Nupe Basin in west central Nigeria, Wikki Warm Spring area in the north-eastern part of Nigeria, the Anambra Basin,

Chapter 5. Results and Discussions

This chapter presents the results of the Nigerian LEAP model from 2010 to 2040. The chapter is divided into two sections; the first section presents the results of the forecasted energy demand and supply, electricity supply, GHG emissions and the energy balance. The second section provides an in-depth analysis that will discuss the interrelations between energy, environment and the society in Nigeria from 2010 to 2040 under the four scenarios proposed, the least-cost electricity generation, cost-benefit analysis of the scenarios and sustainable strategies. Finally, key findings and policy implications are provided.

5.1 Results

In order to ensure a well-defined interpretation of the results, a scenario base approach is employed for the result interpretation. In this section, all scenarios projections are analyzed based on the sectors specified in Chapter 4. To further simplify the interpretation of the results, the results are presented in the following order; future energy demand and supply, electricity supply projections, GHG emission projections and energy balance analysis.

5.1.1 The Reference Scenario (REF)

This scenario was developed considering the most-likely-developmental-pathways of the Nigerian Government. The results are presented as follows.

5.1.1.1 Future Energy Demand and Supply (REF)

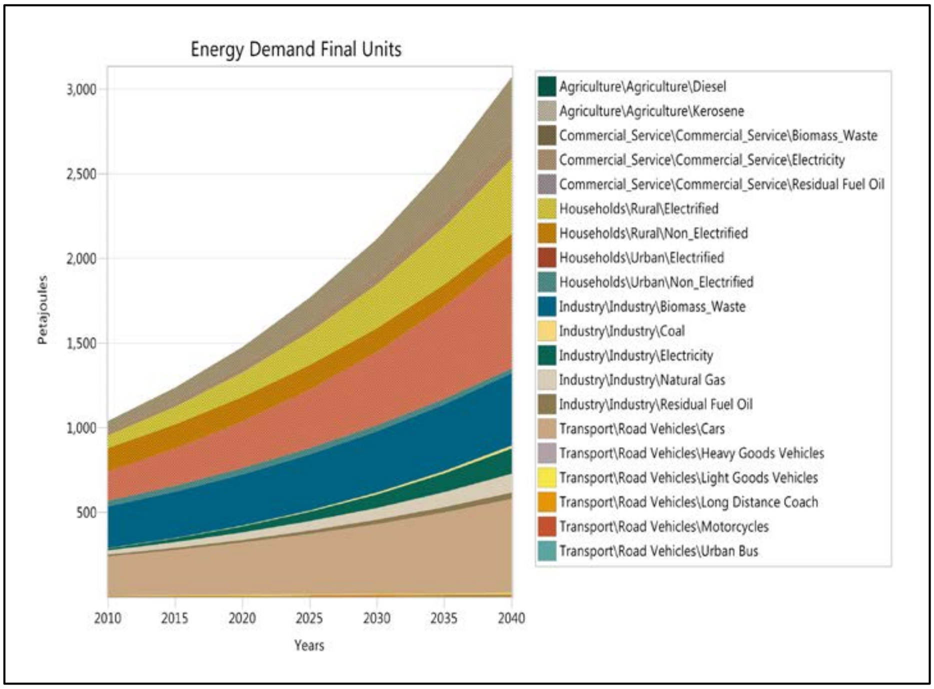
5.1.1.1.1 Future Energy Demand by Sector (REF)

Energy demand under the REF scenario is expected to grow from 1,039.3 PJ in 2010, to 3,075 PJ in 2040 as shown in Figure 5-1 and presented in Appendix B1. In the households sector, the urban household energy demand grows to 714.7 PJ in which the larger share of energy demand goes to the electrified households (i.e. 686.9 PJ). The rural households which is composed of both the electrified and non-electrified have a cumulative demand of 552.8 PJ by 2040. As can be observed from the results, energy demand in the urban and rural electrified households had an increase in energy demand as against the non-electrified households in the urban and rural households.

This is due to the increase in population and income as can be recalled from Table 4-1 in Chapter 4. Another reason for this feat in the household is based on the NEMP (2014) recommendations on the government's plan to achieve a 100% electrification rate by 2040 and the need to reduce reliance on biomass for cooking and replace it with electricity in the household sector. This entails the need for the reduction in non-electrified households and the increase in electrified households[105].

[105] This does not mean the physical reduction in household numbers, but the effect of switching the type of fuel used to meet energy needs (e.g. switching from firewood to electric stoves, while improving electricity access).

Figure 5-1: REF scenario energy demand



The industrial sector as observed in the results in the REF scenario, presents a growing energy demand from 297 PJ in 2010 to 742.2 PJ by 2040. The larger share of demand by fuel remains biomass and waste which stands at 426.8 PJ in 2040 as against the 2010 value of 247.9 PJ. The share of electricity in the fuel mix is also observed to increase to 148.4 PJ by 2040, as is the case of natural gas which is 111.3 PJ. Other fuel source such as residual fuel oil which is mainly used for powering privately owned electricity generator[106], is assumed to grow at much lower rate as compared to other fuels. The growth in the energy demand in the industry sector is in line with the industrial growth rate specified in Table 4-1 in Chapter 4, and also in the

[106] The electricity generated from privately owned generators are different from the electricity stated in the fuel mix, because the electricity in the fuel mix comes directly from the national grid supply.

absence of improved energy efficiency and electricity supply. In other words, the industries will continue to depend on privately owned generators to meet their electrical needs until 2040.

The commercial and service sectors which includes public service sector and private business and service sector[107], will have an energy demand of 482.5 PJ by 2040 and will compose of a larger share of biomass and waste (368.4 PJ) and electricity (112.7 PJ). Just as in the household and industry sector, energy efficiency practice are not observed and as such, the increase in energy demand from 84 PJ in 2010. The agriculture sector which according to the base year value of 0.1 and 0.3 for kerosene and diesel respectively, will have a little increase in energy demand which is due to the low energy consumption experienced in the Nigerian agricultural sector[108]. In Nigeria today, the rate of mechanized has not improved form more than 30 years and this is due to the level of government commitment in the development of the agriculture sector[109].

The current status of vehicles in the transport sector under the REF scenario is assumes to value in the base year (see Appendix B15 and B16), and expected to increase its total energy demand to 581 PJ by 2040. The fuel type which consist of gasoline and diesel are observed to be higher for cars with an energy demand of 557.2 PJ in 2040 which increased from 229.6 PJ in 2010. The reason for the increase in cars demand is due to the increase in

[107] E.g. hospitals, small business enterprises
[108] www.businessdayonline.com/2014/09/the-mechanisation-of-agriculture-in-nigeria/
[109] This was the case presented in Lamidi and Akande (2013) study as the point out that this was caused by the availability of capital, poor infrastructural facilities, poor attitudes toward adoption of new innovation and non-availability of storage means.

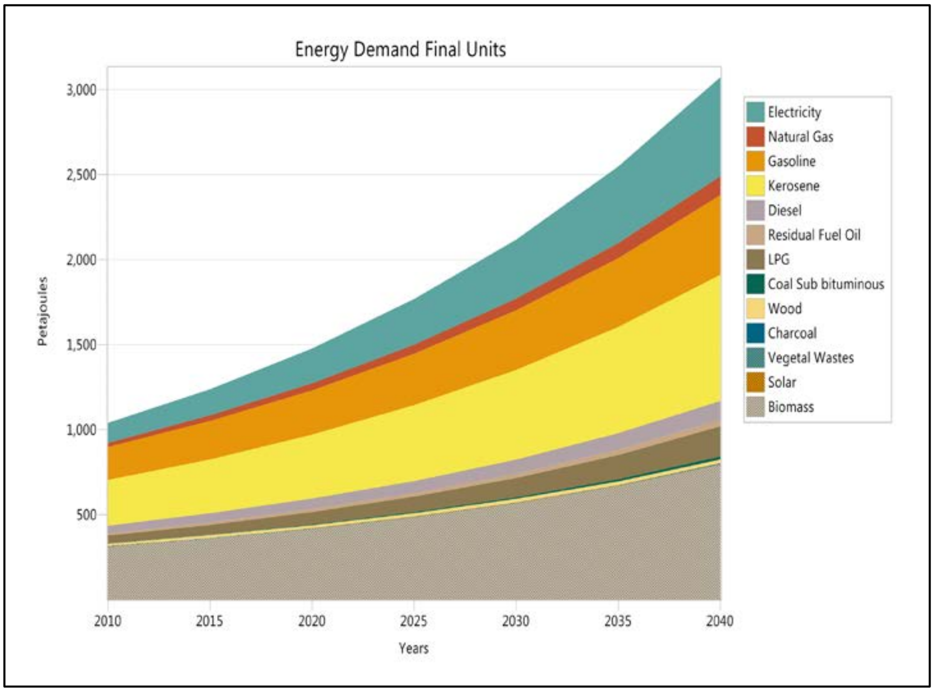
population size, as more people tend to buy more cars for private use and also the demand for fuel in cars with low/poor fuel efficiency. Motorcycles which is popular among the Nigerian populace for both private and commercial use, is expected to grow from 2.4 PJ in 2010 to 5.8 PJ in 2040. The energy demand for other vehicles such as LGV, HGV, UB and LDC are 4.9, 0.8, 4.1 and 8.1 PJ respectively.

5.1.1.1.1 Final Energy supply (REF)

The final energy supply under the REF scenario for both primary and secondary energy are shown in Figure 5-2 and presented in Appendix D2. The results show that out of the 3,075 PJ of the total energy supply, biomass (795.1 PJ) and kerosene (740.6 PJ) will be the most sort after fuel source by 2040. Following this energy source will be electricity[110], gasoline, LPG, diesel and natural gas with the demand of 582.5, 470.4, 177.2 PJ, 112, and 111.3 PJ respectively. The increase demand in kerosene and biomass demand will be mostly concentrated in the household and industry sector. As mentioned in the last subsection above, the increase in the demand for energy is due to the considerations specified in Table 4-1 and 4-2 in Chapter 4.

[110] The value of electricity here is measured in Petajoules (PJ) units which was converted from the Megawatts unit utilized/consumed in the sectors.

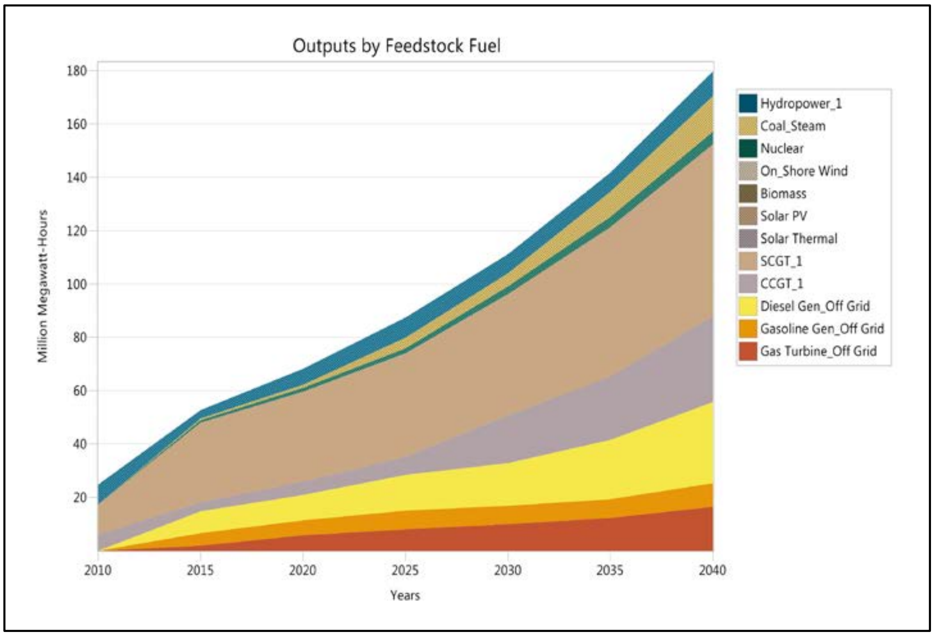
Figure 5-2: REF scenario energy supply



5.1.1.2 Future Electricity Supply (REF)

The future electricity supply (see Figure 5-3) from the installed capacity of 155,283 MW in REF scenario (please refer to Appendix A1) is expected to generate 179,800 MWh by 2040. This power plants with the most share of electricity production is the SCGT plants which will generate about 64,200 MWh, followed by CCGT power plants at 32,200 MWh and diesel generators for off-grid power supply (30,400 MWh). In the REF scenario, the government's plan to increase electricity access in off-grid areas will be achieve in a large extent through the use of diesel and gasoline generators, in association with small gas turbine (Presidential Task Force on Power [PTFP], 2013). The nuclear power plants slated to come online in 2015 is expected to generate about 800 MWh to the population, and as expansion in it capacity grows, the power generation will contribute about 4,600 MWh by 2040.

Figure 5-3: REF scenario electricity supply



Coal power plants which the Nigerian government intends to use as a means to curb the energy poverty situation in Nigeria will generate about 13,400 MWh by 2040 from the installed capacity of 13,000 MW. The contribution of renewables in the REF scenario is relatively small as compared to the supply from fossil fuel plants. The highest electricity supply of renewables will be generated from large hydropower plants[111] to the tune of

[111] Although hydropower plants are actually renewables, most organizations and states in the United States of America and other countries don't consider larger hydropower plants as renewables and this due to the effects the dams has on aquatic habitat/life such as fisheries and water flows. This sometimes block migrating fish from reaching their spawning grounds. Further, dam reservoirs impact the flows, temperature and silt loads of rivers and streams

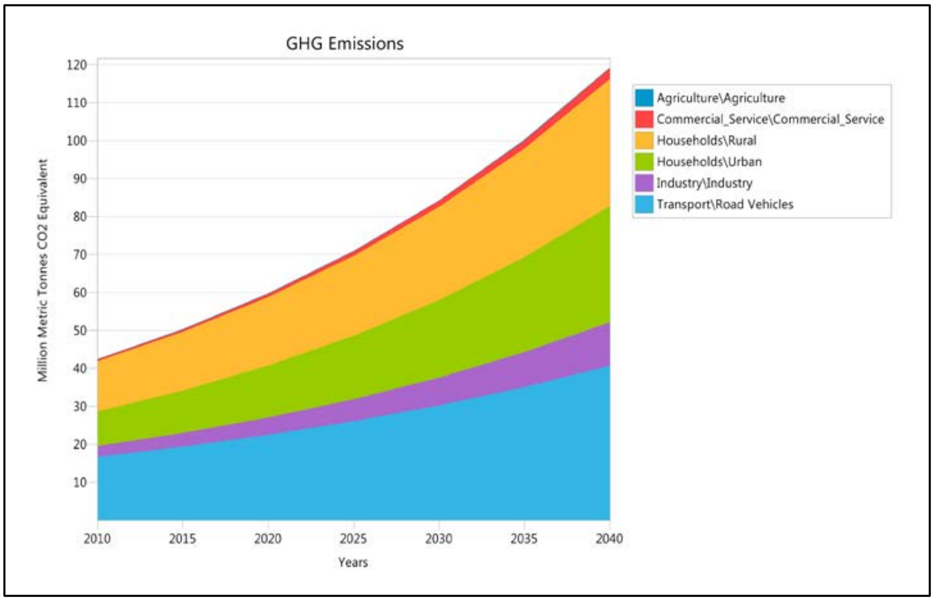
9,300 MWh, while other renewables such as on-shore wind, biomass, solar PV and thermal will contribute about 16 MWh, 58 MWh, 170 MWh and 22 MWh respectively by 2040.

5.1.1.3 GHG Emission (REF)

The ever increasing energy demand in the REf scenario ensured the rise in GHG levels from 42.4 million metric tonnes of carbon dioxide equivalent (henceforth, MMTCDE) in 2010 to 119.2 MMTCDE. By 2040. The GHG emission under the REF scenario is shown in Figure 5-4 and presented in Appendix G1. The increase as observed will have the highest contributions from three sectors; the households, industry and transport sector accounting for 64.1, 11.5 and 40.7 MMTCDE respectively. As described in the scenario development (please refer to Chapter 4), no meaningful policy strategy was in place to effect the reduction of GHG in all the sector under this scenario. The GHGs from agriculture and commercial/service sectors will remain considerably small as compared to other sector of the economy by 2040.

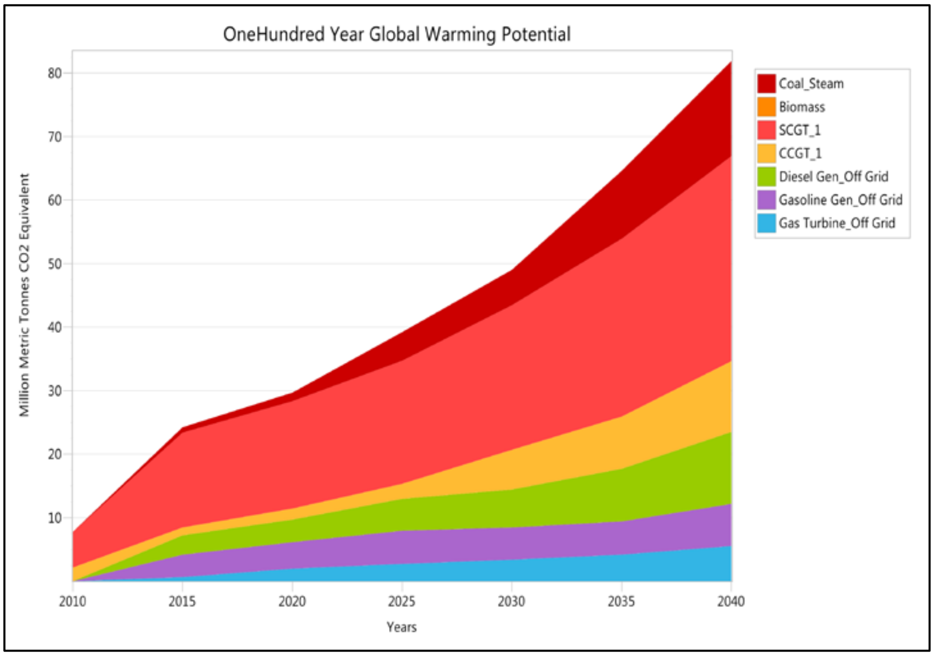
(World Watch Institute [WWI], 2013; Daigneau, 2013). Also in some countries such as Canada and those in the European Union, methane emissions have been credited to hydropower plants which is caused by the plant material in flooded areas decaying in an anaerobic environment, and forming methane, which is a GHG (World commission on Dams [WCD], 2000; Newscientist, 2001). Other probles associated with hydropower plants includes the relocation of people living where the reservoirs are planned and the high rate failure risk due to poor construction, natural disasters and sabotage (International Rivers, 2008; Osnos, 2011; British Broadcasting Corporation News [BBC], 2012).

Figure 5-4: REF scenario GHG emission from energy consumption



The GHGs from electricity generation was analyzed separately from the energy demand in the five sectors. In the REF scenario, the fossil fuel power plants as shown in Figure 5-5 and presented in Appendix G5 is observed to emit 81.9 MMTCDE. Due to the capacity size of SCGT power plants in the electricity mix by 2040, the GHGs amounts to about 32.3 MMTCDE and it's the highest among other fossil fuel power plants. The next power plant with high emission is the coal steam with an emission contribution of 15 MMTCDE by 2040. Off-grid energy technologies such as gasoline and small gas turbine will have less GHG emission of 6.6 and 5.5 MMTCDE by 2040.

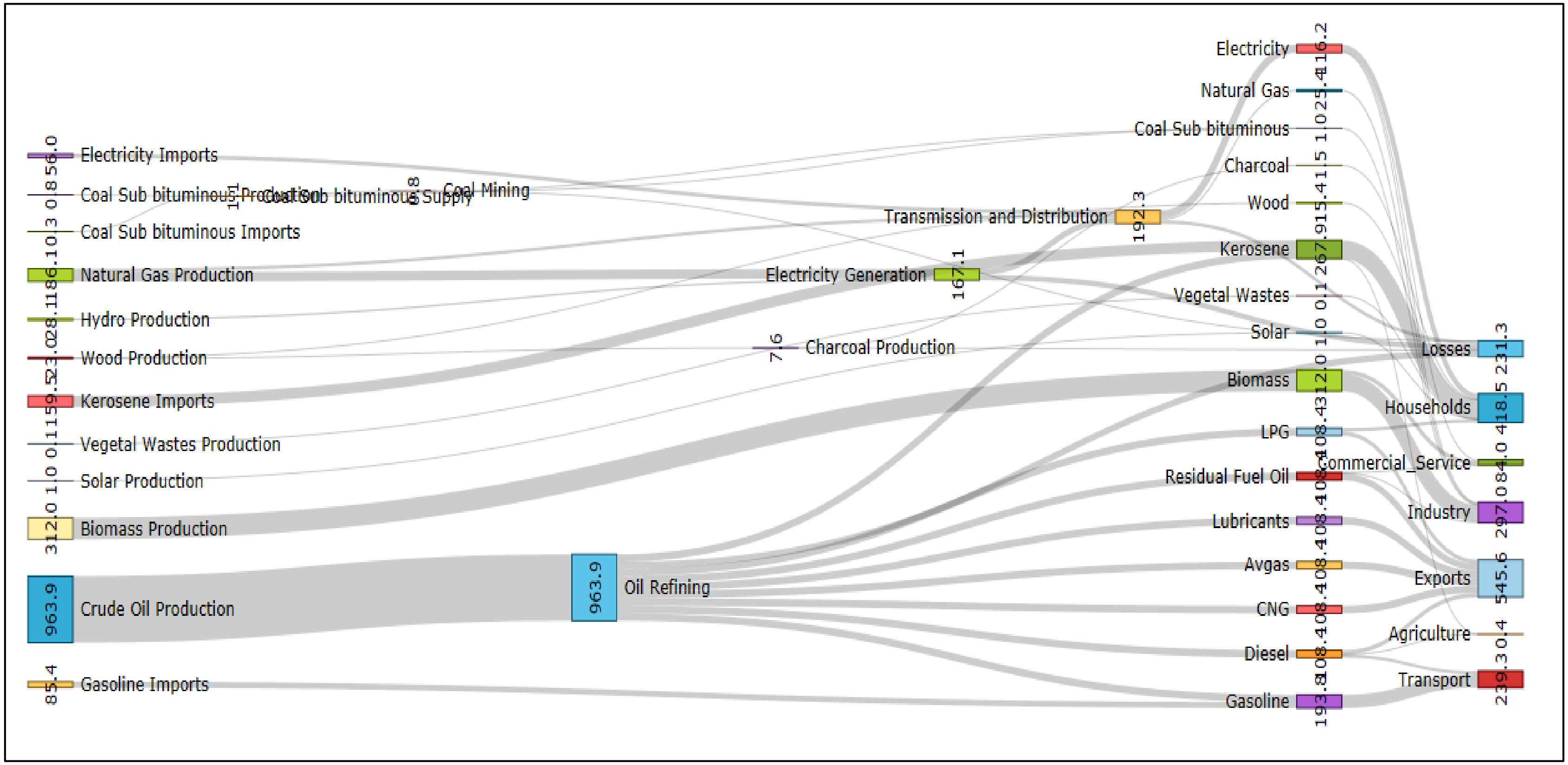
Figure 5-5: REF scenario GHG emission from electricity generation



5.1.1.3 Energy Balance (REF)

The future energy balance in Nigeria was analyzed in order to examine the interactions between energy and the society in the year 2010 and 2040. In order to take account for the changes in the energy system, the base year (2010) was represented using a Sankey diagram and this is shown in Figure 5-6 and presented in Appendix H1.

Figure 5-6: Sankey Diagram of Nigeria's Energy Balance in 2010 (REf Scenario)



In the base year, the REF scenario presents a situation whereby Nigeria relies heavily on gasoline (85.4 PJ) and kerosene (159.5 PJ). According to the level of installed crude oil production capacity and products in the base year (see Appendix B7 and B18), the demand for natural gas which was 186.1 PJ was meet from the local refineries in Nigeria. Out of this production (i.e. natural gas), 139 PJ was used for electricity generations in the gas power plants in 2010, while about 21.7 PJ was lost due in the process of transmission and distribution. Industrial energy demand for natural gas took the remaining 25.4 PJ.

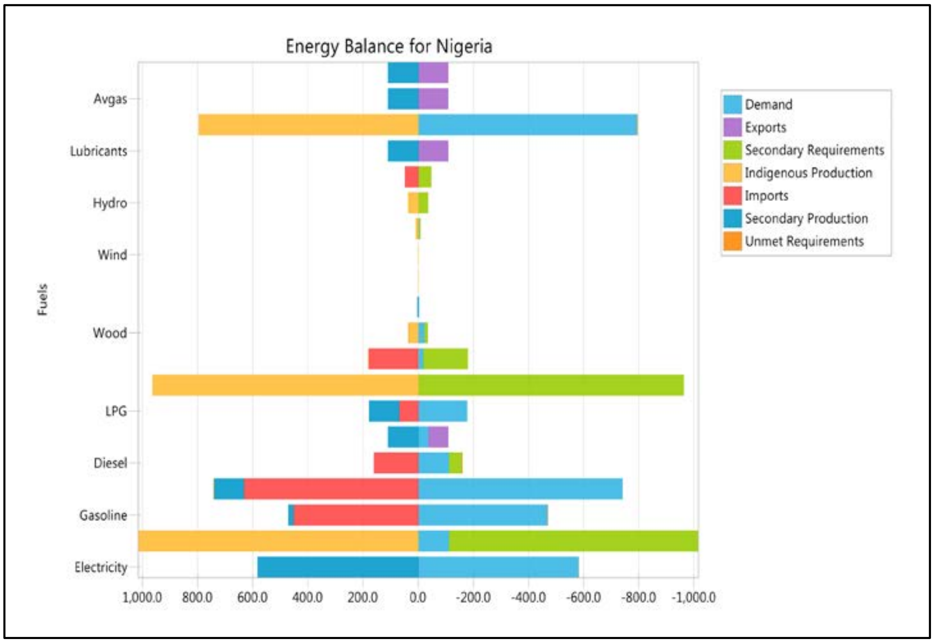
Electricity generation in energy unit was 89.2 PJ and out of this was the loss of 29 PJ to T&D. the supplied electricity to the five sectors in which household's electricity demand was 84.9 PJ, a deficit can be observed in the power supply as the production was unable to meet demand. In order to meet the electricity demand, the model assumed the importation of electricity[112] from near-by countries in the value of 56 PJ. The Sankey diagram also shows the interactions between the production and demand of other energy fuels in the Nigerian energy system. It is important to note that in this scenario, the production of a type of fuel that is not utilized in the domestic market or has no or less demand, is exported to foreign markets. This can be seen in some fuels such as diesel (62.6 PJ) which have less demand, residual fuel oil (97.1), LPG (60.6 PJ), lubricants (108.4 PJ), Avgas and CNG (108.4 PJ)[113].

[112] In the real world situation, Nigeria does not import electricity from any neighboring country. However, in the Nigerian Model, the import can be seen as off-grid electricity production as clearly stipulated in Appendix A1 and Figure 4-3 of Chapter 4.

[113] It is also important to note that these fuels (except CNG) are actually in demand and used in

The chart showing the energy balance with provision for secondary energy requirements, indigenous production, secondary production and unmet requirement is presented in Figure 5-7. This chart was developed in order to further explore the Nigerian energy situation in 2010, as it could not be fully described in Figure 5-6 and Appendix H1. From Figure 5-7, it can observed that in 2010, the demand for biomass was met through indigenous production and this amounted to 312 PJ. Imports had a considerable impact in meeting demand for kerosene and to extent, gasoline in the base year under the REF scenario.

Figure 5-7: Nigeria's energy balance in 2010[114] (REF Scenario)



Nigeria today, but due to the energy demand data for the various sectors (e.g. air transport for Avgas), this fuels were assumed to be exported in the base year.

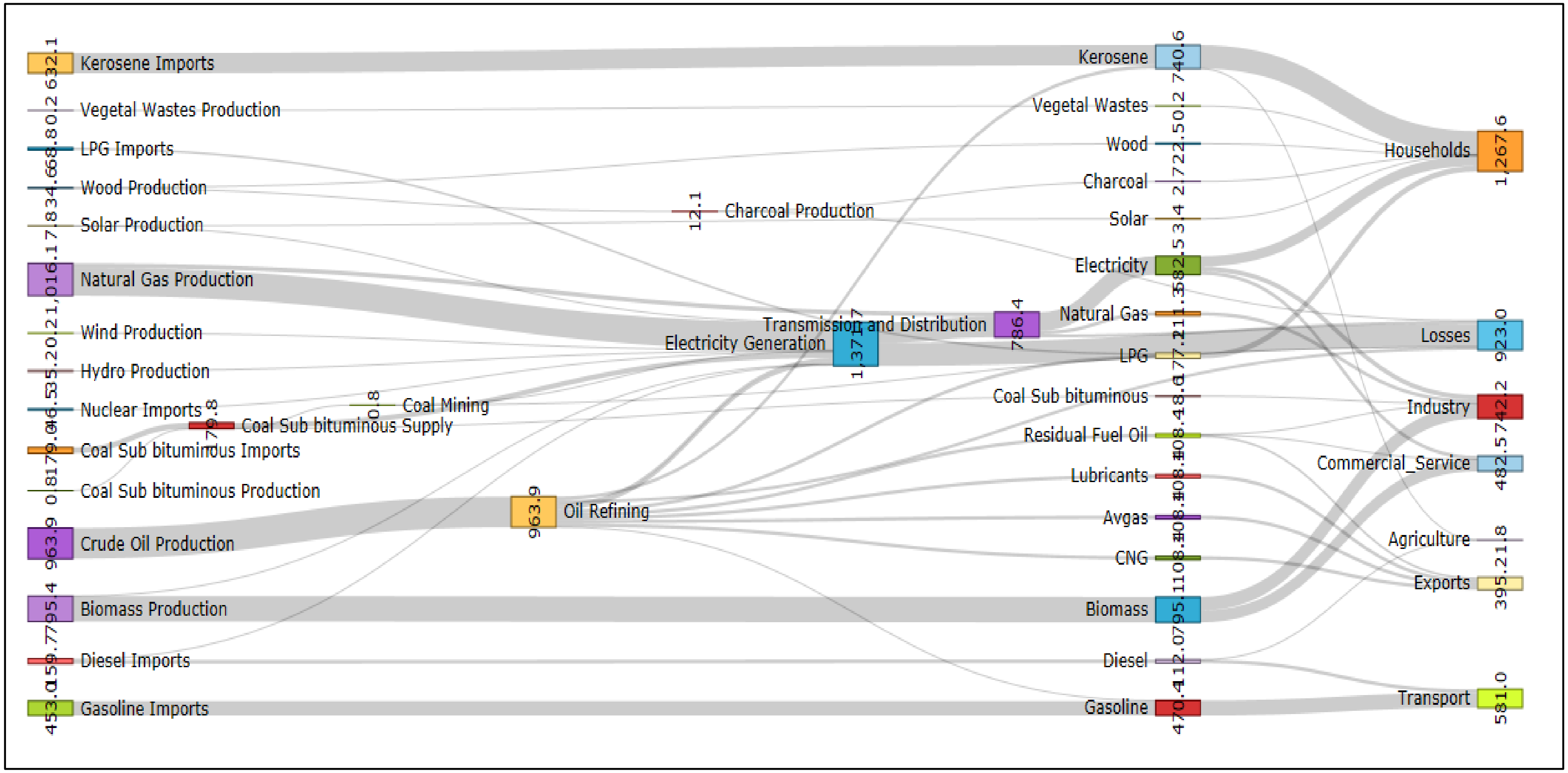
[114] Order of fuels; CNG, Avgas, Biomass, Lubricant, Hydro, Solar, Vegetal waste, charcoal, wood, coal sub bituminous, Crude oil, LPG, Residual fuel oil, Diesel, Kerosene, Gasoline, Natural gas, Electricity.

By 2040 under the REF scenario, the Nigerian energy balance is expected to change, considering the fact that all sectors of the economy will experience growth increase, while the power sector will also have some improvement in the electricity mix. This is shown in Figure 5-8 and presented in Appendix H2. By 2040, Nigeria is expected to generate an energy equivalent of 582.5 PJ, which will be able to meet the demand in the households (321.4 PJ), industry (148.4 PJ) and commercial/service sector (112.7 PJ). The increase in fossil fuel power plants that utilize natural gas e.g. SCGT, CCGT, gas turbine), will use 876.9 PJ of natural gas produced by 2040 for power generation, while 27.8 PJ will be lost due to T&D.

Gasoline, kerosene, diesel, LPG will be imported in a higher value than in 2010, to account for the increase in the households, transport and industry. In general, the total primary energy supply under the REF scenario is 3,998 PJ in which 923 PJ is lost due to T&D, leaving about 3,075 PJ for the supply to the various sector in Nigeria. The construction of the coal steam power plants with the installed capacity of 13,000 MW by 2040 is expected to use about 161.1 PJ of the 179 PJ imported sub bituminous coal[115]. Renewables such as wind (0.2 PJ) and solar (7.8 PJ) will be used to power the solar and wind power plants in Nigeria.

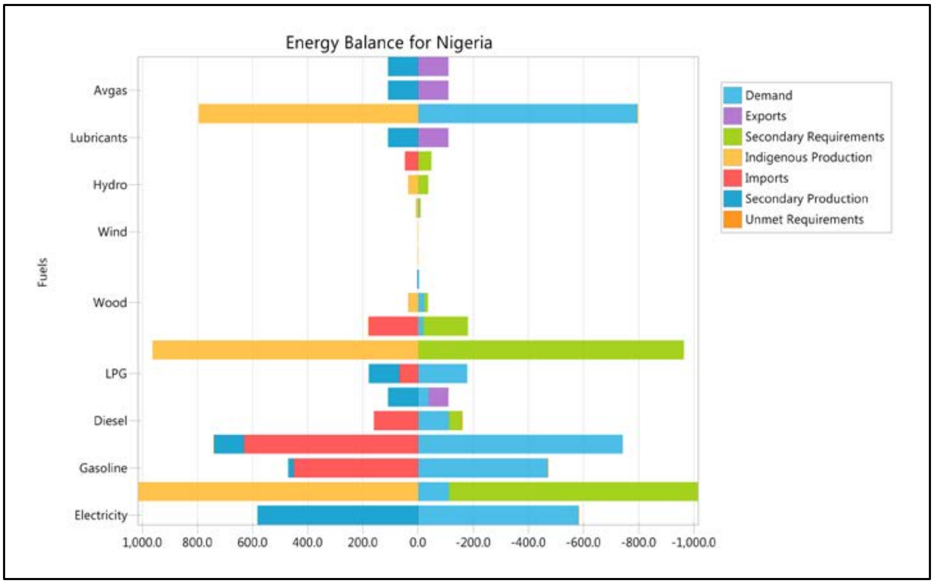
[115] In this case, the model assumes that the current state of coal mining in Nigeria will not improve due to the Nigerian government policies that have not considered the development of the coal mining sector that has been long dead on its feet since the 1960s.

Figure 5-8: Sankey Diagram of Nigeria’s Energy Balance in 2040 (REF Scenario)



The Nigerian energy balance for 2040 is graphically represented in Figure 5-9. Is shows that the demand for nuclear energy supply will be meet through importation, and this will be for the 4000 MW capacity nuclear power plants which is expected to utilize about 46.5 PJ of nuclear fuel[116]. Gasoline energy demand will be supplied mainly from imports (453 PJ), while secondary production will account for 108.4 and off-grid gasoline generators will use 91.1 PJ of it.

Figure 5-9: Nigeria's energy balance in 2040[117] (REF Scenario)



[116] In this case, the nuclear fuel imported will be uranium. It's important to note that Nigeria has a considerable amount of uranium deposits in Cross River State, Adamawa State, Taraba State, Plateau State, Bauchi State and Kano State as recorded by the British Geological Survey (WISE Uranium Project, 2015).

[117] Order of fuels; CNG, Avgas, Biomass, Lubricant, Nuclear, Hydro, Solar, Wind, Vegetal waste, charcoal, wood, coal sub bituminous, Crude oil, LPG, Residual fuel oil, Diesel, Kerosene, Gasoline, Natural gas, Electricity.

LPG use is expected to increase in the household sector as more people use LPG for cooking and this will require the importation of additional 68.8 PJ of LPG to compliment the 108.4 PJ produced domestically. An alarming increase in kerosene use will also require the importation of 632.1 PJ to the domestically produced product, so as to meet the demand in the households (740.2 PJ) and agriculture (0.4 PJ) sector by 2040. Diesel will mainly be imported by 2040 to meet both the demand such as transport (110.5 PJ) and agriculture (1.4 PJ), and secondary requirement such as for power generation (156.1 PJ).

5.1.2 The Low Carbon Moderate Scenario (LCM)

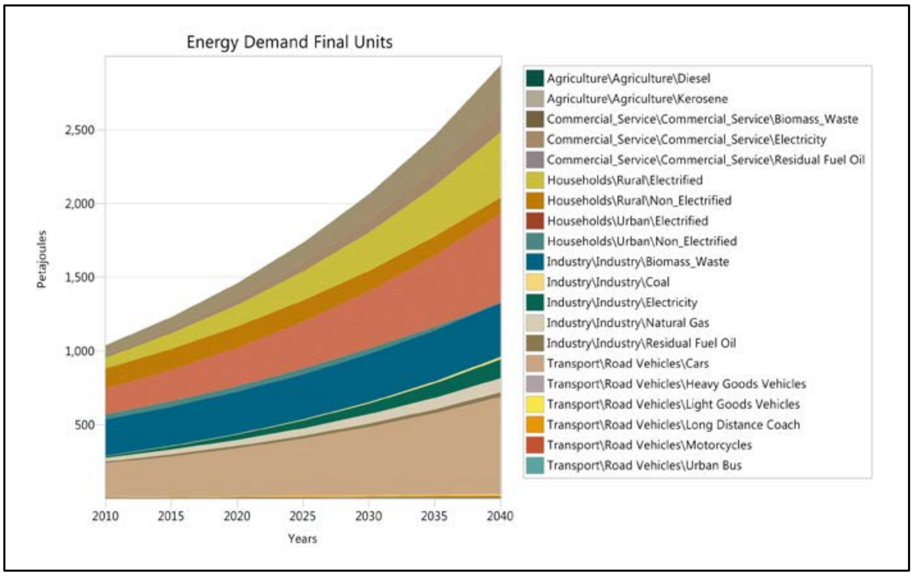
This scenario is driven by cheaper capital, cost and readily available fuels to improve power supply, and moderately reduce energy demand is the sectors analyzed. The results are presented as follows.

5.1.2.1 Future Energy Demand and Supply (LCM)

5.1.2.1.1 Future Energy Demand by Sector (LCM)

The quest to moderately reduce energy demand, while considering cheaper capital investment on various energy technology and policies, lead to the development of the LCM scenario. The results are shown in Figure 5-10 and presented in Appendix C2. The results shows that the total energy demand in this scenario was 2,940.5 PJ as against the REF scenario's energy demand of 3,075 PJ. The household sector energy demand by 2040 was 1,157.4 PJ, which shows the reduction from the REF scenario. The non-electrified urban households were completely connected to the national grid by 2040, while little changes in the rural households were observed. However, the changes in the households energy demand is also in line with the scenario specifications in Table 4-1 and 4-2 in Chapter 4.

Figure 5-10: LCM scenario energy consumption



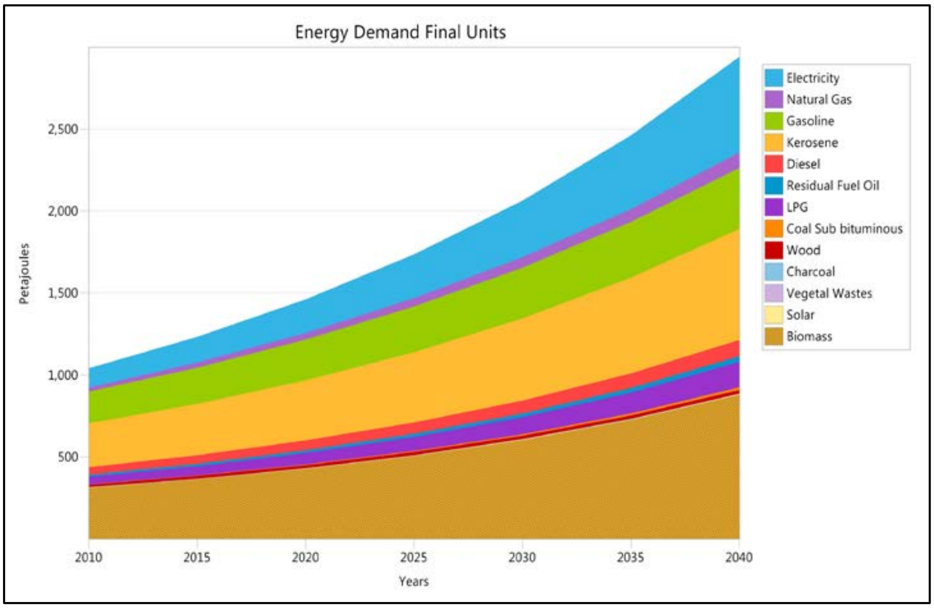
The industry also experienced a reduction in energy demand from 742.2 PJ in the REF scenario to 638.6 PJ in the LCM scenario. The only policy observed for the industry sector in this scenario was the general introduction of CFL bulbs for lighting which covers both the households, commercial/services and industry sector. This is observed to have an impact in terms of reduction in electricity demand from 148.4 PJ in the REF scenario to 127.7 PJ in the LCM scenario. In the commercial sector, the CFL bulbs introduced was expected to reduce electricity demand but due to the impact of economic activity (e.g. GDP) may have contributed to the increase in electricity demand. This may also be the same for the industry sector which is expected to grow at 7.1 % by 2040, while commercial/services sector grows at 13.3 %. The agriculture sector however, followed the status quo of in the REF scenario, and this is due to the low energy demand of the sector, lack of mechanized farming that will increase energy consumption from 2010 to 2040.

The total energy demand in the transport sector was 688.3 PJ, which is higher than the REF scenario (581 PJ). It should be taken into account that an increase in income and population was taken into consideration in the LCM scenario, which means more people will buy more cars as income increases and population size increases. The noticeable increase in energy demand in the transport sector was observed in the cars with about 658.9 PJ in 2040 as against the energy demand of 557.2 PJ in the REF scenario. The introduction of biofuels in the transportation fuel mix (see Appendix A2) is bound to increase energy demand but may reduce GHG emission as will later be discussed in subsequent sections.

5.1.2.1.2 Future Energy supply (LCM)

The total energy supply (2,940.5 PJ) under the LCM scenario was lower than the REF scenario and these saw a shift in the fuel mix. This is shown in Figure 5-11 and presented in Appendix D3. Natural gas supply in the LCM scenario was reduced to 95.8 PJ as against the value in the REF scenario (111.3 PJ), while domestic fuels which are usually in high demand (e.g. kerosene and gasoline) had a reduction in demand. The reduction in gasoline (371.6 PJ) in the LCM scenario was due to the fuel switching in the transportation sector. However, the increased capacity of gasoline generators (14,000 MW) for off-grid electricity production did not cause an increase in gasoline fuel demand. This was also observed in the case of diesel, with its demand accounting for 99.1 PJ in 2040 as compared to the higher demand in the REF scenario (i.e.112 PJ). The increase in the demand for biofuels is expected to increase the demand for biomass from 312 PJ in the 2010, to 880.1 PJ by 2040, which is higher than the REF scenario.

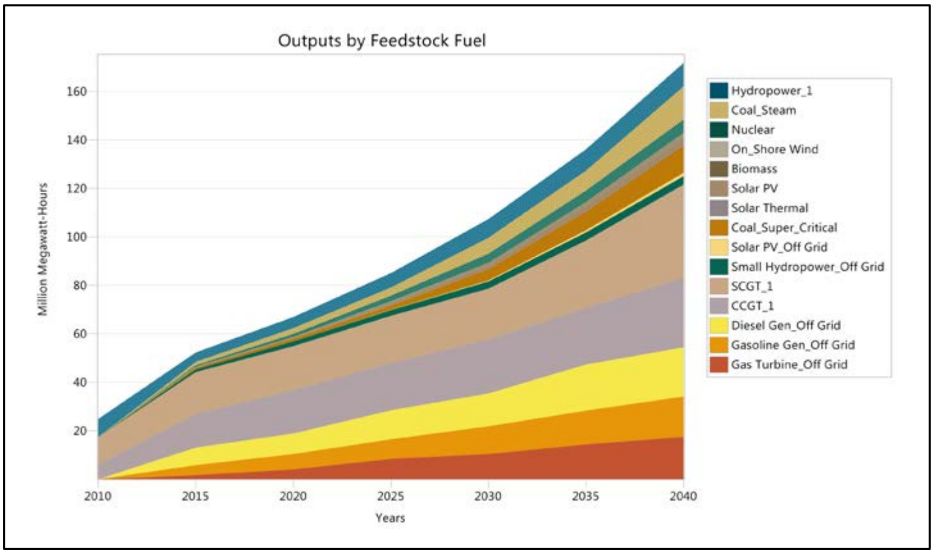
Figure 5-11: LCM scenario energy supply



5.1.2.2 Future Electricity Supply (LCM)

The installed capacity of 170,500 MW by 2040 under the LCM scenario is expected to generate about 171,800 MWh, and this is shown in Figure 5-12 and presented in Appendix E2. The bulk of electricity generation is expected to come from SCGT power plants (38,300 MWh) which make up about 31% of the total on-grid electricity power plants (see Appendix A4). CCGT power plants is expected to generate 28,900 MWh by 2040 from its installed capacity of 25,000 MW. The nuclear power plant capacity was increased from 4,000 MW in the REF scenario, to 5,000 MW in the LCM scenario and this will ensure the generation of 5,500 MWh of electricity by 2040 as against the 4,600 MWh generated from nuclear power in the REF scenario.

Figure 5-12: LCM scenario electricity supply



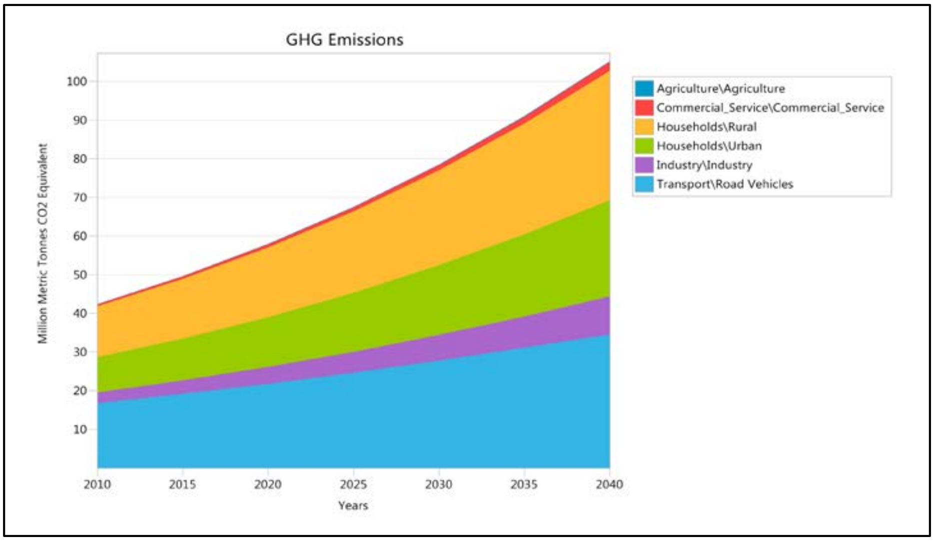
Coal supercritical power plant with an installed capacity of 11,000 MW by 2040 will generate about 11,400 MWh of electricity. Coal supercritical is by far, more efficient and emits less GHGs as compared to the coal steam power plants. However, this scenario takes into consideration, cheaper cost of energy technologies for the Nigerian power sector until 2040. The presence of renewables is low as compared to fossil fuel energy technologies. There was a little observable increase in electricity generation from hydropower (9,700 MWh). Small hydropower on the other hand, is expected to contribute about 3,500 MWh of electricity to off-grid areas in Nigeria by 2040 and will aid in the improvement of electricity access in Nigeria. Solar PV is expected to contribute to both on-grid and off-grid areas in Nigeria, with effect from 2020. On-grid electricity supply from solar PV in the on-grid areas will be 2,700 MWh, while off-grid areas will receive about 1,300 MWh of electricity from solar PV systems in off-grid areas. The LCM scenario also considered the increased expansion of off-grid fossil fuel plants such as diesel, gasoline and gas turbine plants to generate about 20,200 MWh, 16,700 MWh, and 17,500 MWh respectively.

5.1.2.3 GHG Emission (LCM)

Although the main motive behind the development of the LCM scenario was to increase energy supply through the use of cheaper energy technologies, while moderately improving on energy efficiency, a moderately reduce GHGs was also considered. The total GHGs emission observed in the

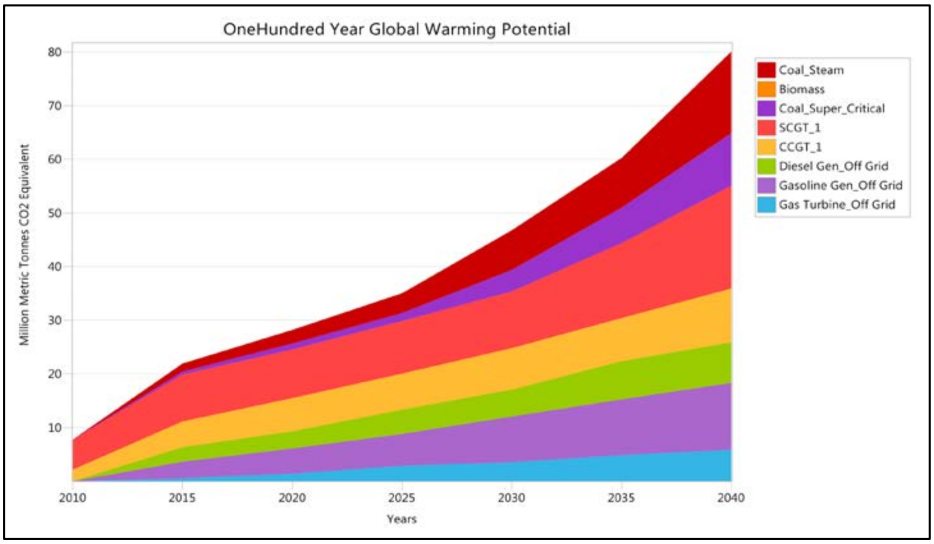
LCM scenario was 105.2 MMTCDE by 2040 as shown in Figure 5-13 and presented in Appendix G2. In this scenario, the households sector had a reduced GHGs from energy consumption from 64.1 MMTCDE in the REF scenario, to 58.4 MMTCDE by 2040 in the LCM scenario. The industry sector had a GHGs amount of 9.9 MMTCDE in 2040, from 2.8 MMTCDE it had in 2010. The Transport and commercial/services sector had a lower GHG emission rate of 2.3 and 0.1 MMTCDE in 2040 respectively. These value are lower than the REF scenario, except for the agriculture sector which holds similar situation as the REF scenario. The transport sector which saw the inclusion of biofuels in the fuel mix, with an intension to reduce GHG emission, achieved a reduction to about 34.5 MMTCDE by 2040. This reduction is by far, a boost to the transportation sector, as it provides a cleaner fuel and made provisions for fuel options.

Figure 5-13: LCM scenario GHG emission from energy demand



The GHGs from Electricity generation on the other hand (Figure 5-14 and Appendix G6), had the total emission of 80.1 MMTCDE by 2040 from its 2010 values of 7.8 MMTCDE. The reduced capacity of the SCGT plants in the LCM scenario as compared to the REF scenario, led to the reduction in its GHGs to 19.2 MMTCDE. However, this still contribute the most in GHG emissions when comparing the GHGs of other fossil fuel power plants in the electricity mix.

Figure 5-14: LCM scenario GHG emission from electricity generation



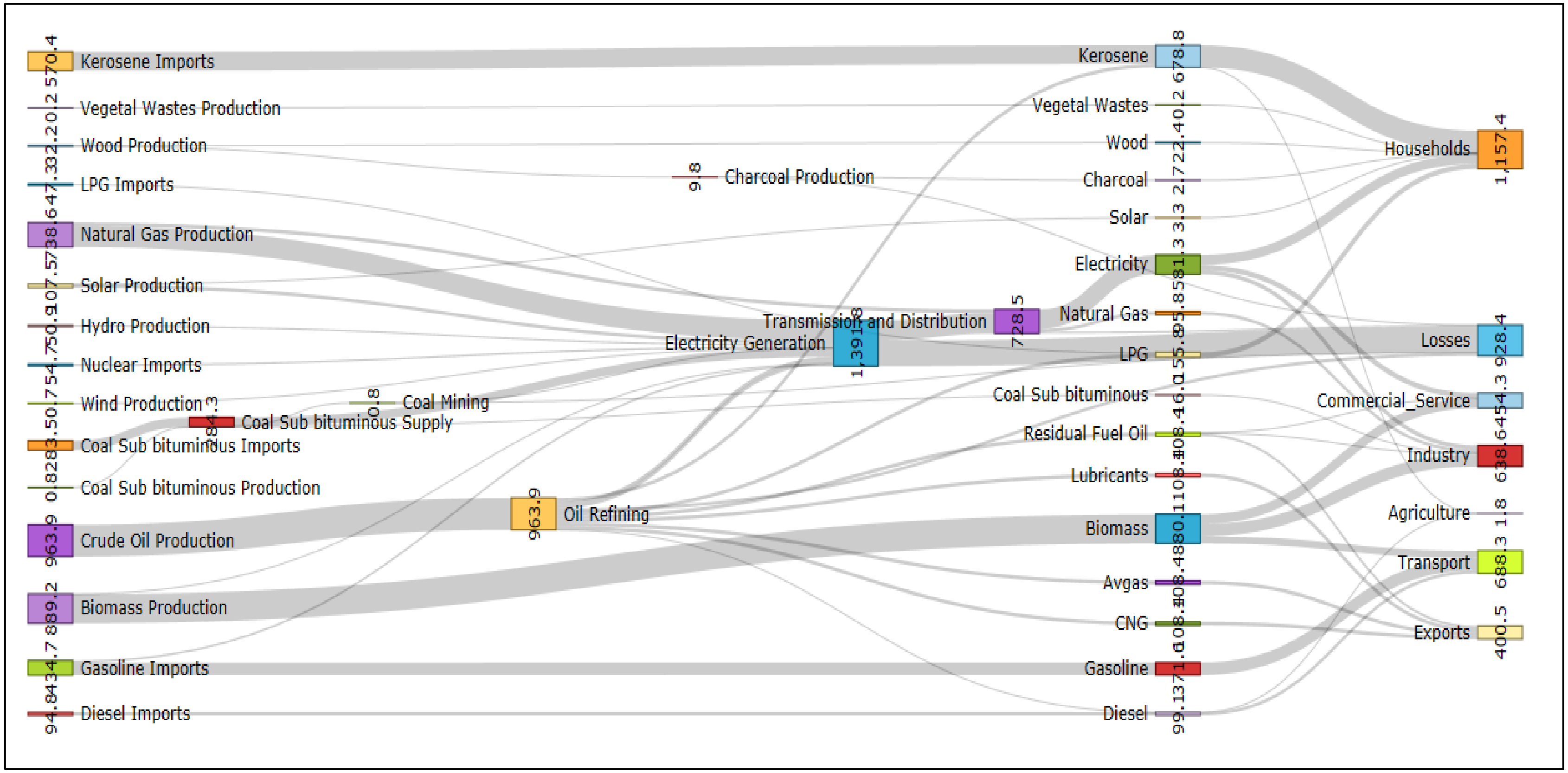
Diesel generators for off-grid electricity production contributed less amount of GHGs when compared to its counterpart energy technology, gasoline generators. The installed capacity of diesel for off-grid was 17,000 MW (about 30% share of off-grid), while gasoline generators was 14,000 MW (about 24% share of off-grid) and in comparison, diesel emitted less GHGs than gasoline generators. Coal supercritical and coal stem under the LCM scenario emitted 15.2 and 9.8 MMTCDE in 2040. This however, may be termed as a high amount of GHGs from power generation, but the concept of cheaper energy technology and available fuels needs to be taken into considerations in this scenario.

5.1.2.4 Energy Balance (LCM)

Under the LCM scenario, Nigeria’s energy balance differs from the REF scenario and this is shown using a Sankey diagram in Figure 5-15 and presented in Appendix H3. According to the diagram, Nigeria’s total primary energy supply by 2040 is expected to amount to 3,868.9 PJ. The increased capacity of power plants under this scenario eliminated the need for importation of electricity, since the production of 618.4 PJ of electricity is able to meet sectorial electricity demand (i.e. households, industry, commercial/services).

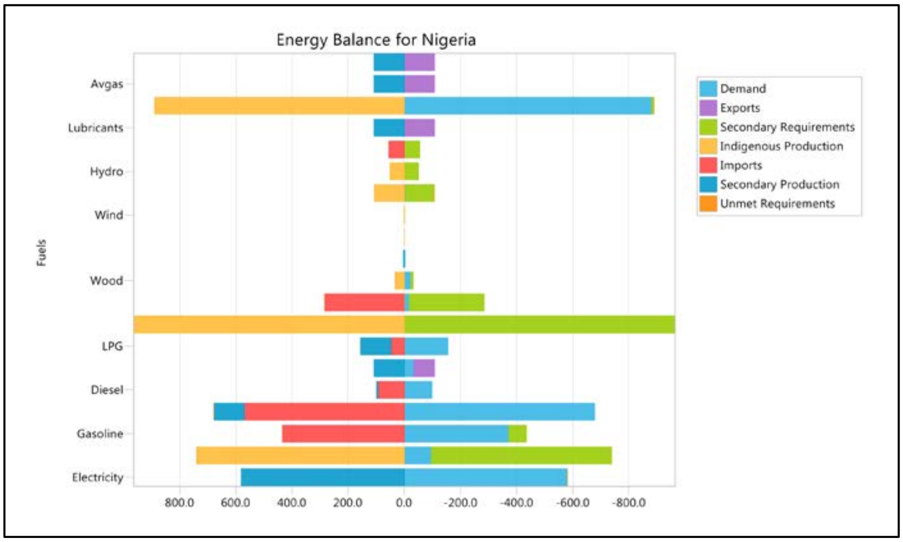
Natural gas import by 2040 under the LCM scenario will not be required because its domestic production of 738.6 PJ is enough to meet power plants (628.5 PJ) and industry sector (95.8 PJ) demand. Unlike natural gas, petroleum products such as gasoline, kerosene, diesel and LPG will continue to be imported to meet domestic demand up to 2040. Wood production of 32.2 PJ will meet the domestic demand for charcoal production (9.8 PJ) and firewood (or fuel wood) demand of 22.4 PJ.

Figure 5-15: Sankey Diagram of Nigeria’s Energy Balance in 2040 (LCM Scenario)



As shown in the chart diagram of the energy balance in Figure 5-16, the increa se demand for LPG will require the importation of additional 47.3 PJ to compl iment the domestically produced 108.4 PJ to meet the demand of 155.8 PJ.

Figure 5-16: Nigeria's Energy Balance in 2040[118] (LCM Scenario)



Biomass produced from indigenous source[119] of about 795.4 will in essence meet the domestic demand of 426.8 PJ for the industry and 368.4 PJ for the commercial/services, while about 0.3 PJ will be consumed by the biomass power plants[120] in 2040. Wood in this scenario will be used to meet households demand (firewood) and for charcoal production, since there is an

[118] Order of fuels; CNG, Avgas, Biomass, Lubricant, Nuclear, Hydro, Solar, Wind, Vegetal waste, charcoal, wood, coal sub bituminous, Crude oil, LPG, Residual fuel oil, Diesel, Kerosene, Gasoline, Natural gas, Electricity.

[119] It's important to note that biomass production differs from wood and charcoal production, because when we say "wood", we mean the firewood for domestic consumption and this is different from biomass used for electricity generation and industrial or commercial/services consumption.

[120] This according is also shown in Figure 5-16 as the secondary requirement.

improvement in type of kilns used for charcoal production[121]. Other fuels such as CNG, Avgas and lubricants are exported to the international markets since there were no domestic requirements[122] for the fuels.

5.1.3 The Low Carbon Advance Scenario (LCA)

The motivation for the development of this scenario is the will to move Nigeria towards a cleaner fossil fuel economy and aggressively reduce energy demand through policies and strategy. The results are presented as follows.

5.1.3.1 Future Energy Demand and Supply (LCA)

5.1.3.1.1 Future Energy Demand by Sector (LCA)

This scenario presents a much lower energy demand rate as compared to the last two scenarios (i.e. REF and LCM). The total energy demand under the LCA scenario for the year 2040 is 2,488.3 PJ and this by far recorded a reduced energy demand in energy intensive sectors. Household's sector energy demand was 948.3 PJ in which the urban households accounted for 403.6 PJ, while the rural household's energy demand was 544.7 PJ. As in the case of the LCM scenario, the non-electrified urban households are assumed to be totally connected to the grid by 2040, while electricity access is improved in the rural areas.

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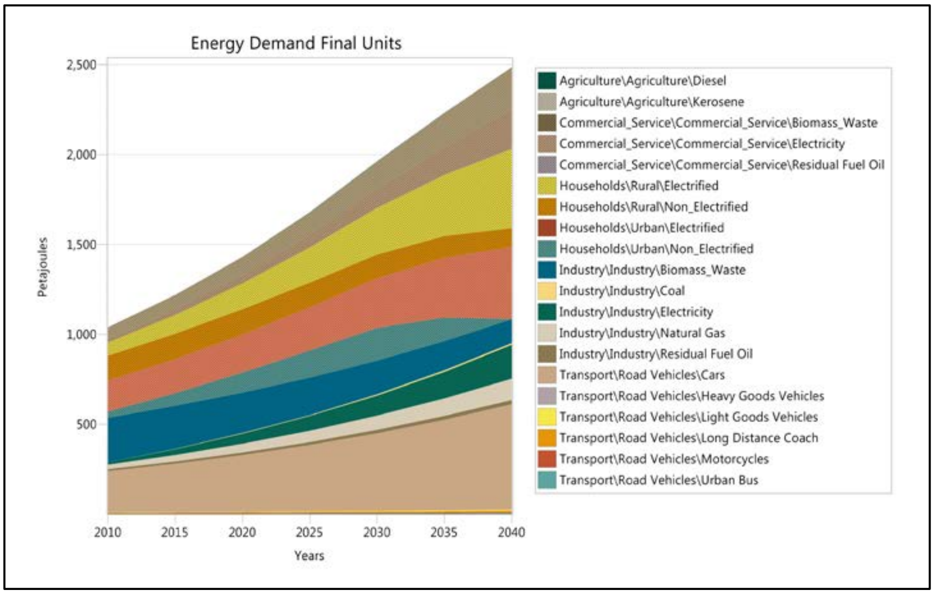
[121] Please refer to Appendix A3 to see the type of Kilns used in the LCM scenario.
[122] The LCM scenario did not assume the use of these fuels in the development of the Nigeria LEAP model. However, these fuels are actually in high demand in Nigeria (except for CNG), but due to lack of available data for the consumption of the fuels, this scenario did not consider the fuels in the energy mix. In other scenarios, the CNG will considered in the energy mix.

The energy demand in the industry sector saw a reduction of about 471.6 PJ by 2040, which was an improvement compared to the LCM and REF scenario. Out of this reduction, biomass/waste demand was 132.1 PJ, natural gas was 117.9 PJ, residual fuel oil 23.6 PJ, coal was 9.4 PJ and electricity which was converted to energy unit had an energy demand of 188.7 PJ. A similar situation is observed in the commercial/ service sector which had an energy demand of 454.3 PJ. The energy demand in this sector was mostly for biomass/waste (234.9 PJ) and electricity (216.7 PJ), while a much lower requirement of 2.7 PJ came from residual fuel oil. The results of the energy demand under the LCA scenario is shown in Figure 5-17 and presented in Appendix C3.

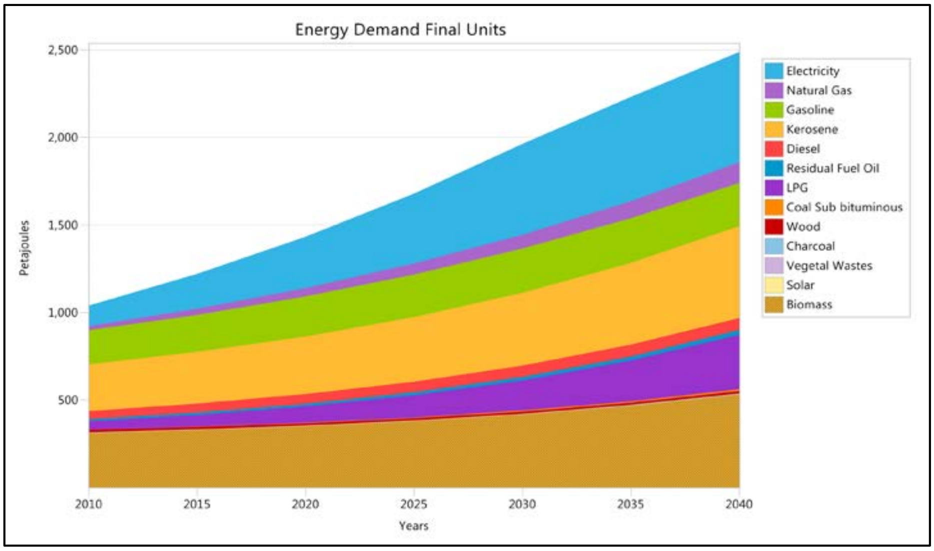
Figure 5-17: LCA scenario energy demand



5.1.3.1.2 Future Energy supply (LCA)

The required energy supply expected to meet the energy demand under the LCA scenario by 2040 is 2,249.2 PJ. This is shown in Figure 5-18 and Appendix D4. From the results, the most form of energy that will be supplied by 2040 will be electricity with about 689.1 PJ, followed by biomass and kerosene with 531.8 PJ and 525.5 PJ respectively. This scenario saw the increase in electricity supply and the reduction in kerosene and biomass as compared to previous scenarios (i.e. REF and LCM).

Figure 5-18: LCA scenario energy supply



Gasoline supply was reduced to 158.7 PJ as compared to the LCM scenario which had its supply of gasoline to the value of 246 PJ, while natural gas supply increased to 121.5 PJ from 95.8 PJ in the LCM scenario by 2040.

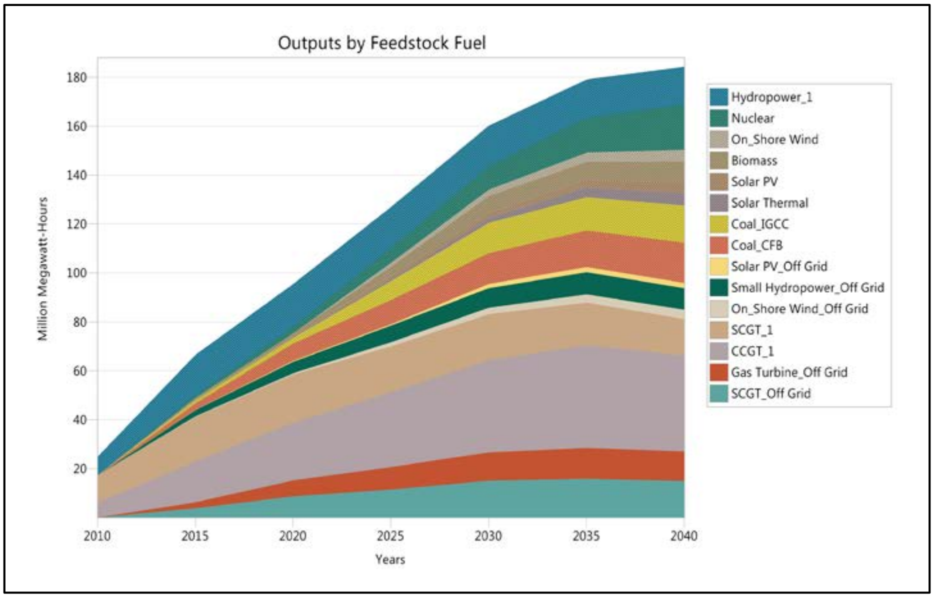
An increase in LPG fuel supply was observed to amount to 312.2 PJ and can be attributed to the introduction of LPG vehicles in the transport sector.

5.1.3.2 Future Electricity Supply (LCA)

In modelling the electricity supply under the LCA scenario, consideration was given to more efficient, low-carbon power plants such as CCGT, nuclear, coal IGCC and CFB power plants. The total electricity generated under this scenario amounted to 184,300 MWh from the installed capacity of 180,500 MW by 2040. In the electricity generation mix, CCGT accounts for 39,300 MWh of power generation from the installed capacity of 30,000 MW, while the less efficient SCGT plants for on-grid electricity supply will generate 14,900 MWh of electricity in 2040. Off-grid CCGT plants which had an increased capacity unlike the REF and LCM scenarios, will generate about 14,900 MWh which is the same generation capacity as the on-grid SCGT.

The introduction of coal IGCC and CFB technology with an installed capacity of 13,000 and 14,000 MW respectively, is expected to generate 15,200 and 16,400 MWh respectively from coal energy resources. The fuel for the IGCC and CFB power plants (i.e. sub bituminous coal) is expected to be sourced domestically, but this will depend of the future expansion plans for coal mining in Nigeria. Gas turbine power plants for off-grid electrification was expanded to 11,000 MW capacity to be capable in the generation of 12,100 MWh by 2040. This will be supported by the SCGT power plants for off-grid power generation, because of the retirement of the gasoline and diesel generators before 2015[123]. The results for electricity generation under the LCA scenario is shown in Figure 5-19 and presented in Appendix E3.

Figure 5-19: LCA scenario electricity supply



Renewables in the electricity mix include biomass with an increased electricity supply of 8,600 MWh and this is due to the increased installed capacity of 7,500 MW in 2040. Large hydropower electricity generation was modelled to generate 15,400 MWh in 2040, small hydropower which was installed for off-grid generation produced 8,800 MWh of electricity. The increased capacity of small hydropower was intended to support the gas and

[123] This is shown in Appendix A6, and the intension was due to the quest for cleaner energy technologies of the LCA scenario, as well as the assumption that natural gas will become readily available for natural gas power plants in both off-grid and on-grid areas.

SCGT turbine. Solar PV and thermal systems are expected to have an increasing capacity from 2015 to 2040, and this will contribute 4,200 MWh for solar PV and 5,200 MWh for solar thermal. The solar PV and thermal systems was intended to come in the form of solar farms, which will contribute a significant amount of electricity to the grid. On-shore wind power will also have an increased capacity to be able to generate 4,700 MWh of electricity from its installed capacity of 8,000 MW by 2040 for on-shore, and 3,900 MWh for off-shore from an installed capacity of 6,500 MW.

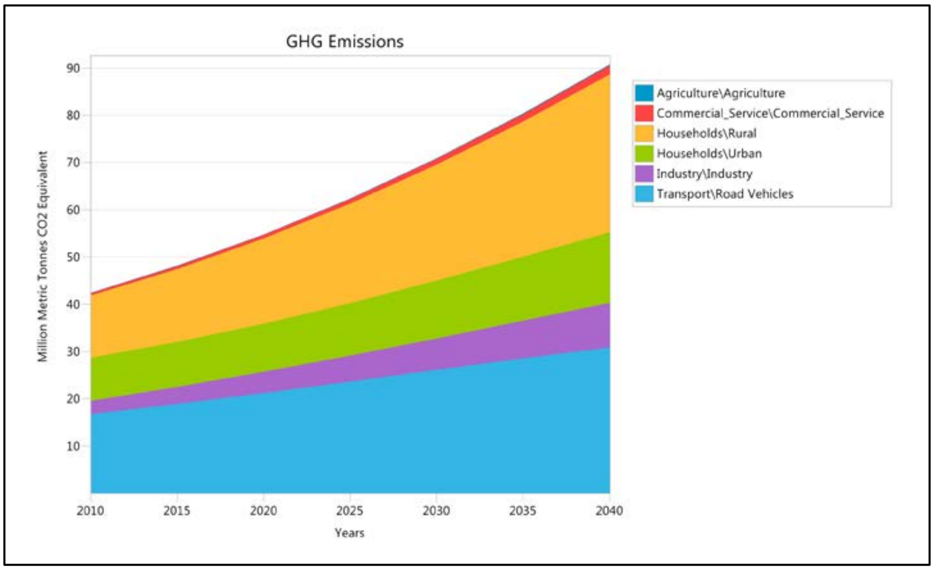
5.1.3.3 GHG Emission (LCA)

The aim of achieving a low-carbon society with cleaner fuels and efficiency practice in the LCA scenario led to the reduced total GHG emission of 90.8 MMTCDE by 2040. The household sector saw the most reduction in GHGs with 48.4 MMTCDE, in which the urban household emitted less GHGs as compared to the rural households. This is shown in Figure 5-20 and Appendix G3. The industry sector in this scenario emitted less GHGs of about 9.4 MMTCDE, as compared to the REF (11.5 MMTCDE) and LCM (9.9 MMTCDE) scenario.

The commercial/services sector had a reduced GHGs of 2.0 and 0.1 MMTCDE respectively in 2040. The reduction in GHG emission in the commercial/services sector was due to fuel switching whereby the energy demand for biomass was reduced, while electricity supply was increased. The last sector which is the transport sector saw a decrease in GHGs emission to

30.8 MMTCDE in 2040. The reduction was much lower, compared to the LCM (34.5 MMTCDE) and REF (40.7 MMTCDE) scenarios.

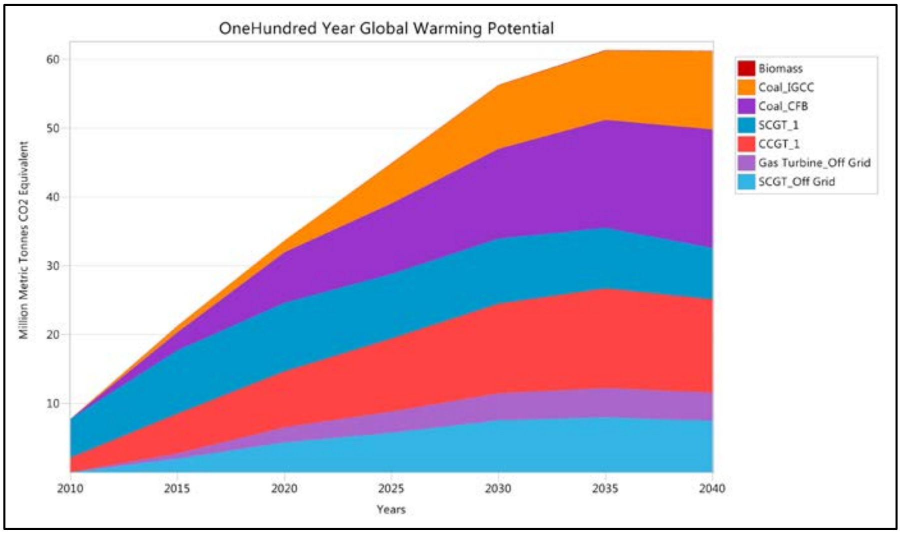
Figure 5-20: LCA scenario GHG emission from energy consumption



On electricity generation, the GHG emission increased from 7.8 MMTCDE in 2010, to 61.2 MMTCDE by 2040 and this can be observed to be very low when compared to the previous scenarios. The increased generating capacity of coal plants (IGCC and CFB) unlike the previous scenarios, led to the combined GHGs of 28.5 MMTCDE for both coal power plants. These results are shown in Figure 5-21 and presented in Appendix G7. The emission level recorded for SCGT plants for on-grid was 7.5 MMTCDE by 2040, and this was the same amount for the SCGT off-grid power plants. The gas turbine power plants for off-grid was observed to emit less GHGs of about 4.1

MMTCDE when compared to SCGT power plants. When the capacity are compared, it's about a 1000 MW difference between the two power plants[124].

Figure 5-21: LCA scenario GHG emission from electricity generation

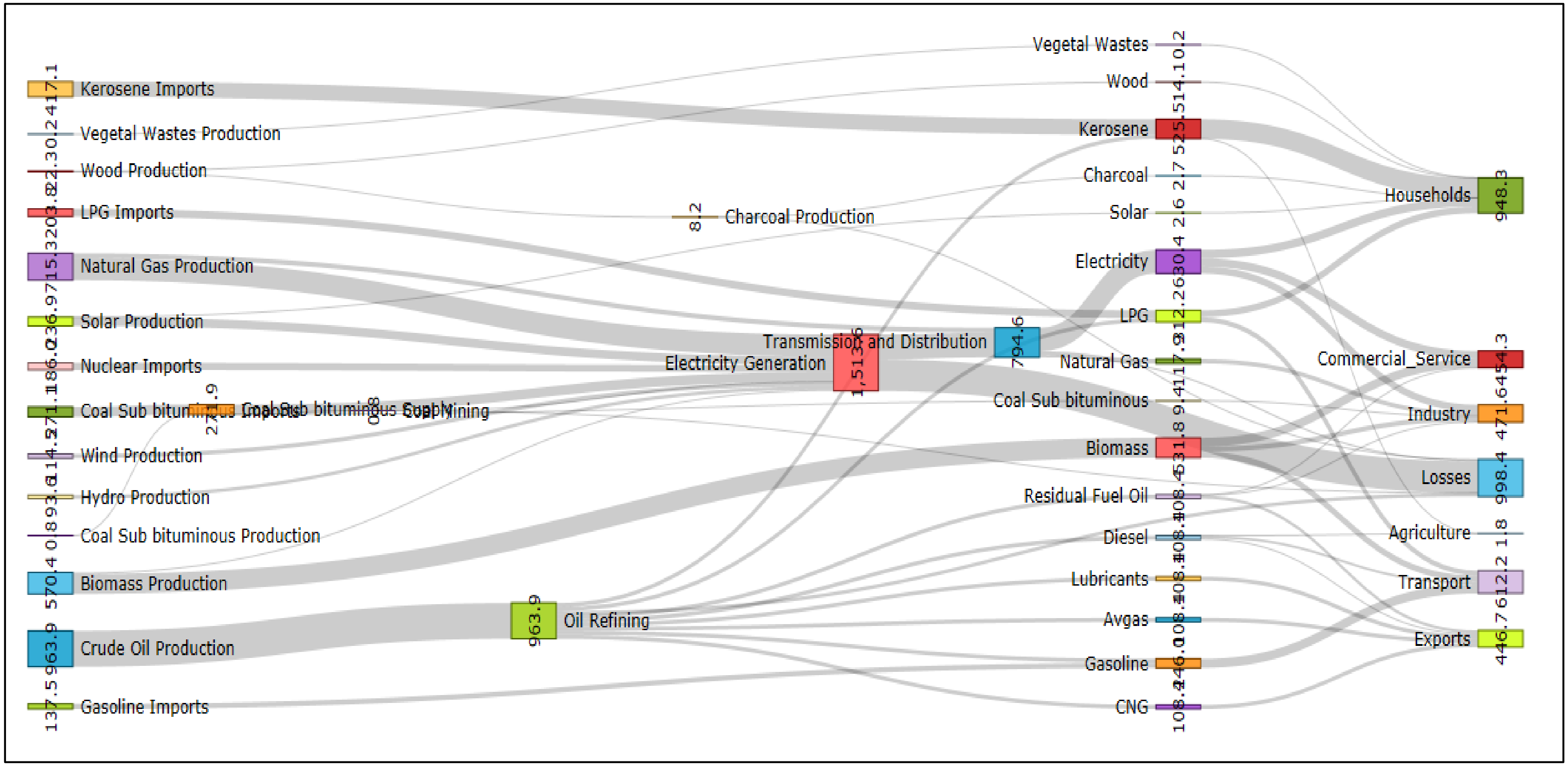


5.1.3.4 Energy Balance

The energy balance under the LCA scenario is bound to differ from the previous scenarios and this is shown in Figure 5-22 and presented in Appendix H4. The total primary energy supply under this scenario is 3,486.7 PJ and this was at a reduced level unlike the LCM and REF scenarios.

[124] This situation can be observed in Appendix A6, where the installed capacity for the off-grid SCGT was 12,000 MW, while the off-grid gas turbine was 11,000MW. One would expect a close GHGs or even a less GHGs from the SCGT power plant. This will however, be explained in the discussion section of this Chapter.

Figure 5-22: Sankey Diagram of Nigeria's energy balance in 2040 (LCA Scenario)



Electricity generation in this scenario in 2040 was 663.5 PJ and was enough to meet the sectorial electricity demand of 630.4 PJ, even after the T&D losses (i.e. 33.2 PJ). Although electricity demand for the households was 225 PJ which was lower than the LCM and REF scenarios households demand, the industry and commercial/services sector had higher demand. The increase in electricity demand in industry and commercial/services sectors is due to the fuel/energy switching[125]. Also, the reduced T&D electricity demand was due to the improvement in T&D losses which was reduced to 5% by 2040.

Natural gas produced from domestic refineries were sufficient to meet the demand for natural gas in the industry sector and for electricity generation, while losses due to T&D was 13.1 PJ. Since gasoline generators were retired before 2015 under this scenario, the demand for gasoline went to the transport sector alone and amounted to 246 PJ. This demand was however, sourced from both secondary production[126] and imports as can be observed in Figure 5-23.

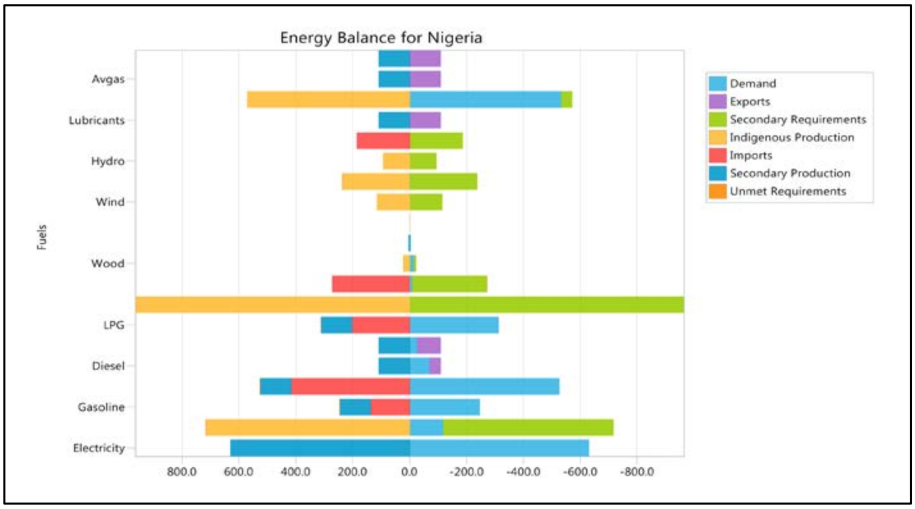
Kerosene also follow the same suit as gasoline with the importation of 417.1 PJ of kerosene to complement the domestic production of 108.4 PJ, which will be able to meet the demand of 525.5 PJ in the households and agriculture sector. The demand for diesel on the other hand, will be meet by productions from domestic oil refineries. This occur because the power sector

[125] In this case, the industries and commercial/service sectors used more electricity and less forms of other fuel/energy sources.

[126] This means productions from domestic refineries which was considered to have the base year capacity continue until 2040 with no expansion plans.

will be have its diesel plants retried as far back as 2015, while demand in the transport sector will shrink to 67.7 PJ as compared to previous scenarios. However, about 39.3 PJ of diesel will be exported to the international market since the fuel will be produced in excess[127].

Figure 5-23: Nigeria's energy balance in 2040[128] (LCA Scenario)



The increased use of LPG in the transport sector will increase its demand to 133.7 PJ by 2040, while 178.6 will be required to meet households demand for cooking and lighting. The demand for LPG will be meet through import (203.8 PJ) and secondary production of 108.4 PJ (see Figure 5-22 and 5-23). The coal mining capacity was insufficient to meet the demand for sub bituminous coal and as such, required the import of about 271.1 PJ to meet

[127] This however, may still be sold to private diesel operators and to the waterways transporters (ships and boats), or may be exported to neighboring countries.
[128] Order of fuels; CNG, Avgas, Biomass, Lubricant, Nuclear, Hydro, Solar, Wind, Vegetal waste, charcoal, wood, coal sub bituminous, Crude oil, LPG, Residual fuel oil, Diesel, Kerosene, Gasoline, Natural gas, Electricity.

both the secondary requirement for electricity generation (262.3 PJ) and industry demand of 9.4 PJ.

The increase in nuclear power plant capacity in the future (i.e. 2040) to 15,000 MW will require the importation of 186 PJ of nuclear fuel (uranium). Biomass produced from domestic sources will amount to 570.4 PJ which will meet biomass power plant demand of 38.6 PJ for its 7,500 MW installation. Other demand for biomass will come from industry with the demand of 132.1 PJ, while commercial/services will require 234.9 PJ to meet its energy demand. Biofuel which is produced from biomass will have an energy demand of 164.9 PJ in the transportation sector. In all, out of the total primary energy supply of 3,486.7 PJ in 2040, 2,488.3 PJ will be required to meet sectorial energy demand, while about 998.4 PJ will be required for the transformation sector.

5.1.4 The Green Optimistic Scenario (GO)

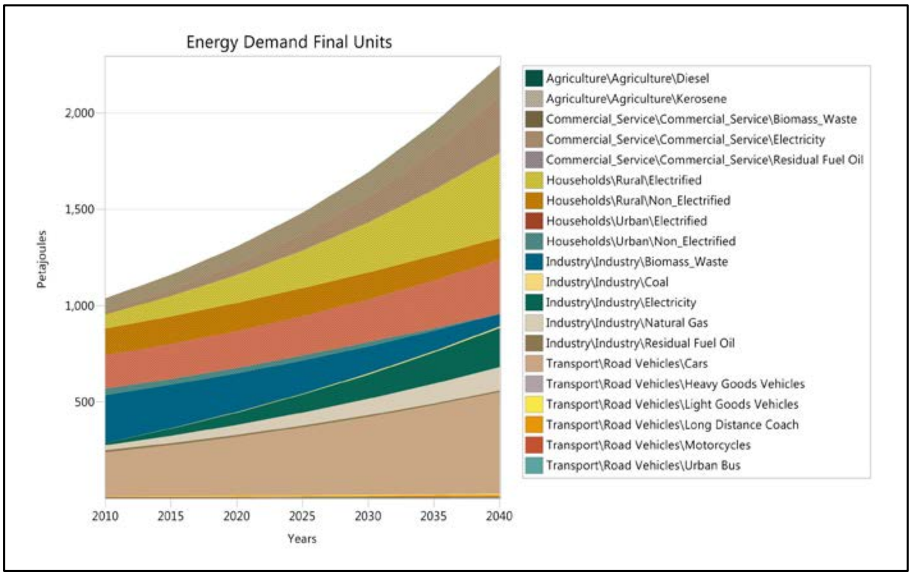
This scenario was developed in-view of Nigeria attaining a low-carbon-green growth economy which will contribute in the mitigation of climate change, reduce energy poverty and ensure energy sustainability. The results are presented as follows.

5.1.4.1 Future Energy Demand and Supply (GO)

5.1.4.1.1 Future Energy Demand by Sector (GO)

The total energy demand under the GO scenario was observed to be 2,249.2 PJ which account for the lowest energy demand among the four scenarios proposed in this thesis. The most energy demand among the five sectors was the households sector with 836 PJ of energy demand by 2040. Out of this, the rural households had the largest share of energy demand with 552.8 PJ, while the urban household's energy demand was 283.1 PJ. The results is shown in Figure 5-24 and Appendix C4. From the results, it can be observed that rural energy demand increased in the GO scenario when compared to the previous scenarios. However, energy demand in the urban sector was reduce unlike the situation observed in the previous scenarios (these will be fully discussed in the discussion section).

Figure 5-24: GO scenario energy demand



The energy demand in the industry sector is expected to amount to 404.9 PJ by 2040 from its 2010 values of 297 PJ. This will observed to be a reduction as compared to the LCA, LCM and REF scenario. Along with the reduction in energy demand, biomass which had the highest fuel demand in the base year and in the REF and LCM scenario, was reduced to 64.8 PJ by 2040. Natural gas demand on the hand, gradually increased in its share of the fuel mix to 121.5 PJ from its 2010 value of 25.4 PJ. The demand for other fuels such as coal and residual fuel was observed to have a near value of 8.1 PJ each. This scenario assumes an increase in electricity demand in the industry sector due to the introduction of electric arc blast furnace[129].

The commercial/service sector had an increasing energy demand of 84 PJ in 2010, 147.4 PJ in 2020, 258.8 PJ in 2030, and 454.3 PJ in 2040. These values are the same for the total energy demand for the LCM and LCA scenarios, but the difference observed was in the energy mix. The difference was observed in the increased share of electricity demand which was 289.4 PJ by 2040. The energy demand for the agriculture sector was the same as the previous scenarios. In the transport sector, considerable reduction in energy demand was observed and the total energy demand for the sector was 552.2 PJ in 2040.

The demand for energy by motorcycles which is used for both private and commercial transport option was 5.6 PJ, while cars was 528.4 PJ in 2040. It should be taken into account that besides the inclusion of various fuels types

[129] This was fully discussed in the scenario development section (GO scenario) in Chapter 4.

to create fuel options, the energy demand was still low as compared to other scenarios. Light goods vehicle and heavy goods vehicles had their demand for energy increase from their 2010 values, to 5.1 PJ and 0.9 PJ respectively in 2040. Energy demand for urban bus and long distance coach was 4.2 PJ and 8 PJ respectively.

5.1.4.1.2 Future Energy supply (GO)

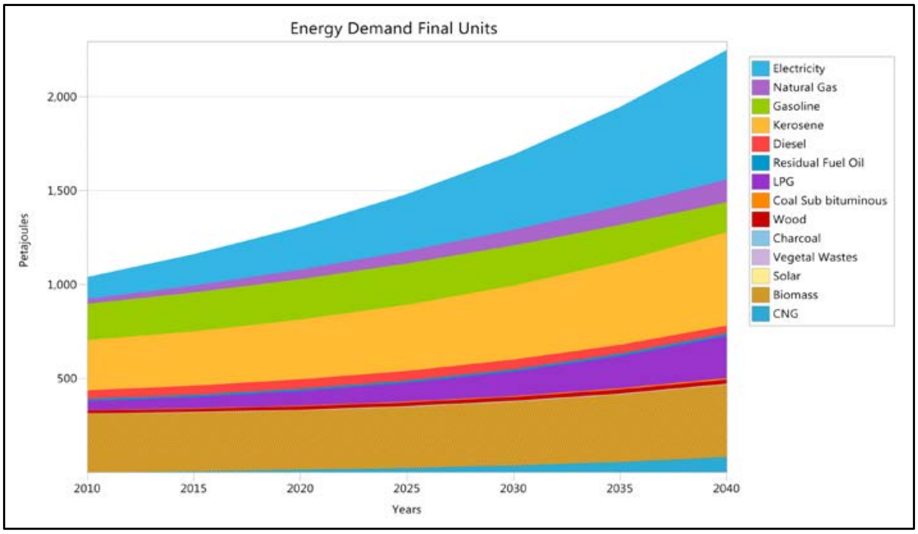
The energy supply by fuel required to meet the energy demand in the sectors analyzed under the GO scenario is shown in Figure 5-25 and presented in Appendix D5. The total energy supplied by 2040 is 2,249.2 PJ by 2040 and the energy with the largest share was electricity with a supply rate of 689.1 PJ by 2040. This was an increased when compared to the LCA (630.4 PJ), LCM (581.3 PJ), and REF (582.5 PJ) scenarios. Natural gas was observed to have an increased value of 121.5 PJ in 2040, and these is due to the increased use in the transformation sector. The reduction in the share of gasoline vehicles and the retirement of gasoline power plants before 2015, ensured the reduction in its supply to 158.7 PJ in 2040, from its 2010 value of 193.8 PJ.

Kerosene supply in the GO scenario was 499.4 PJ by 2040, and this was observed to be the lowest supply value when compared to previous scenarios. The supply for diesel was on the decline from 2010 to 2040, and this was observed to occur between the years 2030-2035[130]. As the demand

[130] This coincides with the reduction in diesel cars around that same period as alternative fuels were introduced in to the transportation sector.

for LPG grew due to its increased use in the transport and household sector, so did the supply rate increased to about 223.3 PJ by 2040. Wood supply increased from 15.4 PJ in 2010 to 22.2 PJ by 2040. Biomass supply slowly increased from 312 PJ in 2010 to 386.7 PJ in 2040, while CNG which was launched in 2015, had its supply increase to 80 PJ by 2040.

Figure 5-25: GO scenario energy supply

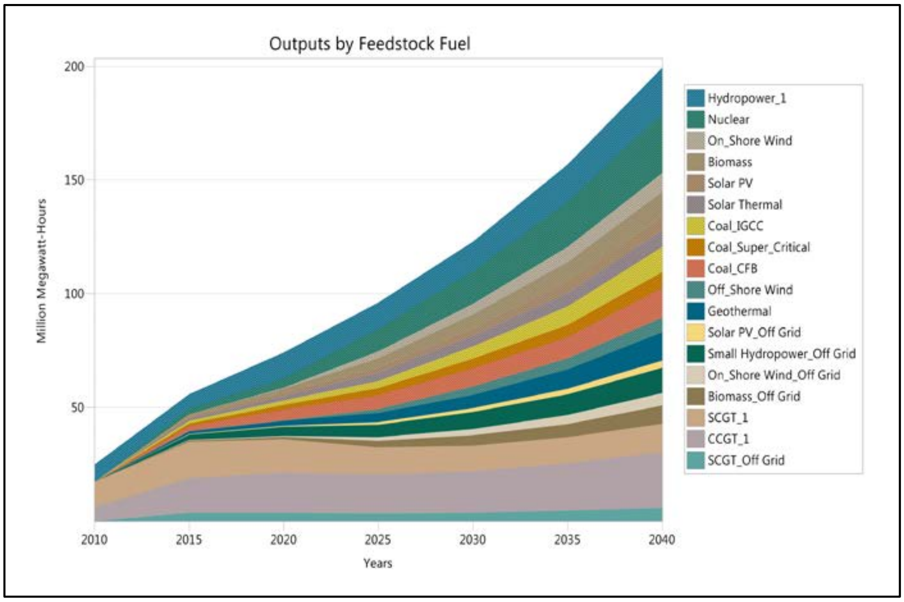


5.1.4.2 Future Electricity Supply (GO)

Considering the advancement to a low-carbon-green growth in Nigeria, the GO scenario presented an increased share of renewables in the electricity mix. With the total installed capacity of 180,000 MW, electricity generation by 2040 was 199,400 MWh. In the mix, large hydropower plants generated 20,100 MWh, from its installed capacity of 15,500 MW in 2040 and this contributes 11% of the on-grid electricity power plants. The installed capacity of small hydropower for off-grid electricity production was 8,000 MW and this generated 11,000 MWh.

The GO scenario assumes the retirement of all fossil fuel power plants for off-grid electricity generation, except the SCGT power plants which will generate 5,800 MWh of electricity. However, to complement the retried fossil fuel power plants, biomass was added to improve electricity supply with the production of 8,100 MWh. Biomass was also installed for on-grid electricity generation and this produced 10,700 MWh of electricity. The results electricity generation under the GO scenario is shown in Figure 5-26 and presented in Appendix E4.

Figure 5-26: GO Scenario Electricity Supply



In order to expand the share of renewables and also include those not currently installed in the base year and also considered in previous scenarios, geothermal and off-shore wind power was introduced into the mix. These energy technologies were introduced in 2015 with an installed capacity of 1,000 MW for geothermal and 100 for off-shore wind power. The geothermal power plant will have its capacity increased up to 2040 and will generate 12,400 MWh, while the off-shore wind power will generate about 6,600 MWh from its increased capacity of 9,000 MW by 2040.

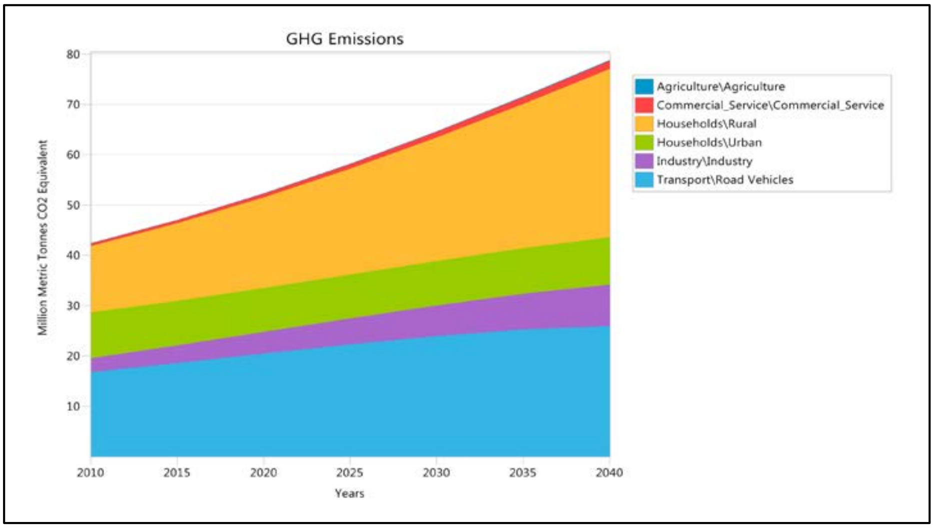
Solar PV systems which will be on a large scale farm had an installed capacity of 17,000 MW for on-grid and 9,000 MW for off-grid electricity generation. On-grid electricity generation from solar PV systems will be up to 6,100 MWh, while off-grid electricity generation will be 3,200 MWh by 2040. Nuclear power plants had an increased expansion of 18,000 MW by 2040 and this generated 26,200 MWh of electricity. This capacity is observed to be the largest installed capacity when compared to previous scenarios.

Meanwhile, the fossil fuel power plants in the GO scenario include gas and coal power plants. In a bid to invest in fossil fuel power plants with higher efficiency, CCGT power plants had an increase capacity when compared to SCGT power plants. Electricity generation from CCGT power plants amounted to 24,500 MWh, while 12,400 MWh was generated from SCGT plants. For coal power plants, a mixture of three energy technologies which include IGCC, super critical and CFB generated 11,000 MWh, 6,900 MWh and 13,100 MWh respectively by 2040.

5.1.4.3 GHG Emission (GO)

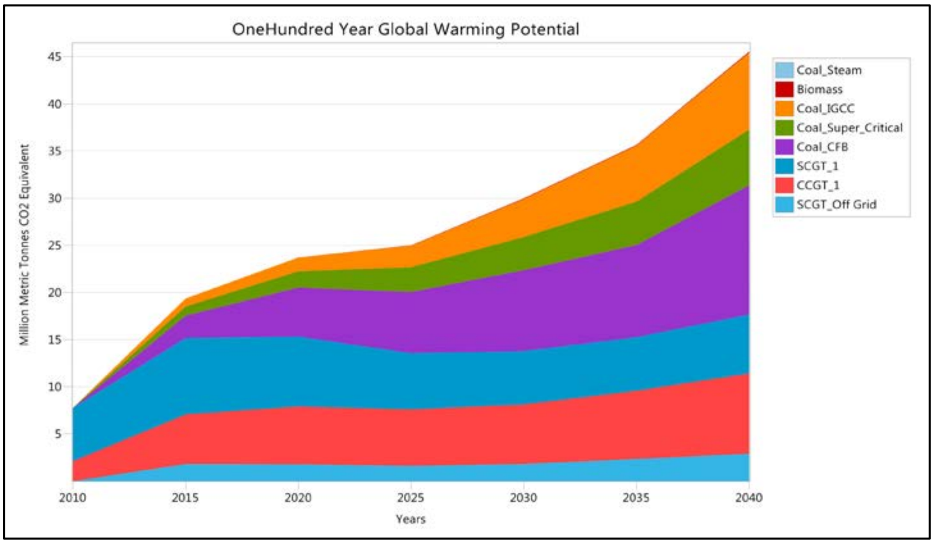
Considering the fact that the GO scenario much emphasis on the expansion of renewables in order to achieve a low-carbon-green growth, a much lower GHG emission is expected from this scenario. The total GHG emission for energy demand under this scenario was 78.9 MMTCDE in 2040, and this is by far the lowest among the four scenarios. The result is shown in Figure 5-27 and presented in Appendix G4. The households GHG emission was 42.9 MMTCDE, which was a reduction from the LCA (48.4 MMTCDE), LCM (58.4 MMTCDE) and REF (64.1 MMTCDE). The improvement in efficiency and fuel switching in the industry led to the decrease in GHGs from the sector to 8.3 MMTCDE by 2040. The commercial/service sector recorded a reduced about 1.6 MMTCDE by 2040, while the transport sector had a reduced GHG emission of about 26 MMTCDE.

Figure 5-27: GO Scenario GHG emission from energy consumption



The result for the GHG emission from electricity generation in the GO scenario is shown in Figure 5-28 and presented in Appendix G8. The fossil fuel power plants in the GO scenario emitted the total of 45.6 MMTCDE in 2040 from its 2010 emission rate of 7.8 MMTCDE. Much of these emission was from coal CFB power plants with an emission rate of 13.7 MMTCDE from its generation capacity of 9,500 MW.

Figure 5-28 GO scenario GHG emission from electricity generation



Coal IGCC power plants emitted 8.2 MMTCDE in 2040, and this was similar to the emission recorded from CCGT power plants of installed capacity of 16,000 MW. An observation from these two power plants (i.e. IGCC and CCGT) is that even with the large capacity of 16,000 MW for CCGT power plants, the emission rate was lower when comparing to the coal

IGCC power plant of 8,000 MW[131]. Biomass power plant had the lowest emission rate of 0.1 MMTCDE from its installed capacity of 8,000 MW in 2040.

5.1.4.4 Energy Balance (GO)

The energy balance for Nigeria in 2040 under the GO scenario presents a case where by the presence of renewables in the energy mix is of an increased value when compared to the previous scenarios. The total primary energy supply for this scenario was 3,507.5 PJ by 2040 and this was less than the REF and LCM scenario, but a little over the LCA scenario. Electricity generation in energy unit was 717.9 PJ, and this had a loss of 28.7 PJ due to T&D losses[132]. The total transmitted electricity to meet the sectorial electricity demand was 689.1 PJ. The demand sector includes; households with an electricity demand of 197.3, industry with an electricity demand of 202.4 PJ, and commercial/service sector with an electricity demand of 289.4 PJ.

Natural gas production was greatly reduced to 445.7 PJ, and this is due to the reduced demand for it in electricity generation (316.5 PJ), lower T&D losses[133] (-7.8 PJ), and moderate industry demand (121.5 PJ). Gasoline which has a reduced demand in the transport sector due to the decrease in the share of gasoline vehicles and the absence of gasoline power plants for off-

[131] This will be explained in a more elaborate manner in the discussion section of this chapter.
[132] This accounts for the lowest rate of T&D losses in the power sector which translate to 4% T&D loss.
[133] As described in the GO scenario development in Chapter 4, the losses in natural gas T&D was reduced to 6% by 2040 from its 2010 value.

grid electricity generation, will see the reduced import of only 50.2 PJ of the product from overseas. The same situation is observed for kerosene with an import value of 391 PJ to meet household domestic demand of 499.1 PJ, while 0.4 PJ will be channeled to the agriculture sector. The reduction in demand for diesel in the transport sector will see the increase in its export of 67.1 PJ from Nigeria's domestic oil refineries by 2040.

The household sector energy demand for LPG under the GO scenario was 112.6 PJ, while its use for transportation required 110.8 PJ, which was a significant reduction when compared to previous scenario. This led to its reduced import of 114.9 PJ from overseas to increase the domestic refineries production of LPG (108.4 PJ). The inclusion of three type of coal power plants with various rate of energy conversion efficiencies, will require coal consumption of 263.5 PJ, while the industry sector will demand 8.1 PJ of coal for its energy use.

On renewables[134], wind energy of about 240.4 PJ will be used for power generation in both off-shore and on-shore turbines in 2040. Solar PV and thermal systems will utilize 341.1 PJ of solar radiation for electricity supply (339.1 PJ) and domestic solar installation of 1.9 PJ. Nigeria's large and small hydropower in both on-grid and off-grid areas will require about 120 PJ of hydro. The energy balance for 2040 under the GO scenario is shown in Figure 5-29 and presented in Appendix H5.

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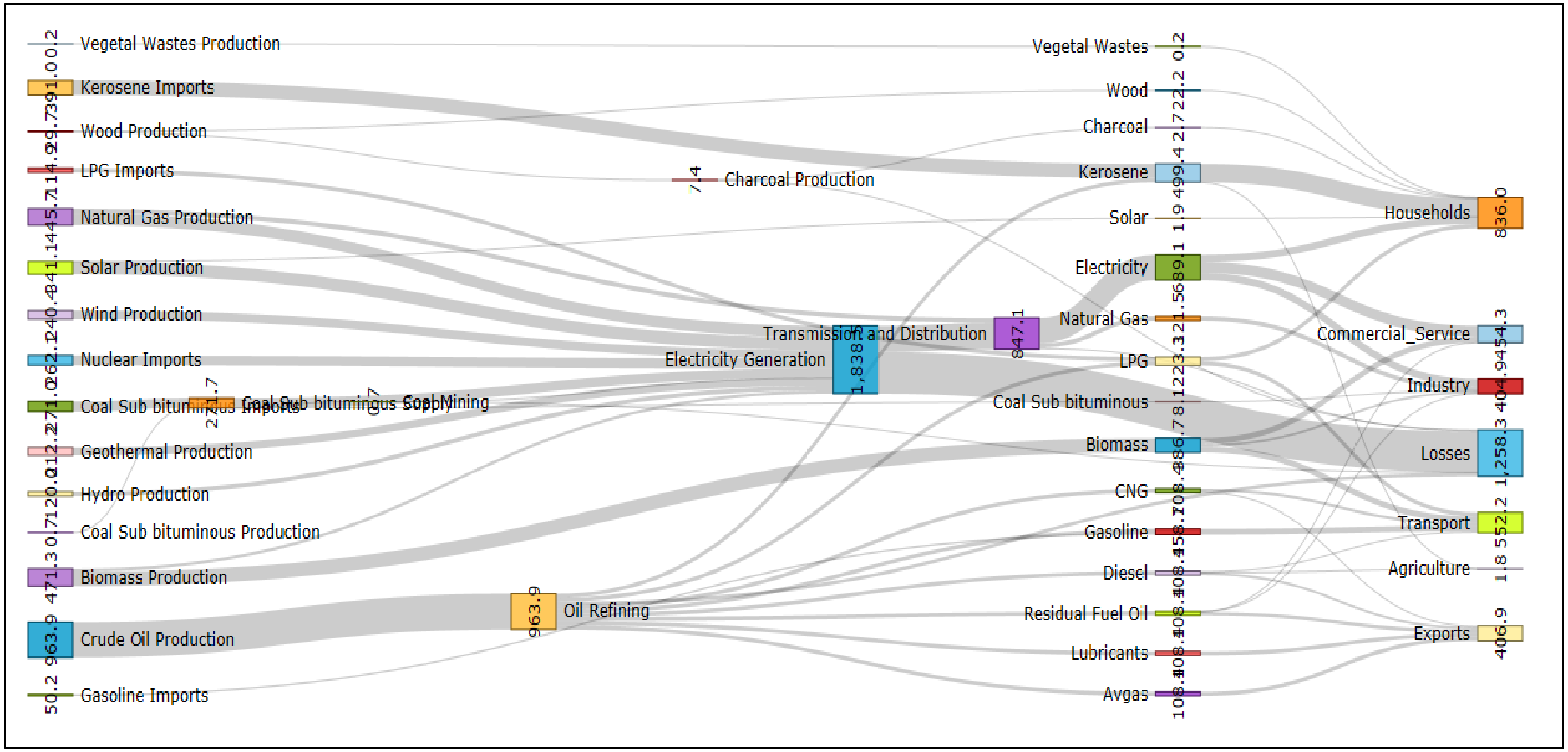
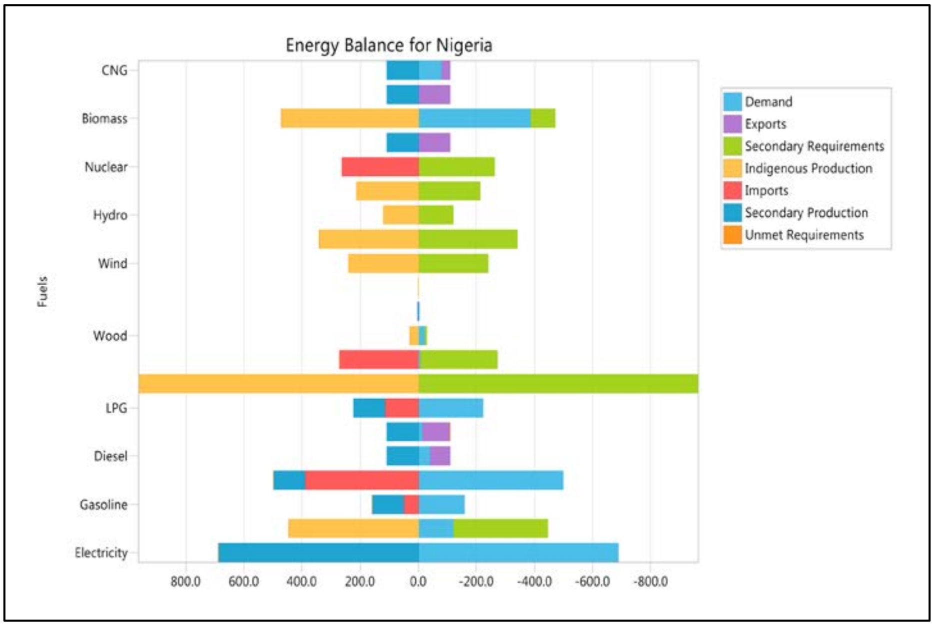
[134] Note that the supply of energy for renewables is not be seen as a conventional energy source since renewable energy are non-depleting. The primary energy supply from renewables shown in the energy balance are for the modelling purpose alone. Therefore, the figures listed in the energy balance are the amount of energy supplied to meet the demand of renewables (e.g. solar radiation, hydro, wind speed, etc.).

Figure 5-29: Sankey Diagram of Nigeria’s energy balance in 2040 (GO scenario)



Geothermal power plants which was considered to increase power supply under the GO scenario will require 212.2 PJ of geothermal energy to generate 12,400 MWh by 2040 from its 8,500 MW installed capacity.

Figure 5-30: Nigeria's energy balance in 2040[135] (LCA scenario)



The capacity expansion of 18,000 MW nuclear power plants by 2040 to generate 26,000 MWh of electricity will require the importation of 262.1 PJ of uranium fuel. This is also shown as secondary requirements in Figure 5-30. It can also be observed from Figure 5-30, that the indigenous production of biomass (471.3 PJ) will be used for domestic demand of 386.7 PJ and secondary requirement of 84.6 PJ by 2040.

[135] Order of fuels; CNG, Avgas, Biomass, Lubricant, Nuclear, Geothermal, Hydro, Solar, Wind, Vegetal waste, charcoal, wood, coal sub bituminous, Crude oil, LPG, Residual fuel oil, Diesel, Kerosene, Gasoline, Natural gas, Electricity.

Avgas and lubricants are exported to international markets or are used domestically but was not considered in the Nigerian LEAP model. In the GO scenario, CNG vehicles was promoted and this reduced the amount of its export from domestic refineries (28.4 PJ), since its demand in the transport sector increased to 80 PJ in 2040. In conclusion, out of the total primary energy supply of 3,507.5 PJ in the GO scenario, 1,258.3 PJ was used in the transformation sector, while 2,249.2 PJ was used in the demand sector.

5.2 Discussions

This section analyze the scenarios from a policy based prospective in order to fully explore the effects of the strategic policies implemented in each scenario, while interrelating them together. In other words, this section examine the impact of policies on the energy supply mix, energy demand, electricity supply mix and GHG emissions in whole scenarios developed and the primary resource requirements. Further, this section also discuss on the cost-benefits of each scenarios in relation to the government based scenario (i.e. REF scenario) and presents the least cost electricity generation from the power plants proposed in the scenarios in this thesis.

5.2.1 Meeting Energy Demand with Supply

Energy policies and strategies been developed in each scenario were intended to balance the demand for energy with available supply. But before the provision of energy to the demand sectors, measures or strategies have to be taken in ensuring that energy is efficiently utilized. The households sector is a case to begin with in the discussion of energy savings in Nigeria. Going by the REF scenario or business-as-usual case, household hold energy demand is bound to increase to 1,267.6 PJ from the base year value of 418.5 PJ. However, energy efficiency polices such as the introduction of CFL bulbs and replacement of inefficient refrigerators in the LCM scenario contribute to the reduction of energy intensities to 1,157.4 PJ. This means an energy saving of 110.2 PJ was achieved through this policy strategy alone, notwithstanding the increase in population, household and income growth rate.

The more aggressive steps taken in the LCA and GO scenario proved that with more energy efficiency strategies in place, more energy could be saved in Nigeria's household. This was realized through the introduction of LED bulbs for lighting with an intension of phasing-out incandescent bulbs in the LCA scenario. This strategic policy also came with the increase in LPG share for cooking and lighting[136] to 20%, while inefficient air conditioning units and refrigerators were replaced with efficient units. This increase in energy efficiency policy ensured the energy savings of 319.3 from the LCA scenario.

Mixing LED and CFL with share of 40% and 60% respectively by 2040 was the main focus of the energy efficiency policy in the GO scenario

[136] It should be taken into account that other fuels such as kerosene, firewood, charcoal, etc. also had their share reduced as shown in the energy supply results in the Appendix section.

for lighting[137]. Besides the CFL and LED bulbs, the GO scenario ensured the reduction in the share of fuels such as kerosene, firewood, and charcoal by encouraging LPG fuels and electricity instead. Solar thermal cookers, PV systems, efficient firewood and charcoal stoves were provided in the GO scenario. All these promoted energy savings of 431.6 PJ by 2040[138].

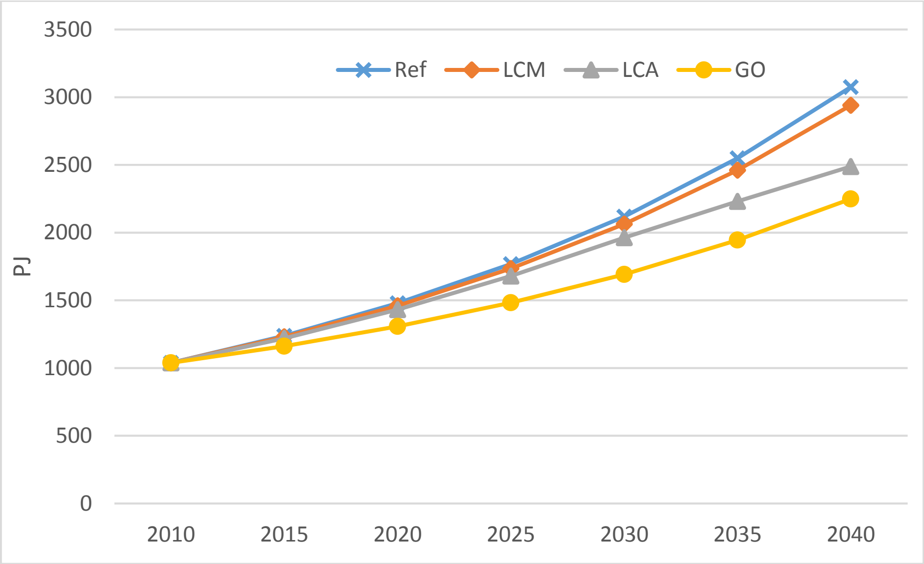
The same situation that occurred in the households sector was also observed in the commercial/service sector which had its electric light bulbs changed according to the alternative scenarios. In all, energy savings for the sector in the alternative scenario was 28.2 PJ, while the change in the energy mix in the sector also ensured that the energy supply was sufficient in reducing dependence on one fuel source[139]. Agriculture sector was not affected by policy changes due to the lack of mechanization associated with Nigerian farmers for the last two decades. Meanwhile, the more energy intensive industry sector had a more promising energy reduction potential through policy interventions in the form of energy efficiency, fuel switching and technology upgrade/ switching. The total energy demand in the four scenarios are shown in Figure 5-31.

[137] This ensured the complete phasing-out of incandescent bulbs before 2040.

[138] These were also some of the potentials discussed in Akinbami and Lawal (2009) where they estimated the future trend of electricity demand in Nigeria using the Model for Analysis of Demand for Energy (MADE-II). The study employed the useful energy demand concept and found considerable energy savings potentials in the residential and commercial sectors in Nigeria.

[139] This can be observed in the fuel switching from reduction of biomass to the increase in electricity supply.

Figure 5-31: Energy demand in the four scenarios



Although a significant level of energy efficiency policies were not in common in the LCM scenario, the LCA goes a step further in ensuring the improvement in energy efficiency in industrial equipment which will reduce energy demand. Energy savings achieved due to the energy efficiency policy in the industry sector includes about 103.6 PJ in the LCM scenario, 270.6 PJ in the LCA scenario, and 337.3 PJ in the GO scenario. In additions to the policies observed in the LCM and LCA scenarios, the GO scenario introduced a policy recommending the technology change of blast furnace from conventional blast furnace to electric-arc blast furnace. This technology change will in effect, bring to the reduction in fossil fuel use in the industrial sector, while the increase in electricity demand will be observed[140].

[140] This is shown in Appendix C4 for energy demand in the industry sector.

The transport sector which is another energy intensive sector experienced a considerable amount of policy effect across the four scenarios. From the REF scenario which had the demand for energy rising to 581 PJ in 2040, the impact of various strategies such as the provision of fuel options and efficiency improvement had a significant impact in energy savings. The introduction biodiesel for motorcycles and biofuels for vehicles in the LCM scenario actually increased energy demand, and these is as a result of adding more fuel options and increase in income[141]. The LCA scenario made a shift from the LCM scenario through the inclusion of LPG fuel in the transport sector. By 2040, the mix was expected to change as developed in the Chapter 4, which will see LPG increase its role in competition with biofuel/biodiesel.

Unlike the LCM scenario, energy demand was much lower in the LCA scenario and this is due to fuel economy policy introduced. A more successful policy impact was observed for the transportation sector in the GO scenario. This was made possible through the inclusion of more policies which include an improved fuel economy for all vehicles, especially cars, the introduction CNG into the transport mix with the active presence of LPG, biofuel/biodiesel, and gasoline/diesel. Diesel was phased-out or reduced in some vehicle types such as cars which had no diesel engines by 2040, and long distance coach and heavy goods vehicle which had their shares reduced from the base year. The reduced energy demand due to the after mentioned

[141] In order words, people will purchase more private cars, commercial vehicle operators will increase their vehicle fleet since biodiesel becomes more available and income increases at the same time.

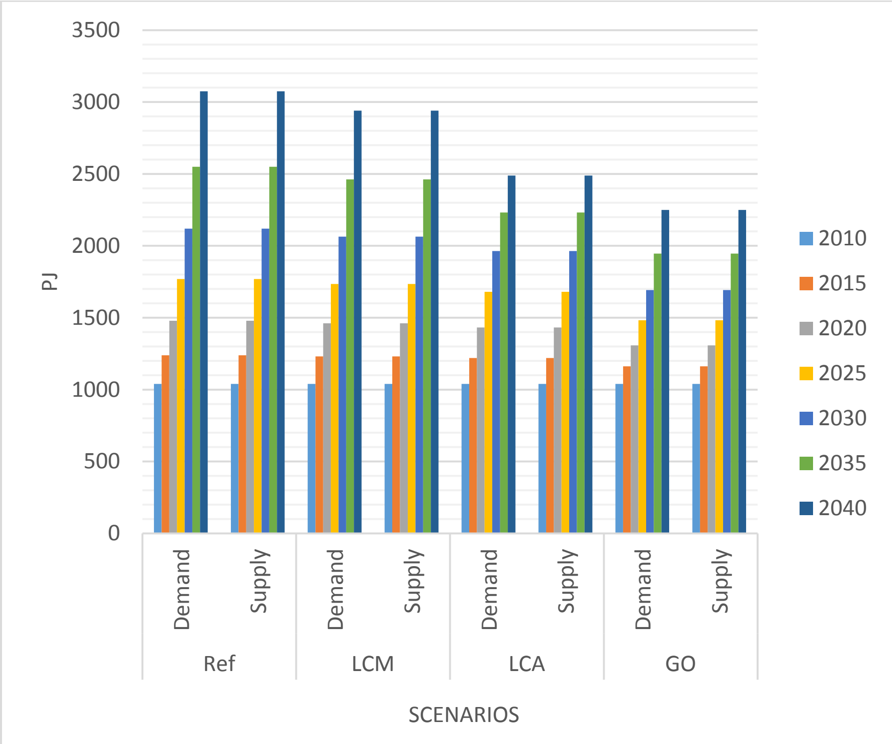
policies resulted in the energy savings of about 28.8 PJ for all the vehicles in the transport sector under the GO scenario by 2040.

Since the reduction in energy demand among the alternative scenarios have been discussed, the energy supply side will be the next focus. In meeting the demand for electricity in the three sectors (i.e. households, industry, and commercial/service), about 582 PJ of electricity was supplied under the reference scenario. However, the alternative scenarios proved that the supply of electricity in Nigeria could be reduced if proper energy efficiency policy and strategies are in place in the demand side[142].

Natural gas supply for the reference scenario was 111.3 by 2040, and these was reduced as demand for the product fell in the LCM scenario (95.8 PJ). However, with the increased use of natural gas in industry and power plants, the supply for industry increased to 117.9 PJ, while power plants were supplied 584.3 PJ in 2040. To view the balancing of energy demand and supply, Figure 5-32 is presented to show how the various scenario energy demand is meet with supply.

[142] The discussion on electricity demand and supply will be given in the next subsection which deals with matching electricity demand with supply.

Figure 5-32: Scenario's energy demand and supply



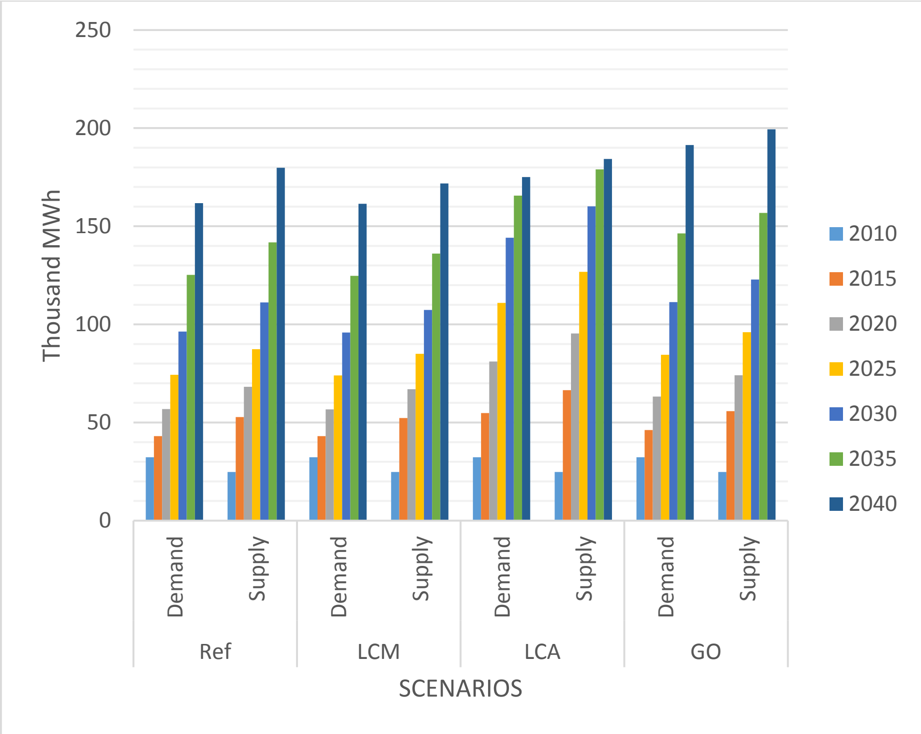
The fuels (supply) shown in Figure 5-32 covers all the fuels required in meeting the five sector's energy demand. As observed in figure 5-32, whenever the demand in a scenario increase or reduce, so does the supply for the energy fuels. In a bid to understand these, a close observation of some fuels such as gasoline, kerosene and diesel for example, had a supply of 470.4, 740.6 and 112 PJ respectively under the reference scenario in 2040. This however, was reduced in the alternative scenario where the demand for the fuel fell short due to the impact of energy efficiency policies and fuel switching options in the sectors.

The supply of LPG in the REF scenario was just 177.2 PJ due to low demand for the fuel in the household sectors. But in the alternative scenarios such as the LCA and GO scenario, the supply increased due to the introduction of LPG fuel for vehicles and its increased use in the households sector. Biomass supply, which was 795.1 PJ in the REF scenario had an increased supply in the LCM (880.1 PJ) scenario due to increasing demand in the transport sector. But this was reduced in the LCA (531.8 PJ) and GO (386.7 PJ) due to the introduction and increased share of LPG and CNG for the transport sector, and also other sectors such as households, industry and commercial/service sectors.

5.2.2 Matching Electricity Supply with Demand

Matching Nigeria's electricity supply with demand has been a "tough-nut to crack" which is due to challenges in the power generation sector. This challenges include among others, improper planning of power plants construction and capacity expansion (Sambo, 2008; Iwayemi, 2008). However in matching electricity supply with demand in the future, proper knowledge is needed in order to understand the growing electricity demand on one hand and the proper generation capacity needed to supply electricity on the other hand (Ajao et al. 2009). To achieve this, a comparison among the four scenarios was carried out in order to observe the electricity demand and supply in each scenario and this is shown in Figure 5-33 and presented in Appendix E1 and E2.

Figure 5-33: Scenario's electricity demand and supply



From Figure 5-33, it's observed that electricity demand in the REF scenario will increase from 32,300 MWh in the base year, to 161,800 MW by 2040. This demand will be matched with the supply of 179,800 MWh from electricity generation by 2040. Although the supply of electricity far exceeds demand under the REF scenario, it should be noted that the power plants proposed by the government will include more inefficient plants such as SCGT, gasoline, diesel, coal steam and gas power plants that are also known for their high emission rate. On the demand side, policies were not in place under this scenario, while fuel switching was absent in all sectors in order to ensure the maximum utilization of energy forms.

Moving to the LCM scenario, electricity demand (161,500 MWh) was not very much reduced due to the near absence of energy efficiency policies in the five sectors. However, electricity supply was still sill higher than demand but lower than the REF scenario. More increase in electricity demand as compared to the LCM and REF scenarios was observed in the LCA scenario with an increase of 175,100 MWh in electricity demand. This was attributed to not only the increase in income of households alone[143], but the increased reliance of electricity as a form of energy preferred in the industry and commercial sector. However, the provision of solar electricity in households which is present even in the REF scenario base year, had its capacity increased and intends to reduce the dependency on grid supply in the demand sectors[144].

The GO scenario which is focused on the increased use of renewable for electricity generation at the supply and to some extent, the demand side, had an increase demand for electricity to 191,400 MWh in 2040. This will be matched with the supply of electricity from mostly renewable and low carbon source to produce up to 199,400 MWh by the end of 2040. As previously

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143 This comes with households consumers purchasing more electrical appliances as reported in Dzioubinski and Chipman (1999), Robertson, Ndebele and Mhango (2011), and Abd'razack, Ludin and Umaru, (2013). More recently, Euromonitor International (2014) consumer lifestyle report on Nigeria population identified the growing relationship between increasing income and the behavior of consumers to acquire more goods to satisfy their needs. This includes household electronics and appliances which they intend to use in making their daily lives more comfortable.

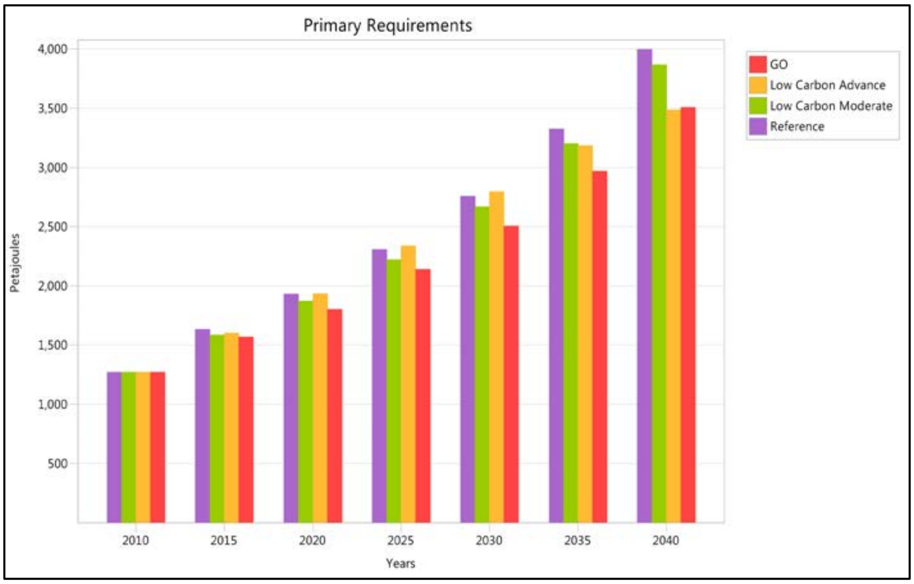
144 This in some point includes residential buildings in both the urban and rural areas, as well as commercial/service buildings such as banks, hospitals, government and agency buildings.

explained in the Chapter 4 and the Results section in this chapter, off-grid electricity supply will come mainly from renewable energy source with the exception of SCGT power plant to support electricity generation from renewables.

5.2.3 Primary Resource Requirements

In general, the primary resource requirement is expected to increase as each scenario changes its form of energy and electricity consumption. This is evident as shown in Figure 5-34 and presented in Appendix D1 which shows the value of primary resource requirement for each scenario from 2010-2040.

Figure 5-34: Primary resource requirements

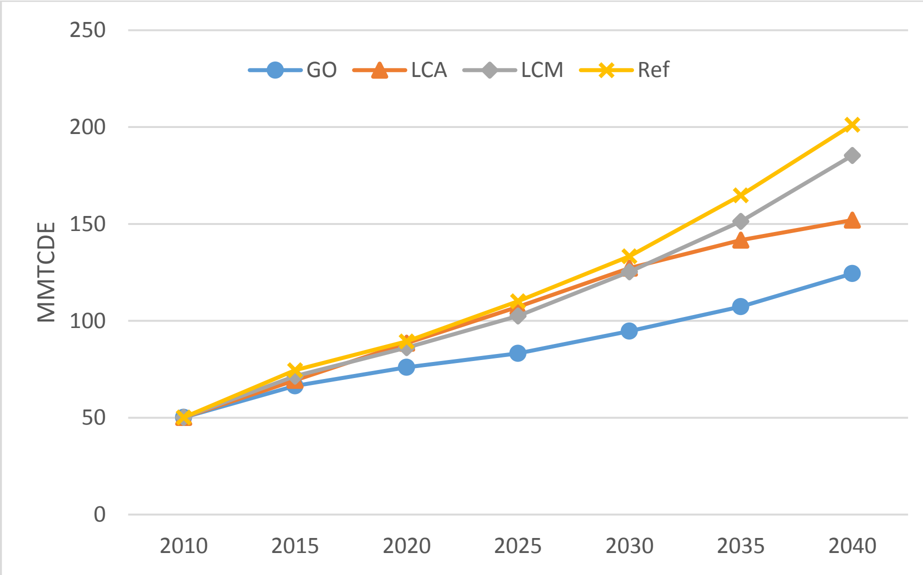


It is can be observed that the LCA scenario presented a lower primary resource requirement when compared across scenarios. This is due to the reliance on both conventional and renewable energy resources at an amount that is efficiently utilized for both power generation and energy consumption. This ensured the reduction of primary resource requirement of 3,507 PJ in the LCA scenario. The GO scenario also presented a low primary resource requirement of 3,507.5 PJ by 2040 which is better in terms of primary resource conservation as compared to the LCM and REF scenario.

5.2.4 GHGs Reduction Potential

The GHGs recorded in the four scenarios shown various level of reduction GHGs due to the various energy policy applied at different stages of the development of the Nigeria LEAP model. The summary of the GHGs from energy consumption and electricity generation are shown in Figure 5-35. This shows that in the REF scenario, GHG emission will increase from 50.2 MMTCDE in 2010, to 201.2 MMTCDE in 2040. The next scenario which is the LCM scenario presented a slightly lower emission of 185.4 MMTCDE in 2040. It can be recalled that the energy policies and strategies implemented in the LCM scenario was moderate and not aggressive as the LCA and GO scenario.

Figure 5-35: GHG emissions summary for all scenarios



As observed from Figure 5-35, the LCA scenario developed initially had an increased GHGs levels from 2020 to 2030 (10 years) after which the impact of energy policies began to reduce GHG emissions. It is however, important to note that this reduction is not only from the GHGs from energy use alone, but also electricity generation. The GO scenario displayed a very low emission rate from 2015 to the target year, 2040. This was achieved due to the more aggressive policies in reducing energy demand on one hand, and improving the share of renewables on the other hand. This led to the reduction of GHGs to 124.4 by 2040 from its 2010 levels. In terms of GHG emissions savings, 15.8 MMTCDE was saved in the LCM scenario, 49.1 MMTCDE in the LCA and 76.7 MMTCDE in the GO scenario.

5.2.5 Cost-Benefit Analysis

A cost-benefit analysis or benefit-cost analysis can be described as a systematic approach to estimating the strengths and weaknesses of alternatives that satisfy transactions, activities or functional requirements for a business. It is an analytical tool or technique used in the determination of options which provide the best possible approach in the adoption or practice in terms of benefits in labor, time and cost savings (David et al., 2013). It can further be described as a systematic process observed in calculating and comparing the benefits and costs of a project, decision or government policy. The aims of cost-benefit analysis includes; to ascertain if an investment or decision is feasible, and to establish a basis for projects comparison (Central Expenditure Evaluation Unit [CEEU], 2013; Policy, 2014). This includes comparing the total expected cost of each option against the total expected benefits, in order to observe which benefits outweigh the costs and by how much (Spellman, 2015).

The definitions provided above was intended to establish a general understanding of the term ‘cost-benefits analysis”. The result of the cost benefit analysis for the scenarios analyzed in this thesis is presented in Table 5-1. The results show the extra cost (if it’s a positive cost) of implementing a scenario from the reference scenario. In other words, the differences in cost that remains when the reference scenario is subtracted from the alternative scenario (s).

In some situation, a benefit (if it's a negative cost) when the reference scenario is subtracted from the alternative scenario (s). Usually, the cost observed when a reference scenario is subtracted from the alternative scenarios is usually high or a positive cost. The a more simple formal term, the results displayed on Table 5-1 shows the Net Present Value (NPV) of the alternative scenario relative to the reference scenario. The NPV is the sum of all discounted costs[145] and benefits in one scenario minus another[146].

Table 5-1: Results of the Cost-Benefit Analysis

*Tonne per Carbon Dioxide Equivalent

Cumulative Costs & Benefits: 2010-2040. Relative to Scenario: Reference.			
Discounted at 5.0% to year 2010. Units: Billion 2010 U.S. Dollar			
	Low Carbon Moderate	Low Carbon Advance	Green Optimistic
Demand	36.62	31.32	30.61
Households	0.42	0.56	0.57
Industry	-	-1.61	-2.35
Commercial_Service	-2.73	-5.74	-9.56
Agriculture	-	-	-
Transport	38.93	38.11	41.95
Transformation	15.65	36.12	81.62
Transmission and Distribution	-	-	-
Electricity Generation	15.65	36.12	81.62
Charcoal Production	-	-	-
Oil Refining	-	-	-
Coal Mining	-	-	-
Resources	1,640.19	23,790.23	41,269.17
Production	-209.43	44.14	-303.14
Imports	1,849.62	23,746.09	41,572.31
Exports	-	-	-

145 This thesis assumed the discounted cost to be 5% in 2010.
146 This is summed-up across all the years of the study and in this thesis, it was summed from 2010 to 2040.

Unmet Requirements	-	-	-
Environmental Externalities	-4.02	-24.05	-34.48
Non Energy Sector Costs	-	-	-
Net Present Value	1,688.44	23,833.61	41,346.92
GHG Savings (MMTCDE)	221.73	332.14	952.00
Cost of Avoiding GHGs (U.S. Dollar/TCDE)	7,615.00	71,757.93	43,431.71

From Table 5-1, we can observe that under the demand variable (or demand side), the cost for the implementation of the LCM scenario is 36.62 million US dollar, while LCA and GO scenario was 31.32 and 30.61 million US dollar respectively. In implementing the polices in the LCM scenario, the benefit of 2.73 million US dollars will be saved by the Nigerian government, while 38.93 million US dollars would have been spent in achieving the policies in the transport sector and 42 million US dollars on the households sector. In the LCA scenario, more cost would be spent for household's energy efficiency policies to the tune of 560 thousand US dollars, while 38.11 million US dollars will be spent in the transport sector.

These will include the introduction and increase of LPG vehicles, energy efficiency, and fuel switching. The industry and commercial/service sectors in the LCA and GO scenario gained the benefits of 1.61 and 5.74 million US dollars in the respective sectors. The GO scenario showed a lower investment cost for the demand-side energy policy. Although the cost required to enable the policies in the GO scenario's households and transport sectors were high (i.e. 570 thousand US dollars and 41.95 million US dollars respectively), the benefits were observed in the industry and commercial/service sector (i.e. 2.35 and 9.56 million US dollars respectively).

The transformation sector showed various levels of costs which varied across scenarios. The LCM scenario had a lower amount of cost in terms of implementing the strategies[147], while LCA had a higher cost of 36.12 million US dollars. The highest cost among the alternative scenarios was observed in the GO scenario, which is due to the high capacity installation of the power plants which are mainly renewables. On resources, offset cost or benefits were observed for resource production in the LCM and GO scenario, while the LCA scenario costs about 23.8 million US dollars versus the REF scenario. However, higher cost of import of energy resources was observed in the GO scenario as compared to the LCA and LCM scenarios. This high cost in the GO scenario was due to the increased importation of CNG, LPG and nuclear fuels for the large capacity installed.

Environmental externalities[148] presented a benefit in all the alternative scenarios with the GO scenario having the most benefit of 34.48 million US dollars, followed by the LCA scenario with a benefit of 24.05 million US dollars. The overall NPV for the alternative scenarios are 1.69 billion US

[147] These strategies include the building and capacity expansion of power plants that are not in the Ref scenario. For some power plants in the Ref scenario that are in the alternative scenarios, the differences are taken which is the cost of the expanded capacity of the alternative scenario which is the differences between the two scenarios. Please note that the strategies also includes the cost of improvement in T&D.

[148] Environmental externalities refer to the economic concept of uncompensated environmental effects of production and consumption that affect consumer utility and enterprise cost outside the market mechanism. As a consequence of negative externalities, private costs of production tend to be lower than its “social” cost. It is the aim of the “polluter/user-pays” principle to prompt households and enterprises to internalize externalities in their plans and budgets (United Nations, 1997).

dollars for the LCM, 23.8 billion US dollars for the LCA and 41.4 billion US dollars for the GO scenario. This overall NPV is the cost of how much more the alternative scenario[149] costs versus the REF scenario. The amount of GHGs saved in the LCM scenario was lower (221.73 MMTCDE) than the LCA (332.14 MMTCDE) and GO scenario (952 MMTCDE). Lastly, the cost of avoided[150] GHG emissions was higher in the LCA (71.8 US dollar/TCDE) scenario, than in the GO (43.4 US dollar/TCDE).

5.2.6 Least-Cost Electricity Generation

The power sector which has been built and operated under a "supply-follows-demand" philosophy, has always been able to fulfill its obligation by providing adequate and secured supplies of electricity at the lowest practicable cost (Santisirisomboon et al., 2003). The objective of the power generation plan[151] is to seek for the most economical generation expansion scheme to achieve a certain reliability level to meet the forecasted demand increase in a certain period of time (Booma et al., 2006). But this has resulted to a strenuous operating policy/strategy that entail a higher plant margins and extensive environmental impact in the energy system which invariably contribute to the increasing GHGs levels.

[149] Please note that it is one alternative scenario versus the REF scenario (i.e. LCM vs. REF, LCA vs. REF etc.).

[150] This is given by dividing the NPV by the TCDE avoided.

[151] In some circumstances, the plan translate to the least-cost electricity generation which seeks to minimize the total generation cost which is composed of generation capital investment costs, operation and maintenance (O&M) costs, outage cost, transmission losses costs and transmission enhancement costs (Sardou et al., 2013).

According to the U.S. Environmental Protection Agency (EPA), the power sector is the highest contributor to the global GHGs emission with about 26% of the total GHGs by source (U.S. Environmental Protection Agency [EPA], 2015). Since this is the case, then the power sector has the highest potential in GHG mitigation. A lot of options exist in reducing GHG emission from the power sector and they include the transition from high to less or non-GHG intensive sources of electricity[152] generation (Sims et al., 2007).

This subsection however aims to evaluate the most economical power generation of 200,000 MWh by 2040 from the electricity power plant installed in 2010. It's important to note that the basis for the electricity generation limit of 200,000 MWh was due to the maximum electricity generation recorded in the scenario's results in the last subsection which was the GO scenario (i.e. 199,400 MWh). This subsection intends to set the limit to 200,000 MWh instead and then carry-out a least-cost optimization with the energy technologies proposed in this thesis. It is however, important to note that the technologies do not include off-grid gas power plant, diesel and gasoline generators. Therefore, the power plants used in the least-cost optimization was biomass, CCGT, coal CFB, coal steam, coal supercritical, geothermal, large hydropower, nuclear, off-shore wind, on-shore wind, SCGT, small hydropower, solar PV and solar thermal.

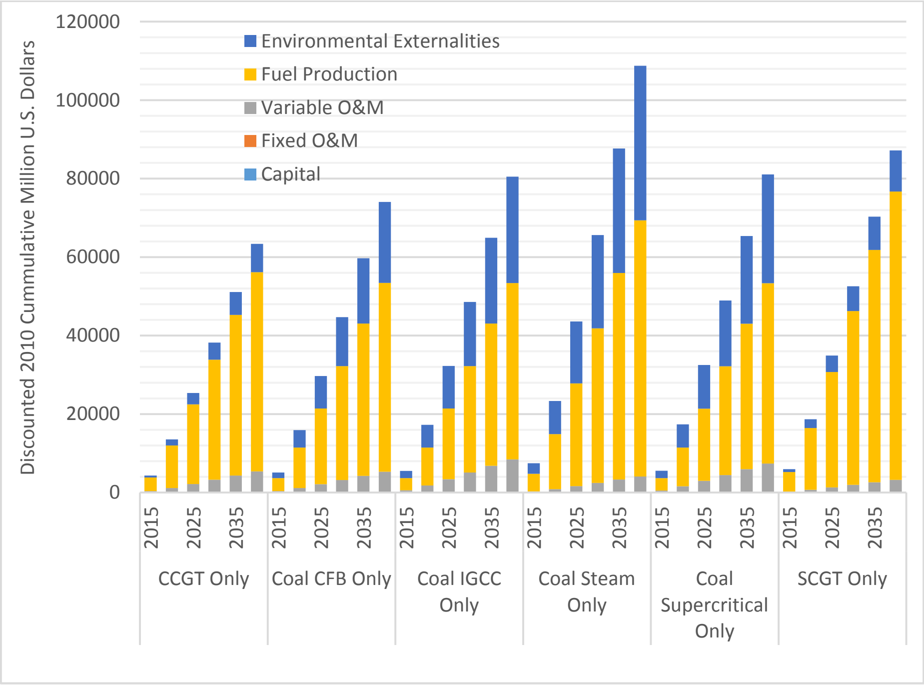
[152] Other measures include the application of Carbon Capture and Storage (CCS), installation of energy efficient power plants with reduced emission rates (e.g. CCGT).

Each power plant was installed and increased to generate 200,000 MWh by 2040 from 2010, and this was done alone (i.e. not an electricity mix, but only that type of power plant was expanded). The methodology used for the least-cost electricity generation was presented in Section 4.1.2.6 in Chapter 4, while the data used are from Appendix B25 and 26. The results are shown in Figure 5-36 to 5-41 and presented in Appendix I1-I6. In order to enhance the understanding of the results, the Figures are arranged in a way that each deals with a set of technology such as fossil fuel, low-carbon, and renewable energy technologies. The power plant specific GHG is also discussed.

5.2.5.1 Fossil Fuel Power Plants

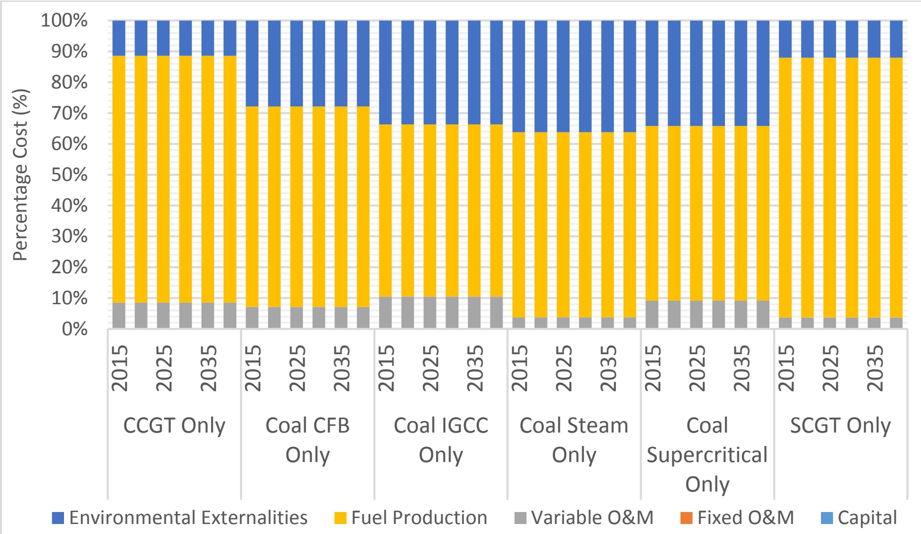
The results for the least-cost electricity generation for fossil fuel power plants are shown in Figure 5-36. It can be observed from the Figure that coal steam power plants had the highest cost for electricity generation in meeting the 200,000 MWh mark by 2040. Among the contribution to the high discounted cost recorded in the coal steam power plant was the cost of fuel production (i.e. cost of purchasing fuels for the power plants, in this case it was coal) which amounted to 65.3 billion US dollars. The next was environmental externality cost which amounted to about 39 billion US dollars, while the total discounted 2010 cumulative cost by 2040 was 108.8 billion US dollars in 2040. However, among the other three coal power plants (i.e. CFB, IGCC and supercritical), CFB presented the least-cost in terms of electricity generation of about 74 million US dollars by 2040.

Figure 5-36: Least-cost electricity generation for fossil fuel power plants



The least-cost electricity generation from fossil fuel power plant came from CCGT plant which had a higher cost in fuel production or cost of purchasing natural gas to be 50.8 billion US dollars. The SCGT was higher than CCGT plants and even the coal power plants in 2040. To also enhance the interpretation of the result, the shares of cost (in percentage) in each power plant is shown in Figure 5-37.

Figure 5-37: Percentage share of Costs for fossil fuel power plants



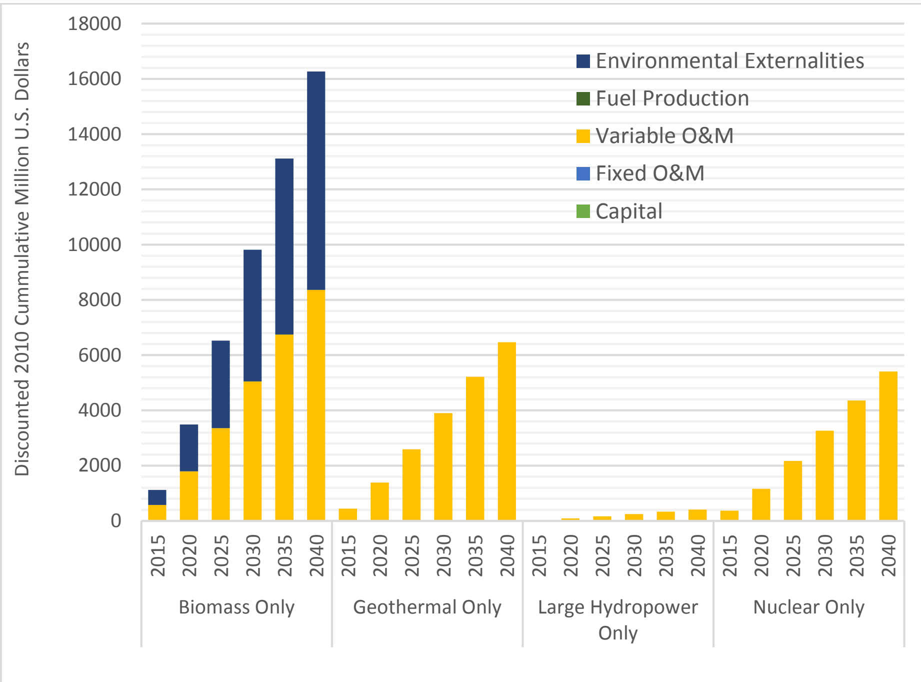
5.2.5.2 Low-Carbon Power Plants

This energy technologies are known to be power plants than emit an insignificant amount of GHGs or sometimes emit no GHGs at all. Large hydropower in real sense does not emit GHGs and is classified as renewable but possess some disadvantages to the environment. This sometimes leads to the indirect emission of methane and carbon dioxide as in the case where by decomposing plants and trees around the dams release methane and carbon dioxide which increase pollution. Other problems includes the disturbance of natural habitat, effects on agriculture, breaking of dams, distortion of fish migration, etc.[153].

[153] www.conserve-energy-future.com/Disadvantages_HydroPower.php

Nuclear power plants presents their own disadvantage, despite not emitting GHGs and the include; nuclear accidents, radioactive waste, nuclear radiation, high capital cost, national risk, fuel availability, major impact on human and aquatic life, etc.[154]. However, geothermal and biomass have not been a subject of discussion that warrant much attention into its disadvantages. The results for the discounted costs in the low-carbon power plants are shown in Figure 5-38.

Figure 5-38: Least-cost electricity generation for low-carbon power plants

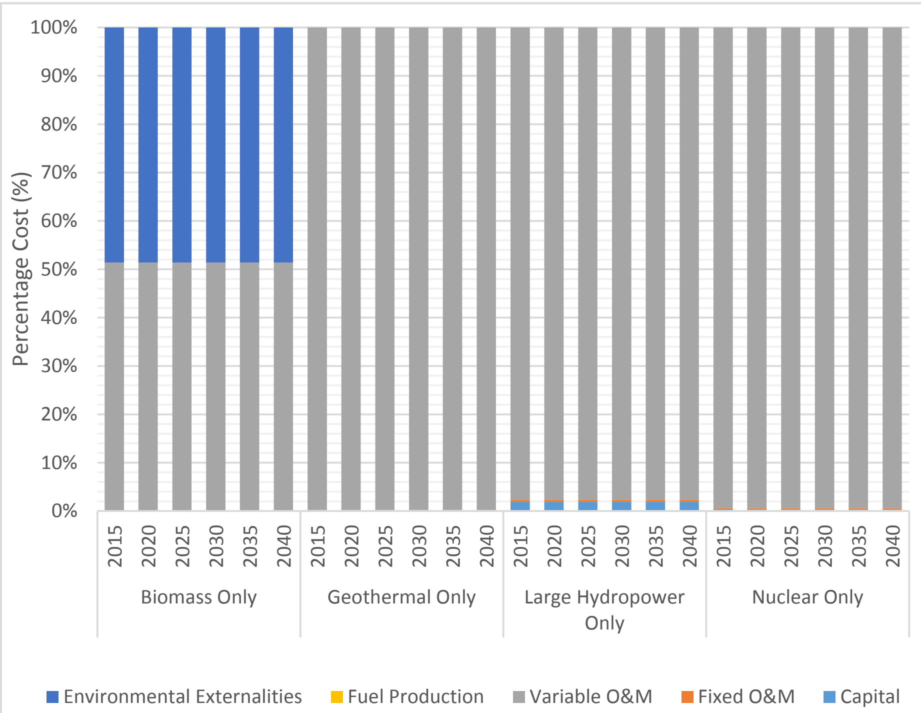


From the results of as shown in Figure 5-38, it is observed that hydropower had the least-cost of electricity generation with the discounted

[154] www.conserve-energy-future.com/Disadvantages_NuclearEnergy.php

cost of 400.9 million US dollars in 2040. This was followed by nuclear power plants with a higher variable O&M cost which increased its discounted cost to 5.4 billion US dollars. Comparable to nuclear power plant was geothermal with an increased discounted cost of about 6.5 billion US dollars. Nuclear power had a higher capital and O&M costs than geothermal power plant. Biomass power plants had a higher discounted cost of generating the 200,000 MWh of electricity by 2040. This was due to the higher variable O&M cost (8.34 billion US dollars) and externalities costs of about 7.9 billion US dollars. This can also be shown in percentage shares in Figure 5-39.

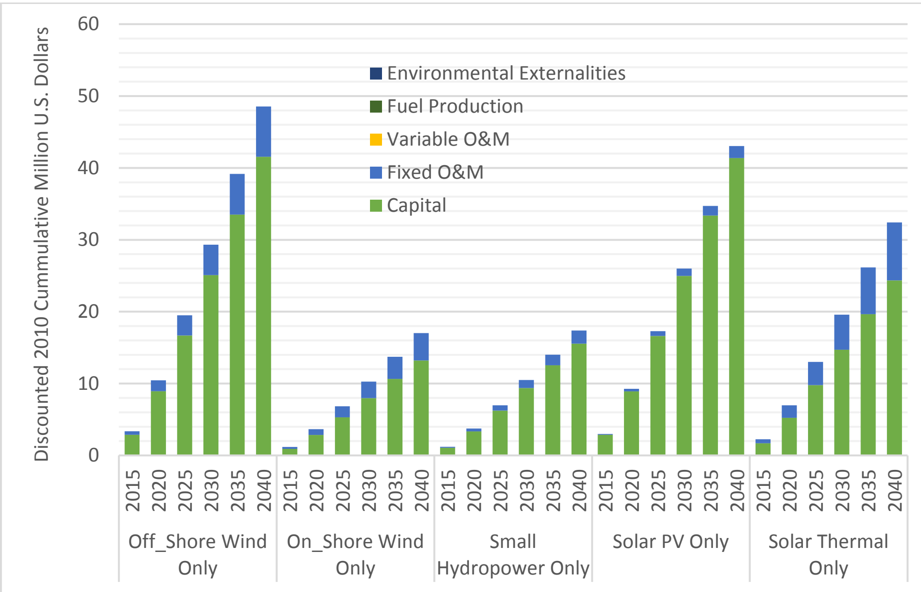
Figure 5-39: Percentage Share of Costs for Low-Carbon Power Plants



5.2.5.3 Renewable Energy Power Plants

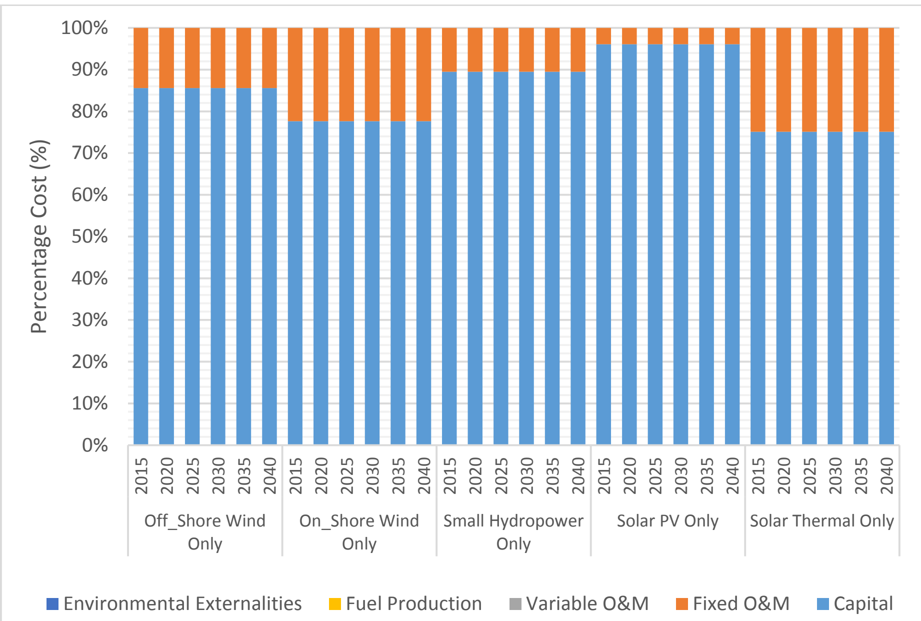
Renewable energy technology presents a society with a zero-emission power generation without fuel requirement, hence no environmental externalities. Among the power plants proposed in this thesis, off-shore and onshore wind, small hydropower, solar PV and thermal system, and large hydropower (as discussed in the last subsection) presented a lower discounted cost when compared to the fossil fuel and low-carbon power plants. For renewable energy technologies, on-shore wind power plant was observed to be the least-cost for electricity generation with a discounted cost of 17 million US dollars by 2040. The discounted cost for the renewable energy power plants is shown in Figure 5-40.

Figure 5-40: Least-cost electricity generation for renewable energy power plants



This is closely followed by small hydropower plants with a discounted cost of 17.4 million US dollars, which differs from on-shore wind with 400 thousand US dollars. However, small hydropower had a smaller fixed O&M discounted cost of 1.8 million US dollar than on-shore wind which was 2 million US dollars. Off-shore wind power plants was observed to have the highest discounted cost among the renewables proposed with a discounted cost of about 48.6 million US dollars in 2040. The percentage share of cost for renewables goes to mainly capital and fixed O&M cost as shown in Figure 5-41. More capital cost is spent solar PV system than other renewable in terms of share comparison, while solar thermal has a lower capital cost.

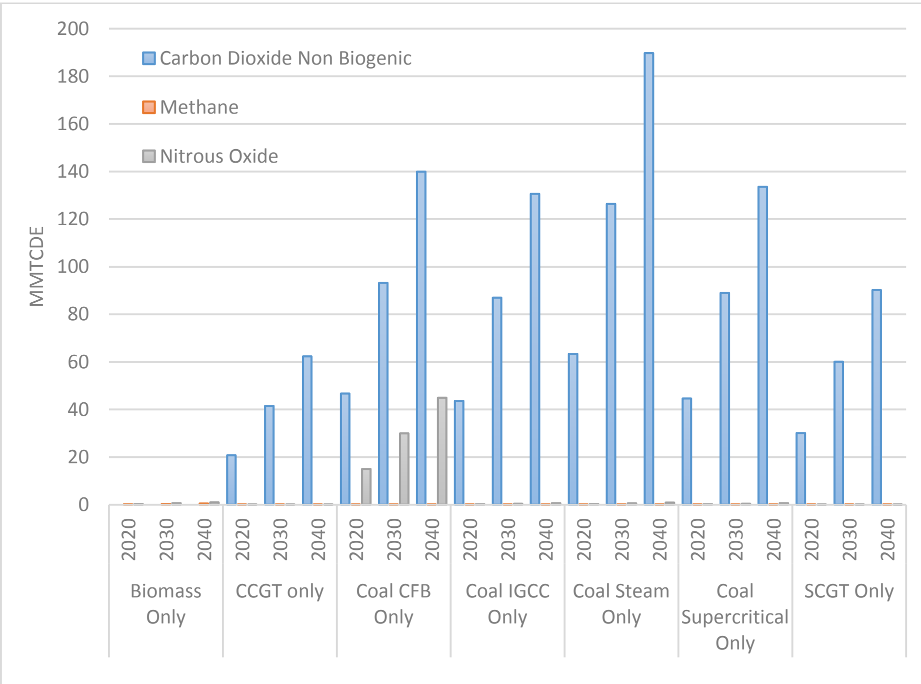
Figure 5-41: Percentage share of costs for renewable energy power plants



5.2.5.4 Power Plant Specific GHG emissions

The least-cost electricity results previously discussed explored the power plant options in order to identify the best option or power plant to achieve an electricity generation of 200,000 MWh by 2040. The results showed that the least power plant was on-shore wind which falls under the category of renewable energy technology, while CCGT power plants was observed to be the least-cost for fossil fuel power plants. This section briefly identify the GHGs from each fossil fuel power plants as it increase from 2020 to 2040, and the result is shown in Figure 5-42 and presented in Appendix I7-I8.

Figure 5-42: GHGs from Power Plants



The results showed that biomass which is considered as a low-carbon energy technology emitted the least amount of GHGs across the years under observation. However, among the fossil fuel power plants, least GHGs was observed in CCGT power plants with an emission of 62.4 MMTCDE in 2040. It is also observed that carbon dioxide had the largest share of GHGs from the fossil fuel power plants. Coal power plants had higher emission rate as compared to gas power plants. Between the coal power plants, coal steam was observed to emit more GHGs in order to generate the required 200,000 MWh in 2040. In conclusion, these results (including the least-cost electricity generation intends to provide some policy guidelines in power plants investment in a way that it benefits the society on the short and long run. Investment in power plants should critically consider the long term impact of each technology and not the low cost of investment on the short term basis.

5.3 Sustainable Strategies

Attaining a low carbon society requires the formulation and implementation of strategic policies that are sustainable in the long term[155]. Usually, a low carbon development is followed by the move towards a green growth which results to a green society (Wang et al. 2010). In a developing country such as Nigeria, green growth can be a kind of economic strategy to ensure sustainability in the presence of resource constraint and climate change (Emodi, 2015). This section however explore the strategies that can ensure a

[155]http://www.greengrowthknowledge.org/sites/default/files/kggp_knowledge%20note%20-series_01.pdf

low carbon development in Nigeria with a view of attaining green growth[156]. The strategies are based on the results obtained in Section 5.1-5.2, and combined with relevant country cases.

5.3.1 Thinking and Adopting the Green Growth Ideology

Over recent years, the concept of "green growth" has been making waves in the international policy scene (Jacobs, 2012). The green growth approach adopted by the Fifth Ministerial Conference on Environmental and Development (MCED)[157] sought to harmonize economic growth with environmental sustainability, while improving the eco-efficiency of economic growth and enhancing the synergies between environment and economy. As with green economy, green growth attracted significant attention as a way out of today's economic doldrums in the aftermath of the 2008 financial crisis[158]. In 2008, the Korean Government adopted "low carbon green growth" as the country's new development vision in response to the global financial crisis (Sustainable Development Knowledge Platform [SDKP], 2008).

The advancement to a low carbon economy and then green growth should start in the manner of thinking of not only the Nigerian government alone, but also the citizens in the country. It is not enough to say that Nigeria

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[156] According to the World Bank, green growth is the growth that is efficient in its use of natural resources, clean in that it minimizes pollution and environmental impacts, and resilient in that it accounts for natural hazards and the role of environmental management and natural capital in preventing physical disasters. The Organization for Economic Co-operation and Development (OECD) define green growth as fostering economic growth and development, while ensuring that natural assets continue to provide the resources and environmental services on which our well-being relies.

[157] This conference was held in March 2005 in Seoul, Republic of Korea.

[158] It is important to note that the concept of green growth has its origins in the Asia and Pacific Region].

is the largest economy in Africa (World Bank Databank, 2015), while energy demand far exceeds supply. Nigeria needs to focus on shifting from quantity of economic growth to quality of economic growth. In adopting a green growth strategy, Nigeria will not only change the way its cities, industries and infrastructures are being built, but also open up opportunities for income generation. As observed in the GO scenario for the household sector, the provision of solar PV systems for household will enable electricity consumers to become electricity generators who can sell power back to the grid ("Prosumers"). This can be done through feed-in-tariff[159] (FIT) for potential household owners, while electricity generators can benefit from renewable portfolio standard[160] (RPS) as observed in the GO scenario for electricity generators.

Ignoring the topic of low carbon-green growth leads to the increased cost of climate change and other natural disaster on economic growth. This has direct impact on a country's GDP as some natural disaster such as floods due to heavy rains and rising sea levels, heat waves, desert encroachment and deforestation alter economic activities[161]. Thinking green growth while implementing low carbon strategies will not only solve the energy poverty situation in Nigeria, it will also create job opportunities which will reduce the

[159] FIT is a policy mechanism designed to accelerate investment in renewable energy technologies through the offering of long-term contracts to renewable energy producers, typically based on the cost of generation of each technologies (Couture, Analytics, Cory, Kreycik & Williams, 2010).

[160] RPS is a regulation that requires the increased production of energy from renewable energy sources, such as wind, solar, biomass, and geothermal (National Renewable Energy Laboratory [NREL], 2015)

[161] http://www.theguardian.com/environment/blog/2014/jul/14/8-charts-climate-change-world-more-dangerous

unemployment rate in Nigeria which still stands at 7.5% (World Bank Databank, 2015).

5.3.2 Energy Policy Reforms

The Nigerian Energy Policy which is also known as the National Energy Policy, was developed to ensure the optimal, adequate, reliable and secure supply of energy to, and its efficient utilization, while ensuring a sustainable development (NEP, 2013). It's vital for policy reforms in the energy sector in order to keep abreast of the latest development going on in the field of energy technology. The introduction and deployment of the suggested low carbon technologies used in the scenario analysis (Chapter 4 and Section 5.1-5.2) can only be actualized through energy policy reforms.

Energy policy reforms will provide a historic opportunity to identify and revitalize some ailing areas in the energy sector and bolster the overall economy. In countries such as Mexico (Romero and Castro, 2008), the United States of America (Joskow, 2000), some European countries (Glachant, 2009), South Korea[162] and other Asian countries[163], energy policy reforms have played important roles in low carbon-green growth. Although the Nigerian government has made some reforms in the energy sector (Usman & Abbasoglu, 2014), the reforms take considerable time in its implementation and the effect of most energy policies take more than 10 years to be felt. The solution to this challenges would be to reduce the lifetime of most policies and

[162] https://www.iea.org/publications/freepublications/publication/Korea2012_free.pdf
[163] http://www.adb.org/sectors/energy/issues/sector-governance-reform

set up policy evaluation units, with the responsibility of evaluating the effectiveness of energy policies in the county.

5.3.3 Long-Term Energy Planning and Target

According to Winston Churchill during the Second World War, "He who fails to plan is planning to fail"[164]. A country that has no proper plans on energy for the future is bound to experience energy crisis[165]. Long-term energy planning can help mitigate not against shortage in energy supply, but also GHGs in the environment. Lack of proper planning can lead to pollution problems experienced in places such as Baoding in China[166] and some cities in India[167]. From the GHGs emissions in the alternative scenarios (i.e. LCM, LCA and GO), various reduction potentials can be achieved if the government strategies are in place. For example in Figure 5-35 shows a reduced emission in the GO scenario as compared to the REF scenario. This leads to the GHGs savings as shown in result of the cost-benefit analysis.

Long-term energy planning and target creates a vision and strategy which has the capacity to promote technological innovation and development in low carbon technologies (Emodi et al., 2015c). The research, development and deployment (RD&D) of low carbon technologies require considerable time for both research and development (R&D), commercialization and

[164] http://www.in.gov/dnr/water/files/wa-IEAP.pdf
[165] http://www.thehindubusinessline.com/opinion/we-lack-a-clear-view-on-energy-planning/article6875164.ece
[166] http://www.theguardian.com/cities/2015/may/22/baoding-china-most-polluted-city-air-pollution-beijing-hebei
[167] http://gizmodo.com/indias-air-pollution-is-so-bad-its-causing-lung-damage-1707775668

funding. Therefore, the Nigerian government should not only plan and set targets for energy development, but also set up important sustainable infrastructure development. This will stimulate investment and improve on innovative ideas between the government and private investors. An example is cited in the South Korea where the government implemented the Five Year Green Growth Plan to stimulate the needed investment and innovations in low carbon technologies (Mathews, 2012; Moon, 2010; Kim, Shin, & Chung, 2011).

5.3.4 Energy Regulations and Standards

In moving towards a low carbon-green growth society, the Nigerian government should improve on its energy regulations and standards. This includes technical regulations and voluntary standards as being handled by the Standard Organization of Nigeria (SON)[168]. However, renewable energy standards have not been adequately developed in Nigeria and this is vital in ensuring the acceptance of renewables in Nigeria (Emodi et al., 2014). The improvement on energy regulations and standards will provide an enabling environment and incentives, increase renewable energy consumers and business owner’s confidence in deployment, and encourage innovation and commercialization of low carbon-green technologies (Bina, 2013; Gibbs & O’Neill, 2014; Bailey & Caprotti, 2014; Linner & Selin, 2014). The realization of the alternative scenarios (especially the GO) will require a stronger commitment by the Nigerian government in improving energy

[168] http://services.gov.ng/son

regulations and standards. This includes a range of standards such as; emissions, energy efficiency, fuel efficiency, energy efficiency building in both residential, commercial and industrial buildings. The effect of this policies were observed in the scenario analysis (see Section 5.2).

An example of a standards that can be enforced as a Law is the National Appliance Efficiency Standards Law. This law would ensure that every electrical appliance, either imported or manufactured in the country, would meet the minimum efficiency standards for energy consumption. The standards would cover all major household appliances (home entertainment appliances, refrigerators, freezers, washing and drying machines, electric cookers, and air conditioners), lighting products (lamps and fluorescent lighting ballasts), and other appliances used in the industrial, commercial, and service sectors of the economy (Geller, 1997).

5.3.5 Environmental Tax Reforms

Environmental tax reform is defined as the reform of the national tax system where there is a shift of the burden of taxes, for example from labor to environmentally damaging activities such as unsustainable resource use or pollution (European Environment Agency [EPA], 2015). This actually means shifting the tax base to resource consumption while maintaining revenue equality which will ensure the non-increase of the overall burden of tax. This has great potential in boosting economic growth and providing employment by reducing labor cost. This is done by increasing the prices of energy resource use (for electricity, transport, household etc.) and pollution (industries, transport etc.) by their accompanying tax. The tax revenues will be used to complement those tax realized from the productive sectors of the economy (Ekins & Speck, 2011).

This will ensure the effectiveness of policies proposed in the alternative scenarios such as fuel switching and economy in the transport sector, conversion to electric arc blast furnace in industries (See Section 5.1.4), and the diversification of electricity generation source such as renewables. Some countries have introduce environmental tax, they include; India (Shukla & Dhar, 2011), Iran (Reza Farzin, Guillaume & Zytek, 2011), China (Liang, Fan & Wei, 2007), Canada (Harrison, 2012), Indonesia (Yusuf, 2008) and the some European countries (Barker, Junankar, Pollitt, & Summerton, 2007). This countries recorded some considerable amount of success in their environmental tax reforms, and this can be replicated in the Nigerian case if properly implemented.

5.3.6 Urban Planning

The increase in urbanization rate as assumed in Table 4-1 in all the scenarios calls for proper urban planning in cities and urban areas. This increase will also lead to increase in car ownership by the population. Most cities and urban areas in Nigeria lacks proper strategic planning (Innocent, 2013). The proper planning of cities with a variety of mass transit options[169]

[169] This includes the increased access to mass transit use and the discouragement of private car

and mixed use (as described in the GO scenario) can reduce energy demand and GHGs emission in the transport sector. The design of urban centers should emulate compact city[170] in order to reduce the need for mobility through transport. This is done by concentrating and mixing offices, commercial and residential areas, and ensuring a walkable way is provided in streets which are well connected (Daramola & Ibem, 2010).

For discouraging private vehicle use, the Nigerian government should set up a parking management authorities in urban areas (Jordan & Infante, 2012). An example is cited in Abu Dhabi which was struggling with its congested traffic system and increased pollution due to large number of private car use by their owners. The government through the Abu Dhabi Urban Planning Council initiated the Abu Dhabi Urban Street Design Manual which sort of guide designers in creating walkable streets to encourage people to walk instead of driving (Abu Dhabi Urban Planning Council, 2015).

5.3.7 Efficient Building Design

The reduction in energy consumption in residential, commercial and industrial buildings can effectively reduce the total demand for energy and reduce GHG emission in Nigeria. As discussed in Section 5.1.4.3 and 5.2.3, great potential exist in buildings if effective energy efficiency policies are rigorously followed. Already existing buildings in Nigeria will have to

use as was discussed in the LCA and GO scenarios for the transport sector.

[170] Measures includes; the promotion of vertical and cluster development, encourage cellular development, and set urban growth boundaries to limit urban and suburban sprawl.

improve on energy efficiency, while new building designs should be based on low carbon building standards.

According to studies by (Change, 2007; Stern, 2007; Davidson, Bosch, Dave & Meyer, 2007; Intergovernmental panel on Climate change, 2007), buildings consume about 40 percent of the global energy, 12 percent of freshwater use and contributes 40 percent of the total GHG emission in the world. The scenario analysis showed that the household sector in the REF scenario (see Figure 5-1), energy demand will increase up to 3,075 PJ in 2040 if effective policy measures are not put in place. This is by far, a high demand for energy as compared to the alternative scenarios. This shows the need for the development of efficient buildings so as to reduce demands for energy.

Some challenges that may arise in the development of efficient building designs includes; lack of public awareness, access to financial resources and the unavailability of new efficient technologies which may be costly to the users. The introduction of energy labelling program in the LCA scenario also presents its potentials for not only efficient appliance use, but also save utility bills to the consumers.

The Nigerian government can use regulatory measures such as building certificate and audit programs, building codes, and appliance standards for high efficiency to aid in improving energy efficiency in buildings. Other means that can be used by the government are through fiscal incentives, which can come in forms of grants, subsidies and tax exceptions which are awarded to residential, commercial and industrial buildings employing energy efficiency measures. This will be useful in encouraging industries in acquiring electric arc blast furnace as applied in the GO scenario (see Section 4.3.5 and 5.1.4).

5.3.8 Efficiency of the Energy System

In order to advance to a low carbon-green economy, the efficiency of the Nigerian energy system needs to be improved. This will facilitate the production and consumption of low GHG emission and energy savings. As developed in the GO scenario, the shifting from fossil fuels to renewable energy options is vital in ensuring sustainability of power supply. In connection to improved urban planning and efficient building design, the demand-side management systems and energy efficiency will contribute to the realization of a low carbon-green economy in Nigeria.

Investing in low carbon and green technology are expensive as was discussed in Chapter 5. The good news to this effect are the reduction in cost of investment overtime (Section 5.2.4). According to the International Energy Agency (2011), for every US$1 of investment in low carbon energy technology not invested before 2020, an additional cost of US$4.3 will be required to off-set the GHG emissions. This means that if the Nigerian government refuse to take actions now in investing in low carbon, energy efficiency and green technologies, the government will spend a lot out of its budget on climate disaster on the medium and long term.

Other areas of the energy system that requires efficiency improvement includes T&D as described in the alternative scenarios. The diversifications to renewables should not only be at the supply side only, but also at the demand side, especially in the household sector (as observed in the GO scenario). In energy system should also incorporate the utilization of urban waste for energy generation as this will reduce pollution (urban waste) and contribute to electricity generation (through biomass power plants).

5.3.9 Efficiency of Passenger Transport System

Improve the efficiency of the passenger transport system in Nigeria. The transportation sector is one of the main sources of energy consumption and atmospheric pollution in Nigeria. A more sustainable transport system could be achieved if there were proper coordination of urban and transport planning to reduce light vehicle and fuel use. Policy options for a sustainable transport system include the stimulation of public transportation through the introduction of an intermodal passenger and freight transport system that will better integrate and improve the lives of Nigerians. A specific example is the Seoul Metro System in Seoul[171], South Korea, as shown in Figure 5-43.

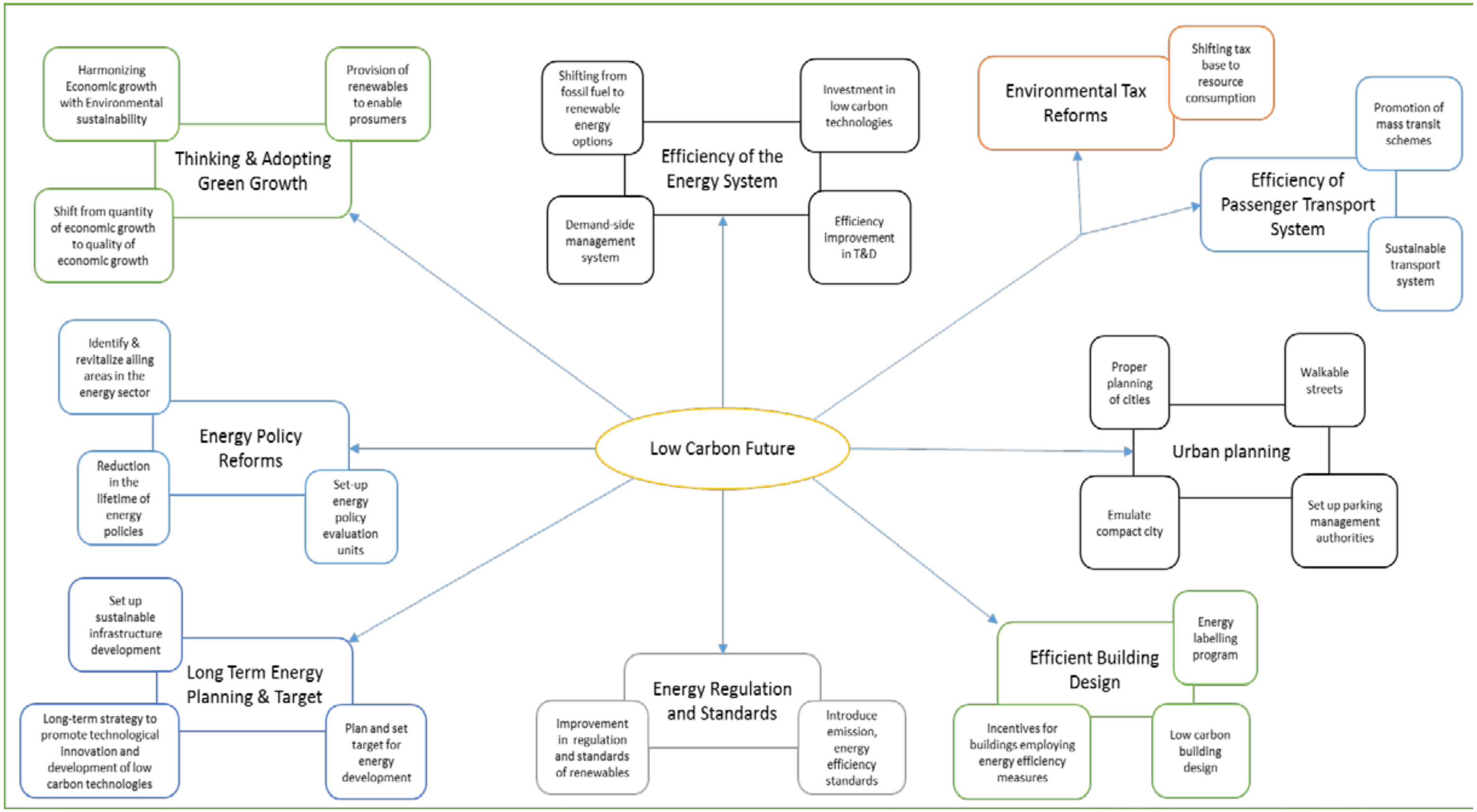
[171] The Seoul Metropolitan Subway is known as the world's longest multi-operator metro system by route length, and consists of 18 lines that serve the Seoul Metropolitan Area. The subway system is packed with advanced technology such as 4G LTE, WiFi, DMB, and WiBro services. Most of the trains are equipped with digital TV screens; all the trains are air conditioned, and include climate-controlled seats that operate automatically during the winter. All the subway lines use the T-money smart payment system using RFID and NFC technology for automatic payment by T-money smartphones or credit cards, and one can transfer to any of the lines within the subway system for free.

Figure 5-43: Seoul metropolitan subway map. Source: Visit Seoul (2015)

This subway system can reduce energy use in cars and buses for urban movement. For the Nigerian government to facilitate and implement this option, some strategies should be explored. These strategies include the promotion of subway use, expansion of the public transport infrastructure, use of urban tolls, increase in the cost of automobile parking spaces in congested urban areas[172], restrictions on the use of automobiles to reduce congestion and air pollution in major cities, and improvements in telecommuting policies in Nigeria. A summary of the proposed strategies in attaining a low carbon development in Nigeria is shown in Figure 5-44.

172 These could be through a parking management policy as discussed in Johansson and Nakićenović (2012), and Jaccard et al., (2012)

Figure 5-44: Summary of low carbon Strategies for Nigeria



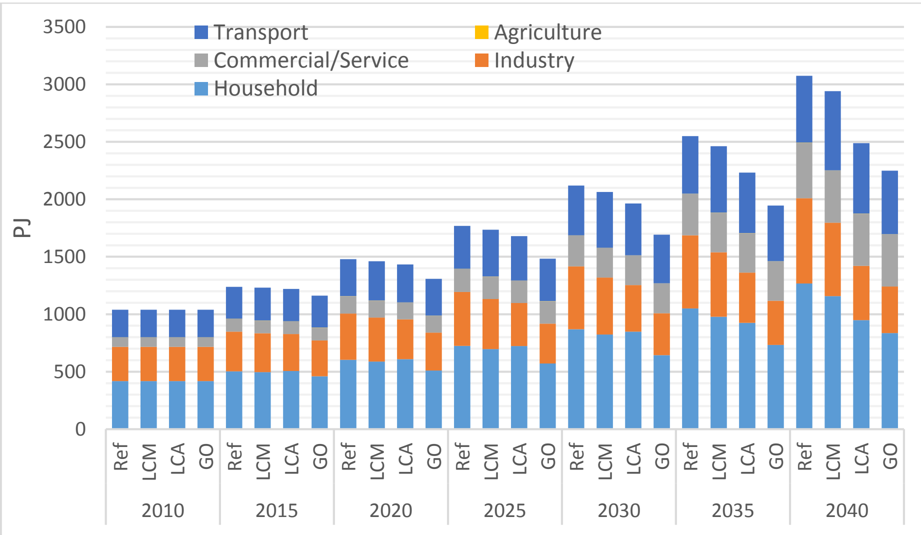
5.4 Key Findings and Policy Implications

5.4.1 Key Findings and Assessment

Based on the scenarios' assumptions of the socioeconomic development and assumed parameters for the Nigerian LEAP model, the energy implications of the four possible pathways for Nigeria were analyzed using the LEAP model for the REF, LCM, LCA, and GO scenarios over the period of 2010-2040. Below are the key findings of the analysis.

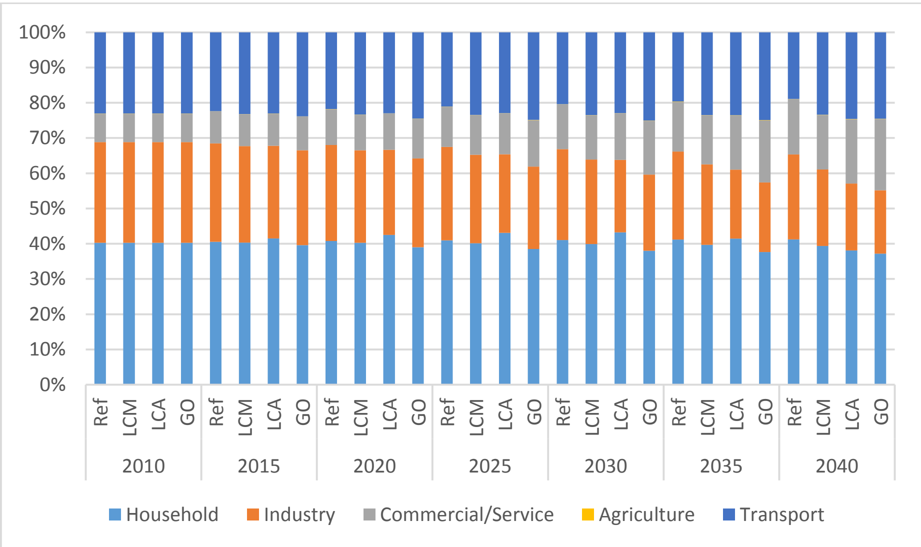
- In the REF, LCM, LCA, and GO scenarios, the energy demand will grow at an annual rate of 3.58, 3.53, 2.95, and 2.61%, respectively. The energy demand will be 2,249.2 PJ, the lowest among the four scenarios, in the GO scenario (see Figure 5-45). The increases in economic activity, population, households, income, and industry and transport needs are the major drivers in Nigeria's energy demand.

Figure 5-45: Total energy demand comparison among scenarios' results



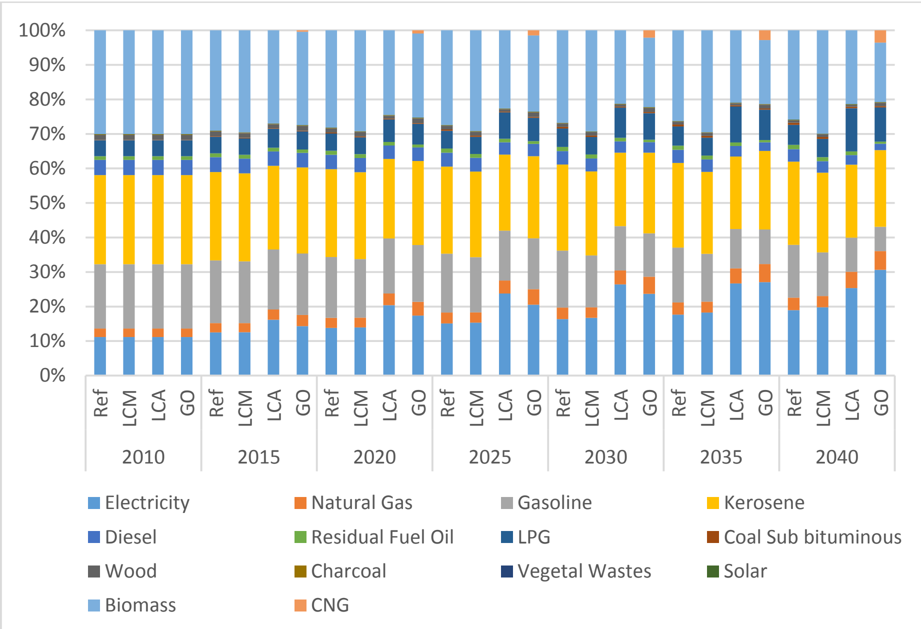
- In the REF scenario, the households' share in the energy demand will increase from 40% in 2010 to 42% in 2040 (see Figure 5-46). As for the industry, its share will decrease to 26% in 2040 from 29% in 2010. The share of the transport and commercial/service sector will increase from 9% in the base year to about 16% in 2040. The households' share of the energy demand will decrease to 39, 38, and 37% in 2040 in the LCM, LCA, and GO scenarios, respectively. Also, the share of the industry sector will decrease across the alternative scenarios while the share of the transport and commercial/service sector will increase to 22, 23, and 23%, respectively, in the LCM, LCA, and GO scenarios. The energy consumption of the residential and transport and commercial/service sectors defines the vital role played by these sectors in shaping Nigeria's overall energy pathways.

Figure 5-46: Share of final energy demand by sector



- The total energy supply is expected to increase from 2010 to 2040, but it will decrease across the scenarios. In the REF scenario, the share of electricity supply will increase from 11% to about 19% while biomass and kerosene will have 25 and 26% shares, respectively, in 2040. Electricity supply will increase in all the alternative scenarios, with the highest share observed in the GO scenario (see Figure 5-47). Oil products (e.g., kerosene and gasoline) and biomass will play a significant role in Nigeria's energy mix in all the scenarios.

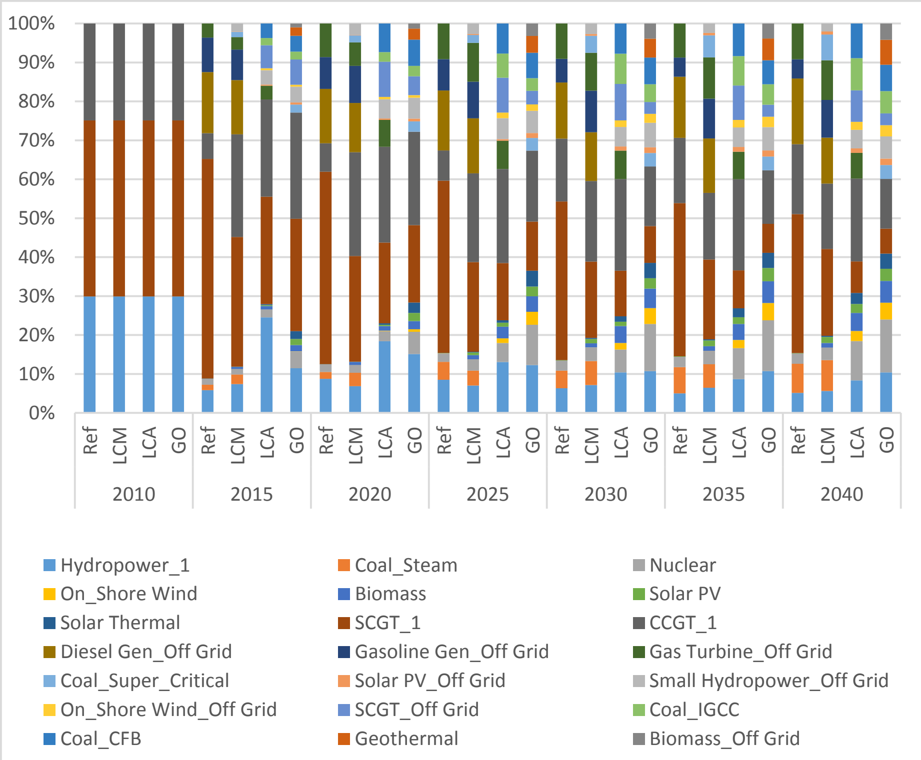
Figure 5-47: Share of energy requirements by fuels (in demand sectors)



- The share of LPG will increase from 5% in 2010 to 13% in 2040 under the LCA scenario while that of CNG will increase to 4% at the end of 2040 in the GO scenario. Gasoline will have a reduced share in all the alternative scenarios, with the lowest share of 7% in the GO scenario. These fuels are expected to play an increasingly important role in the transport sector. The promotion of LPG, CNG, and biofuel is expected to provide alternative fuel options in the transport sector.

- The electricity and natural gas T&D losses will be reduced to 10 and 20% in the REF scenario, 6 and 13% in the LCM scenario, 5 and 10% in the LCA scenario, and 4 and 6% in the GO scenario. In all the scenarios, the improvement in electricity T&D will increase the power supply to the demand sector while natural gas T&D improvement will ensure the sufficient supply of natural gas to the power plants and the industry sector.
- On electricity generation, in the REF and LCM scenarios, the share of fossil fuel power plants will increase as their electricity mix is expanded. The LCA scenario assumes an increased electricity supply from low-carbon technologies such as nuclear, CCGT, and coal CFB while balancing the mix with renewables. The GO scenario considers an increased share of about 70% installed capacity from renewables (see Figure 5-48).

Figure 5-48: Share of electricity generation mix



- The structural changes in the electricity mix, as shown in Figure 5-48, mean that the consumption of fossil fuel will be reduced in the LCA and GO scenarios. This will occur as the energy usage structure in Nigeria is gradually becoming more environment-friendly, with rapid growth in the use of low-carbon green technologies.
- In each scenario in this thesis, the overall GHG emission will increase from 2010 to 2040 (see Figure 5-35). The REF scenario had the highest GHG emission level in 2040 (201.2 MMTCDE), and a lower amount was observed in the LCM, LCA, and GO scenarios (185.4, 152, and 124.4 MMTCDE, respectively). Although Nigeria is not under any obligation to

reduce its GHG emission because its emission level is very low, the global awareness of climate change is taken into consideration in the LCA scenario, and even more so in the GO scenario.

- Nigeria will continue to import oil and gas products from overseas refineries in the long run due to an increase in the energy demand and the low refinery capacity of the domestic refineries. Thus, the government needs to build more refineries and identify more options to increase the production capacity of the Nigerian refineries.
- The cost-benefit analysis showed that among the three alternative scenarios as mitigation to the REF scenario, the LCA and GO scenarios had a higher cost than the LCM scenario. The overall net present value (NPV) of the LCM scenario cost is USD1.69 billion, that of the LCA scenario cost is USD23.8 billion, and that of the GO scenario cost is USD41.4 billion. Although these costs are high because investments are made in energy efficiency, fuel switching, etc., this is somewhat offset by the energy savings on the demand-side, production, and environment externalities.
- On the least-cost electricity generation, on-shore wind power was observed to be the least-cost electricity generation option overall while CCGT was the least-cost option for fossil fuel power plants. The optimization was carried out from 2010 to 2040, with an electricity generation target of 200,000 MWh.
- In the different scenarios, based on the power plants' specific GHG emissions, coal steam will have the highest GHG emission in 2040 while

the least GHG emission will be from the CCGT power plants. Although biomass was included, its GHG was insignificant; besides, the power plant was classified as a low-carbon energy technology.

In summary, the scenarios that were developed in this thesis present the possible energy pathways in Nigeria in the future and their impact on the energy system in terms of the energy demand and supply mix, the energy-related GHG emissions, and the costs and benefits. Further, the thesis examined the least-cost electricity generation from the power plants that were used in modeling the electricity sector in the Nigerian LEAP model. The results are very useful for energy planning and for the formulation of effective energy policies in Nigeria as well as in other developing countries.

5.4.2 Policy Implications

From the alternative scenarios and least-cost electricity generation options examined in this research, a number of policy implications can be drawn for the development of sustainable strategies and energy policies for the energy sector in Nigeria.

The first implication is the need to improve the energy efficiency in both the supply and demand sides through the application of modern energy technologies and practices. On the demand side, the implementation of energy efficiency practices such as the replacement of incandescent bulbs for lighting with CFL and LED bulbs has great energy savings potential. The implementation of these policies should be focused not only on the residential sector but also on the industry and commercial/service sectors. This practice should also extend to the provision of efficient cooking stoves because cooking and lighting are the most energy-intensive activities in the residential sector. Initiating an energy efficiency labeling program for household electronics and appliances such as air-conditioning units and refrigerators will also help reduce the energy demand. On the supply side, efficiency improvement should be focused on the transmission and distribution network in both electricity and natural gas supply. Further, the oil refineries will need an improved energy efficiency practice and not just an increase in production capacity.

Second, the government should make provisions for the development and deployment of alternative fuels in the demand and supply sides. This will ensure a decrease in dependence on a particular fuel source, such as biomass and oil, as seen in this thesis. This can be done through the promotion of the use of LPG for residential consumption (e.g., cooking and lighting) and in the transportation sector. Besides the use of LPG as an alternative fuel, the use of CNG and biomass should be further explored to reduce the country's oil dependency and limit the GHG emissions. The government, in conjunction with the private sector, can work in ensuring the deployment of efficient alternative technologies for production, such as the electric-arc blast furnace for the industry sector. Also, cooperation will be needed in the adoption of CNG and LPG vehicles for transport fleet operators who may find technology switching challenging. This can be achieved through the implementation of a national autogas incentive and policy to stimulate the stakeholders in developing the sector.

Third, the government should encourage the use of renewable energy technologies in both the supply and demand sides through the provision of incentives such as investment tax credits, low-cost loans for power generation, or feed-in tariffs. This should be done considering the importance of reducing the fossil fuel demand and GHG emission and of ensuring the sustainability of the energy system. Although the cost of implementing energy policies and strategies is very high, as shown in the cost-benefit analysis in this study, an offset cost could be realized from energy savings and from the reduction of the natural resource depletion rate and the GHG emission. The possibility of the application of carbon capture and storage (CCS) exist for the coal and gas power plants, but it may be too early for this as the Nigerian government seems not too concerned about the CCS technology at present. Thus, the selection of low-carbon technologies appears to be the most viable pathway in ensuring a low GHG level.

Finally, the results for the least-cost electricity generation options showed that CCGT power plants are the best option for electricity generation for fossil fuel power plants while on-shore wind and small hydropower are the least-cost renewables. This shows the government and policymakers the long-term benefits of utilizing the maximum potentials of these power plants. Other energy technologies, however, such as biomass, large hydropower, and nuclear power, still present low-cost potential, the renewables are still better alternatives for power generation. Overall, the policy implementation strategies should be focused on achieving a long-term impact on the energy system that will positively benefit the society in particular and the environment in general.

Chapter 6. Conclusion and Policy Recommendations

This chapter concludes the thesis, and based on the implications derived from the analysis of the scenarios and the least-cost electricity generation options, some policy recommendations are presented herein. The chapter also presents some limitations of the study and offers suggestions for future research.

6.1 Conclusion

The main objectives of this thesis were (1) to develop an energy model for Nigeria that would consider the vital factors that could influence the country's future energy policies; (2) to explore the least-cost options for electricity generation; and (3) to recommend strategic energy policy options for low-carbon development in Nigeria. These objectives were intended to answer the research questions that were developed from the research problems.

Before developing the model, an extensive review of the Nigerian energy sector was carried out to derive insights into the country's energy resource potentials, energy supply and consumption, and various government agencies and policies. A further review of the available relevant literature on the existing energy models and of the literature applying the LEAP model was carried out. This provided a literature background and a basis for the selection of the LEAP model for Nigeria. The model that was developed incorporated four policy scenarios that differ from one another, which were used to capture the vital factors that could influence the country's future energy policies. These factors, which were taken as parameters, included the GDP, the household/population/urbanization growth rates, and the growth rates of the energy-intensive sectors.

The four scenarios that were developed in this study are the reference (REF), low-carbon moderate (LCM), low-carbon advanced (LCA), and green-optimistic (GO) scenarios. The results of the modeled scenarios showed that the energy demand is expected to grow at an annual growth rate of 3.58% (REF), 3.53% (LCM), 2.95% (LCA), and 2.61% (GO). The REF scenario's energy demand by 2040 (3,075 PJ) was the highest, while the GO scenario's was the lowest (2,249.2 PJ). The GHG emission rate in the GO scenario (124.4 MMTCDE) was very low compared to the other scenarios due to the high level of renewable energy application into the energy mix.

The level of energy policies such as various degrees of energy efficiency improvement and fuel/technology switching will increase in the LCM scenario (which had a moderate policy implementation), in the LCA scenario, and in the more aggressive GO scenario. Furthermore, a cost-benefit analysis was carried out to ascertain the cost of implementing some policies and strategies in Nigeria, including energy efficiency improvement and fuel/technology switching. The results showed that it will cost Nigeria USD1.69 billion to implement policies in the LCM scenario, USD23.8 billion in the LCA scenario, and USD41.4 billion in the GO scenario. These investment costs are understandably high, but the offset cost in the long run will come from the energy savings on the demand-side, production, and environmental externalities.

With regard to the least-cost electricity generation options for power plants in the different scenarios in this study, it was shown that on-shore wind power and small hydropower are the least-cost electricity generation options overall. For fossil fuel power plants, CCGT was identified as the least-cost option for electricity generation as well as the lowest-GHG-emitting power plant besides biomass, which was considered a low-carbon/renewable energy technology. From the results in general, it was observed that low-carbon and renewable technologies will have an important role to play in the realization of low-carbon development in Nigeria.

To achieve this feat, this thesis explored some strategies that can ensure low-carbon development in Nigeria, with a view to attaining green growth. These strategies include adopting the green growth ideology and coming up with energy policy reforms, long-term energy plans and targets, energy regulations and standards, environmental tax reforms, urban plans, efficient building designs, and measures to improve the efficiency of the country's energy and transport system. The findings from this thesis can be used as a guide in the development of energy policies and strategies for the attainment of low-carbon development in Nigeria in the long term.

6.2 Policy Recommendations

Based on the policy implications derived from this thesis, the following policy recommendations are made:

- Domestic water heaters and electricity from renewables such as solar thermal and PV systems should be provided to the households in Nigeria so as to reduce the energy demand and GHG emissions in the country. This is due to the impact of the solar PV system in the household sector in the Nigerian LEAP model, which was projected to increase in the alternative scenario. The household sector in the GO scenario will decrease its energy consumption due to energy efficiency improvement and renewable energy application (solar). This not only has the potential to reduce the electricity demand but can also generate income for the consumers (prosumers). This was also highlighted in section 5.3.
- Some form of government incentives, such as investment tax credits and low-cost loans, should be provided to renewable energy technologies for households, and tax breaks can be offered to electricity companies and industries switching to low-carbon technologies. This was among the sustainable strategies discussed in section 5.3.3 as part of the long-term energy plan and targets. As shown in the cost-benefit analysis in section 5.2.5, funding renewables in the Nigerian context will be expensive in the short term but provides the least-cost option for electricity generation in the long term, as discussed in section 5.2.6.

- Efficiency improvement in both the supply and demand sides through the use of modern technologies should be a topmost priority of the government. This is supported by this study as the alternative scenarios in the study proved that the increased impact of energy efficiency has an important role to play in Nigeria's future energy system. The scenario analysis showed that with the increase in energy efficiency policies in the GO scenario, about 826 PJ energy will be saved as against the REF scenario. On the supply side, energy efficiency improvement in the electricity sector through the reduction of T&D losses will help increase the electricity supply. Further, investing in efficient power plants such as CCGT plants should also be considered because the results of the least-cost electricity generation in this study showed that CCGT power plants were capable of meeting a given electricity demand at the least cost and with the least GHG emission. Therefore, with the increased implementation of energy efficiency policies in Nigeria, greater energy and GHG emission reductions will be realized. The improvement in energy efficiency both in the supply and demand sides will not come without some challenges due to the need for the provision of capital and other bureaucratic issues. With regard to investment/capital, the government can stimulate the residential sector to improve the household efficiency through the provision of subsidies for the consumers who are to purchase and use efficient appliances as well as renewables such as solar thermal and PV systems. The provision of CFL and LED bulbs can also be encouraged through the provision of incentives for households and the commercial/service establishments that will make a switch from incandescent bulbs to CFL/LED. Policies that impose penalties on the use of incandescent bulbs can also be introduced, and the funds that will be generated from such can be used as incentives for those switching to CFL/LED.

- The use of alternative fuels in the transport sector, such as biofuels and CNG, will aid in the reduction of Nigeria's oil dependency and GHG emissions. The stronger promotion of these alternative fuels should be encouraged by the government. This is due to the results obtained from the alternative scenarios. In the GO scenario, the LPG, CNG, and biofuel options were made available for the transport sector, and this reduced not only the GHG emissions but also the dependency on gasoline and diesel. The Nigerian government can promote the use of alternative fuels through fiscal incentives such as a national autogas incentive and policy, which has gained success in many countries around the world.
- Nigeria's energy policy should be reviewed within a shorter time frame, with the aid of policy evaluation experts who can ascertain the impact of government policies at the grassroots level. This was shown in Figure 2-28, where some policy overlaps in the Nigerian energy policies were highlighted. To implement the policies in the alternative scenarios, policy evaluation bodies need to be established. In the Nigerian LEAP model, residential households were categorized into urban and rural households. Most government policies are less effective in the rural areas while those that have an impact in the urban areas are sometimes left to become

obsolete. Therefore, energy policies need to be revised within a shorter time frame while policy evaluation units should also estimate the impact of government policies at the grassroots level.

- The setting up of an aggressive environmental tax by the relevant government agencies will aid in the reduction of GHG emissions as the society will become more aware of the effect of GHG accumulation. Although this was not part of the scenario analysis, it was discussed as a sustainable strategy that can be employed by the Nigerian government in section 5.3.5. This can be an energy reduction measure as a shift will be made from a tax base to resource consumption. The funds that will be collected can also be used to fund renewable energy development through the provision of soft loans and incentives.
- The government, through its relevant bodies and agencies, should ensure proper urban planning to realize energy efficiency in buildings while providing walkways for pedestrians. There may be some challenges in realizing this, but the provision of incentives can stimulate the consumers, house owners, and building contractors. As shown by the cost-benefit analysis in section 5.2.5, the government should look into the long-term benefits of energy efficiency improvement in buildings as this could help in saving the cost of delivering future energy services.
- An increase in private car ownership should be discouraged by the government as this would increase the energy demand and GHG emission. This can be achieved through the provision of an efficient public transport system, tax payments for private car ownership, and parking lots for

private cars. The four policy scenarios showed an increased amount of cars from the base year (2010) to 2040. Although fuel options and energy efficiency measures were in place to reduce the energy demand and the GHG emissions, the rate of private cars was still high. This calls for increased measures to reduce the rate of private cars, as discussed in section 5.3.6.

- Besides the need to increase the production capacity of the refineries in Nigeria, the government needs to introduce, deploy, and promote the use of portable crude oil refineries as a short- and medium-term policies. This will address the nation's current and future energy needs with the continued expansion of the domestic refineries as a long-term policy plan. The energy balance under the REF scenario (section 5.1.1.3) gave an insight on what the Nigerian energy system will be like in 2040 with the high importation of oil products. The production capacity of the refineries in Nigeria cannot possibly meet the country's future energy requirement. Thus, the government needs to device other means of meeting the demand for fossil fuel products. The construction of large refinery facilities is highly considerable but requires long-term planning to become fully operational. This supports the recommendation for the introduction of portable refineries, which are relatively cheaper and more efficient, to meet the short-term demand. The stakeholders in the oil and gas sector need to be encouraged by the Nigerian government to embrace the idea of portable refineries as a short- to medium-term strategy.

6.3 Study Limitations and Suggestions for Further Study

This study is not without limitations due to the nature of the research methodology applied. Below are the study limitations.

- The variables in the transport sector, which include the railway, airway, and seaway transport systems, were incomplete. The datasets for these variables were not available during the development of the Nigerian LEAP model. Therefore, the provision of these datasets will boost the results of the current model.
- The four scenarios that were developed in this study do not exhaust the possibility of providing solutions to low-carbon development in Nigeria. As the future is uncertain, more pathways involving various energy policies could be developed in further studies, and the results could be compared to identify a better pathway.
- The study did not examine some emission reduction schemes that can earn some revenues, such as the clean development mechanisms, among others. This will also provide more sustainable options for low-carbon development in Nigeria if integrated into the Nigerian LEAP model.
- The impact of fuel subsidy removal and oil price change was not taken into consideration in the development of policy scenarios. This can be added to one or more scenarios in further studies so as to identify the adoption measures for Nigeria in the future.
- Finally and most importantly, the Nigerian LEAP model did not consider the impact of climate change on the country's future energy system. This

is important because power plants such as hydropower plants are highly prone to droughts while gas power plants need water to cool the turbines. Also, the identification of possible wind and solar locations with high wind speed and solar radiation is vital in energy planning.

In conclusion, there is room for more improvement in this study if the aforementioned study limitations will be addressed in future studies. It is believed, however, that the strategies that were proposed and the recommendations that were made in this thesis, which were based on the analysis that was carried out on the Nigerian LEAP model, will indeed move Nigeria towards a low-carbon society with the mindset of attaining green growth in the future.

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Appendix A: Projections

Appendix A1: Projected Electricity Generation Capacity under the REF Scenario (2010 – 2040)

	2010		**2015**		**2020**		**2025**		**2030**		**2035**		**2040**	
	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share
On Grid Electricity Generation Technologies														
Biomass					3	0%	16	0%	25	0%	35	0%	54	0%
CCGT	1100	12%	2000	9%	3500	10%	5000	11%	15000	21%	21000	22%	26300	24%
Coal Steam					1000	3%	3500	7%	5000	7%	10000	11%	13000	8%
Hydropower	1900	20%	2100	9%	5000	14%	6500	14%	7000	10%	7500	8%	9000	8%
Nuclear					1000	3%	1500	3%	2500	4%	3500	4%	4000	4%
On-Shore Wind					10	0%	19	0%	22	0%	25	0%	29	0%
SCGT	6500	68%	18000	81%	25000	70%	30000	64%	40000	57%	52000	55%	55260	51%
Solar Thermal					1	0%	10	0%	20	0%	30	0%	40	0%
Solar PV			30	0%	75	0%	200	0%	425	1%	560	1%	600	1%
sub-total	9500		22130		35589		46745		69992		94650		108283	
Off Grid Electricity Generation Technologies														
Diesel Gen	3000	70%	4600	54%	6500	43%	9600	44%	13000	46%	19000	50%	24000	51%
Gasoline Gen	1300	30%	2600	31%	3800	25%	5000	23%	5500	19%	6000	16%	7000	15%
Gas Turbine			1300	15%	4900	32%	7000	32%	10000	35%	13000	34%	16000	34%
sub-total	4300		8500		15200		21600		28500		38000		47000	
Total	**13800**		**30630**		**50789**		**68345**		**98492**		**132650**		**155283**	

Appendix A2: Projected share of Vehicles by fuel type in the LCM Scenario

Vehicle type	Fuel type	Share in 2010 (%)	Share in 2040 (%)
Motorcycles	Petrol	100	80
	Biodiesel	0	20
Cars	Petrol	99	15
	Diesel	1	5
	Biofuel	0	70
Light Goods Vehicle (LGV)	Petrol	100	50
	Biofuel	0	50
Urban Bus (UB)	Petrol	100	30
	Biofuel	0	70
Long-Distance Coach (LDC)	Diesel	100	40
	Biofuel	0	60
Heavy Goods Vehicle (HGV)	Diesel	100	40
	Biodiesel	0	60

Appendix A3: Charcoal Production Shares by Scenarios

Scenario	Production plants	Share (%)
Base year	Traditional earth mound	100
Reference	Traditional earth mound	70
	Brick kiln	30
Low Carbon Moderate	Traditional earth mound	30
	Steel kiln	40
	Casamance	30
Low Carbon Advance	Traditional earth mound	25
	Mud beehive kiln	40
	Adam retort kiln	35
Green Optimistic	Traditional earth mound	20
	Single drum kiln	40
	Brick beehive kiln	40

Appendix A4: Projected Electricity Generation Capacity under the LCM Scenario (2010 – 2040)

	2010		**2015**		**2020**		**2025**		**2030**		**2035**		**2040**	
	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share
On Grid Electricity Generation Technologies														
Biomass					400	1%	800	2%	1000	2%	1500	2%	2000	2%
CCGT	1100	12%	9000	37%	13000	38%	15000	33%	17000	29%	19000	24%	25000	22%
Coal Steam					2000	6%	3000	7%	6000	10%	8000	10%	14000	12%
Coal Supercritical							1500	3%	4000	7%	7000	9%	11000	10%
Hydropower	1900	20%	3000	12%	4000	12%	5500	12%	7000	12%	8500	11%	10000	9%
Nuclear					1000	3%	2000	4%	3000	5%	4000	5%	5000	4%
On-Shore Wind			20	0%	30	0%	40	0%	50	0%	60	0%	100	0%
SCGT	6500	68%	12000	50%	14000	40%	16000	35%	17000	29%	24000	30%	35000	31%
Solar Thermal					100	0%	200	0%	500	1%	800	1%	1000	1%
Solar PV					100	0%	2000	4%	4000	7%	7000	9%	10000	9%
sub-total	9500		24020		34630		46040		59550		79860		113100	
Off Grid Electricity Generation Technologies														
Diesel Gen	3000	70%	4600	54%	6000	38%	9000	35%	10000	31%	15000	33%	17000	30%
Gasoline Gen	1300	30%	2600	31%	4500	28%	6000	24%	8500	27%	11000	24%	14000	24%
Gas Turbine			1300	15%	3500	22%	7800	31%	9500	30%	14000	30%	18000	31%
Small Hydropower					1600	10%	2000	8%	2500	8%	3000	7%	3400	6%
Solar PV					200	1%	600	2%	1500	5%	3000	7%	5000	9%
sub-total	4300		8500		15800		25400		32000		46000		57400	
Total	**13800**		**32520**		**50430**		**71440**		**91550**		**125860**		**170500**	

Appendix A5: Projected share of Vehicles by fuel type in the LCA Scenario

Vehicle type	Fuel type	Share in 2010 (%)	Share in 2040 (%)
Motorcycles	Petrol	100	60
	Biodiesel	0	40
Cars	Petrol	99	20
	Diesel	1	0
	Biofuel	0	40
	LPG	0	40
Light Goods Vehicle (LGV)	Petrol	100	30
	Biofuel	0	30
	LPG	0	40
Urban Bus (UB)	Petrol	100	30
	Biofuel	0	40
	LPG	0	30
Long-Distance Coach (LDC)	Diesel	100	25
	Biofuel	0	40
	LPG	0	35
Heavy Goods Vehicle (HGV)	Diesel	100	30
	Biodiesel	0	70

Appendix A6: Projected Electricity Generation Capacity under the LCA Scenario (2010 – 2040)

	2010		2015		2020		2025		2030		2035		2040	
	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share
On Grid Electricity Generation Technologies														
Biomass					500	2%	2000	4%	4000	6%	5000	5%	7500	5%
CCGT	1100	12%	6000	35%	9000	32%	14000	29%	19000	27%	25000	25%	30000	22%
Coal CFB			1000	6%	3000	11%	5000	10%	7000	10%	10000	10%	14000	10%
Coal IGCC					1000	4%	4000	8%	7000	10%	9000	9%	13000	10%
Hydropower	1900	20%	3000	18%	5000	18%	7000	14%	9000	13%	11000	11%	14000	10%
Nuclear					1000	4%	3000	6%	5000	7%	9000	9%	15000	11%
On-Shore Wind			20	0%	100	0%	1500	3%	3000	4%	5000	5%	8000	6%
SCGT	6500	68%	7000	41%	8000	28%	9000	18%	10000	14%	11000	11%	12000	9%
Solar Thermal					300	1%	800	2%	2500	4%	5500	6%	9000	7%
Solar PV					500	2%	2500	5%	4000	6%	8000	8%	14000	10%
sub-total	9500		17020		28400		48800		70500		98500		136500	
Off Grid Electricity Generation Technologies														
Diesel Gen	3000	70%												
Gasoline Gen	1300	30%												
Gas Turbine			1000	40%	3000	31%	5000	30%	7000	27%	9000	26%	11000	25%
SCGT			1500	60%	3500	36%	5500	33%	8000	30%	10000	28%	12000	27%
On-Shore Wind					500	5%	1800	11%	3000	11%	4500	13%	6500	15%
Small Hydropower					2000	21%	3500	21%	4500	17%	6000	17%	7500	17%
Solar PV					600	6%	1000	6%	3800	14%	5600	16%	7000	16%
sub-total	4300		2500		9600		16800		26300		35100		44000	
Total	13800		19520		38000		65600		96800		133600		180500	

Appendix A7: Projected share of Vehicles by fuel type in the GO Scenario

Vehicle type	Fuel type	Share in 2010 (%)	Share in 2040 (%)
Motorcycles	Petrol	100	50
	Biodiesel	0	50
Cars	Petrol	99	20
	Diesel	1	0
	Biofuel	0	30
	LPG	0	25
	CNG	0	25
Light Goods Vehicle (LGV)	Petrol	100	10
	Biofuel	0	20
	LPG	0	35
	CNG	0	35
Urban Bus (UB)	Petrol	100	5
	Biofuel	0	25
	LPG	0	35
	CNG	0	35
Long-Distance Coach (LDC)	Diesel	100	30
	Biofuel	0	20
	LPG	0	25
	CNG	0	25
Heavy Goods Vehicle (HGV)	Diesel	100	20
	Biodiesel	0	45
	CNG	0	35

Appendix A8: Projected Electricity Generation Capacity under the GO Scenario (2010 – 2040)

	2010		**2015**		**2020**		**2025**		**2030**		**2035**		**2040**	
	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share	MW	Share
On Grid Electricity Generation Technologies														
Biomass					800	2%	2500	4%	4500	5%	6500	5%	8000	5%
CCGT	1100	12%	6000	36%	8000	24%	10000	17%	12000	13%	14000	12%	16000	11%
Coal CFB			1000	6%	2500	7%	4000	7%	6000	7%	7000	6%	9500	7%
Coal IGCC					1000	3%	2000	3%	4000	4%	6000	5%	8000	5%
Coal Supercritical							1000	2%	3000	3%	4000	3%	5000	3%
Geothermal					1000	3%	2500	4%	4000	4%	6000	5%	8500	6%
Hydropower	1900	20%	3000	18%	6000	18%	8000	13%	10000	11%	13000	11%	15500	11%
Nuclear					2000	6%	6000	10%	10000	11%	14000	12%	18000	12%
Off-Shore Wind					100	0%	2000	3%	5000	6%	7000	6%	9000	6%
On-Shore Wind			20	0%	500	1%	4000	7%	7000	8%	10000	8%	12000	8%
SCGT	6500	68%	6700	40%	7000	21%	7300	12%	7800	9%	8000	7%	8500	6%
Solar Thermal					2000	6%	5000	8%	7000	8%	9000	8%	11000	8%
Solar PV					3000	9%	6000	10%	9000	10%	15000	13%	17000	12%
sub-total	9500		16720		33900		60300		89300		119500		146000	
Off Grid Electricity Generation Technologies														
Biomass					500	9%	2000	16%	3500	17%	4500	16%	6000	17%
Diesel Gen	3000	70%												

Gasoline Gen	1300	30%												
SCGT			1500	100%	1700	30%	2000	16%	2500	12%	3300	12%	4000	11%
On-Shore Wind					500	9%	2000	16%	4000	20%	6000	22%	8000	23%
Small Hydropower					2000	35%	3500	28%	5500	27%	6800	25%	8000	23%
Solar PV					1000	18%	3000	24%	5000	24%	7000	25%	9000	26%
sub-total	4300		1500		5700		12500		20500		27600		35000	
Total	**13800**				**39600**		**72800**		**109800**		**147100**		**181000**	

Appendix B: Sources of Datasets used in the Development of Nigeria LEAP Model

Appendix B1: Socio-economic Data

Source: The World Bank. www.data.worldbank.org

National Bureau of Statistics. www.nigerianstat.gov.ng

Index Mundi: www.indexmundi.com/facts/nigeria/access-to-electricity

Appendix B2: Percentage Distribution of Household Source of Fuel for Cooking (2010)

Source: National Bureau of Statistics. www.nigerianstat.gov.ng

Appendix B3: Percentage Distribution of Household by Source of Fuel for Lighting (2010)

Source: National Bureau of Statistics. www.nigerianstat.gov.ng

Appendix B4: Contributions to GDP by Percentage Share and Growth Rate (2010)

Source: National Bureau of Statistics. www.nigerianstat.gov.ng

Appendix B5: Petroleum Product Import (2010)

Source: National Bureau of Statistics. www.nigerianstat.gov.ng

Nigeria National Petroleum Corporation. www.nnpcgroup.com

Appendix B6: Petroleum Product Export (2010)

Source: National Bureau of Statistics. www.nigerianstat.gov.ng

Nigeria National Petroleum Corporation. www.nnpcgroup.com

Appendix B7: Kaduna refining and Petrochemical Company Actual Quality of Output in 2010

Source: National Bureau of Statistics. www.nigerianstat.gov.ng

Nigeria National Petroleum Corporation. www.nnpcgroup.com

Appendix B8: Nigeria Energy Balance (2010) (KTOE)

Source: International Energy Agency (IEA), 2015. http://www.iea.org/statistics/statisticssearch/report/?year=2010&country=NIGERIA&product=Balances

Appendix B9: Value Added and Growth rate of Sectors (2010)

Source: World Bank. www.data.worldbank.org

Appendix B10: Coal Mining in Nigeria (2010)

Source: Nigeria Coal Production by Year. U.S. Energy Information Administration (EIA). Available online: www.eia.gov.

Appendix B11: Distribution of Nigeria Average Household Appliances (2010)

Source: A survey of Nigerian middle class. http://www.fastestbillion.com/res/Research/Survey_Nigerian_middle_class-260911.pdf

Appendix B12: Energy Intensities in Nigerian Households (2010)

Source: Irimiya, Y., & Humphery, I. A and Aondover II (2013)"Assessment of Energy use Pattern in Residential Buildings of Kano and Kaduna Northern Nigeria" American Journal of Engineering Research. Volume, 2, 271-275.

National Bureau of Statistics. www.nigerianstat.gov.ng

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Ibitoye, F. I. (2013). The millennium development goals and household energy requirements in Nigeria. SpringerPlus, 2(1), 1-9.

Appendix B13: Percentage Share by Area for Lighting (Fuel) (2010)

Source: National Bureau of Statistics. www.nigerianstat.gov.ng

Appendix B14: Percentage Share of Area for Cooking (Fuel) (2010)

Source: National Bureau of Statistics. www.nigerianstat.gov.ng

Appendix B15: Categories of major Vehicles in Nigeria (2010)

Source: Babatunde S. Akintayo (2012). World Bank Vehicle Population Survey in Nigeria. Nigerian Institute of Transport Technology (NITT), Department of Professional Transport Studies, Zaria, Nigeria.

Appendix B16: Vehicle Fleet, Activity and Fuel efficiency in Nigeria (km/liters) (2010)

Source: Cervigni, R., Dvorak, I., & Rogers, J. A. (Eds.). (2013). Assessing low-carbon development in Nigeria: An analysis of four sectors. World Bank Publications.

International Association of Public Transport (UITP, from the French: L'Union internationale des transports publics) and African Association of Public Transport ((UATP, from the French: L'Union Afrique des transports publics) (2010). Report on Statistical Indicators of Public Transport Performance in Africa. Available online: www.uitp.org

Appendix B17: Charcoal production Plants and Conversion Efficiencies (2010)

Source: Energypedia. Available online: www.energypedia.info/wiki/Charcoal_Production

Bioenergy Lists. Available online: www.bioenergylists.org/stovesdoc/Smith/kilns.htm

Appendix B18: Nigeria Crude Oil Refineries (2010)

Source: Oil Refining in Nigeria-Overview. MBendi. Available online: http://www.mbendi.com/indy/oilg/ogrf/af/ng/p0005.htm

Oil and Gas. Country Studies. Available online: www.countrystudies.us/nigeria/65.htm

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Appendix B19: Conventional Energy Reserves in Nigeria and their Potentials (2010)

Source: NBS (National Bureau of Statistics). National account. Abuja: Federal Republic of Nigeria

Appendix B20: Renewable Energy Resources in Nigeria and their Potential (2010)

Source: Energy Commission of Nigeria (ECN). Renewable Energy Master Plan

Appendix B21: Cost of Primary Energy Resources (2010)

Source: The Nigerian Petroleum Product Pricing Regulatory Agency (PPPRA). Available online: www.pppra.gov.ng

Coal Price. U.S. Energy Information Administration (EIA). Available online: www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb0709

Natural Gas Price: International Monetary Fund Primary Commodity Prices. Available online: www.imf.org/external/np/res/commod/index.aspx

Crude Oil Price. U.S. Energy Information Administration (EIA). Available online: www.eia.gov/dnav/pet/pet_pri_spt_s1_a.htm

Uranium Price. Uranium Info. Available online: www.uranium.info/daily_u3o8_spot_price_indicator.php, www.acap.com.au/uranium-market

Appendix B22: Capital cost of cooking technologies in Nigeria (2010)

Source: The International Atomic Energy Agency; Energy Master Plan Study for Nigeria (2004). Energy Commission of Nigeria (ECN): Abuja, Nigeria.

World Bank. 2004. Nigeria LP Gas Sector Improvement Study. World Bank, Washington, DC. © World Bank. Available online: www.openknowledge.worldbank.org/handle/10986/18859

Appendix B23: Cost of Secondary Energy Resources (2010)

Source: Price of Gasoline and Diesel in Nigeria. Trading Economics. Available online: www.tradingeconomics.com/nigeria/pump-price-for-gasoline-us-dollar-per-liter-wb-data.html

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Price of lubricant. Jumia. Available online: www.jumia.com.ng/oil-fluid

Price of Avgas in Nigeria. African Manager. Available online: www.africanmanager.com/site_eng/detail_article.php?art_id=12743

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Price of Residual Fuel Oil. U.S. Energy Information Administration (EIA). Available online: www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMA_EPPR_PWG_NUS_DPG&f=M

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The International Atomic Energy Agency; Energy Master Plan Study for Nigeria (2004). Energy Commission of Nigeria (ECN): Abuja, Nigeria.

World Bank. 2004. Nigeria LP Gas Sector Improvement Study. World Bank, Washington, DC. © World Bank. Available online: www.openknowledge.worldbank.org/handle/10986/18859

Appendix B24: Characteristics of household cooking technologies (2010)

Source: International Energy Agency (IEA), 2015. Available online; www.iea.org/statistics/statisticssearch/report/?year=2010&country=NIGERIA&product=Balances

Nigeria Energy Statistics. United Nations (UN) Data Statistics Division. Available online: www.data.un.org/Search.aspx?q=Nigeria

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Gujba, H., Mulugetta, Y., & Azapagic, A. (2015). The Household Cooking Sector in Nigeria: Environmental and Economic Sustainability Assessment. Resources, 4(2), 412-433.

Appendix B25: Environmental Externality Cost of Greenhouse Gases (GHGs)

Source: DOE, U. Electricity generation and environmental externalities: Case studies. Report of Energy Information Administration within the US Department of Energy, DOE/EIA, 598.

Appendix B26: Power Plant Technology Information (2010)

Source: OECD, I. (2010). Projected costs of generating electricity.

Khatib, H. (2010). Review of OECD study into "Projected costs of generating electricity—2010 Edition". Energy Policy, 38(10), 5403-5408.

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Stefansson, V. (2002). Investment cost for geothermal power plants. Geothermics, 31(2), 263-272.

Appendix B27: Electricity Generation Information (2010)

Source: Power Holding Company of Nigeria PLC (PHCN) (2010). National Control Centre Osogbo Generation and Transmission Grid Operations 2010 Annual Technical Report. Osogbo, Nigeria (Unpublished Data).

Appendix B28: Categories of Energy Saving Strategies (2010)

Source: Gallivan, F. (2013). Energy Savings Strategies for Transit Agencies (Vol. 106). Transportation Research Board.

Appendix B29: Technology Cost for Vehicle Fuels (Switching/ Conversion) (2010)

Source: Rahman, M. S. U. (2009). Fuel consumption of transport sector: how the people of Dhaka city will be moving in the future?. Act! Innovate! Deliver! Reducing energy demand sustainably. In Proceedings of the eceee Summer Study (pp. 409-1415).

Appendix C: Sectorial Energy Demand by Scenarios

Appendix C1: Reference Scenario Energy Demand by Sectors

Energy Demand Final Units							
Reference Scenario, All Fuels							
Branch: Demand							
Units: Petajoules							
Branches	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Households	418.5	502.4	603.1	724.2	869.6	1,049.8	1,267.6
Urban	207.2	254.6	312.6	383.6	470.6	580.1	714.7
Electrified	173.9	218.9	275.3	345.7	433.5	546.0	686.9
Lighting	33.8	42.3	52.9	66.0	82.3	102.6	127.6
Electric	11.7	14.6	18.1	22.5	27.8	34.4	42.5
LPG	5.0	6.3	7.9	9.9	12.4	15.5	19.4
Kerosene	16.4	20.6	25.8	32.3	40.5	50.6	63.1
Other	0.7	0.8	1.0	1.3	1.6	2.0	2.5
Cooking	93.2	117.5	147.8	185.7	233.0	293.3	368.8
Electric	3.2	4.0	5.0	6.3	7.8	9.2	10.8
Kerosene	53.8	67.6	84.8	106.3	133.0	166.2	207.4
LPG	36.1	45.8	57.8	73.0	92.1	117.7	150.3
Firewood	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Air Conditioning	2.7	3.5	4.6	6.0	7.7	10.4	13.8
Existing	2.7	3.5	4.6	6.0	7.7	10.4	13.8
Refrigeration	11.3	14.5	18.6	23.7	30.3	39.3	50.8
Existing	11.3	14.5	18.6	23.7	30.3	39.3	50.8
Food Preservation	23.4	29.2	36.2	44.9	55.6	68.8	85.1
Existing	23.4	29.2	36.2	44.9	55.6	68.8	85.1
Water Heating	0.1	0.2	0.2	0.2	0.3	0.4	0.4
Existing	0.1	0.2	0.2	0.2	0.3	0.4	0.4
Electronics	9.3	11.8	15.0	19.1	24.2	31.3	40.3
Existing	9.3	11.8	15.0	19.1	24.2	31.3	40.3
Non_Electrified	33.3	35.6	37.3	38.0	37.1	34.1	27.8
Lighting	8.9	9.5	9.8	10.0	9.7	8.8	7.1
Electric	2.9	3.1	3.2	3.2	3.1	2.8	2.2
LPG	0.2	0.2	0.3	0.3	0.2	0.2	0.2
Kerosene	5.7	6.0	6.3	6.4	6.2	5.7	4.6
Other	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Cooking	19.4	20.7	21.6	22.0	21.4	19.6	15.9
Electric	0.4	0.4	0.4	0.4	0.4	0.3	0.2
Kerosene	12.8	13.7	14.3	14.5	14.1	12.8	10.4
LPG	6.1	6.5	6.9	7.0	6.9	6.4	5.3
Firewood	0.1	0.1	0.1	0.1	0.1	0.1	0.0
Air Conditioning	0.2	0.3	0.3	0.3	0.4	0.4	0.4
Existing	0.2	0.3	0.3	0.3	0.4	0.4	0.4
Refrigeration	0.9	1.1	1.2	1.3	1.3	1.3	1.1
Existing	0.9	1.1	1.2	1.3	1.3	1.3	1.1
Food Preservation	2.9	3.1	3.2	3.2	3.1	2.8	2.2
Existing	2.9	3.1	3.2	3.2	3.1	2.8	2.2
Water Heating	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Existing	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Electronics	0.9	1.0	1.1	1.2	1.2	1.2	1.1
Existing	0.9	1.0	1.1	1.2	1.2	1.2	1.1
Rural	211.4	247.8	290.5	340.6	399.1	469.7	552.8
Electrified	73.6	104.9	144.9	195.5	259.1	340.6	442.7
Lighting	36.5	51.8	71.2	95.7	126.3	164.4	211.6
Electric	3.9	5.5	7.5	10.0	13.1	16.8	21.5
Kerosene	32.5	46.2	63.5	85.4	112.8	147.0	189.5
Other	0.1	0.2	0.2	0.3	0.4	0.5	0.6
Cooking	32.5	46.2	63.6	85.5	112.9	147.1	189.5
Electric	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Kerosene	29.8	42.3	58.2	78.2	103.3	134.6	173.5
LPG	0.4	0.5	0.7	0.9	1.2	1.6	2.1
Firewood	2.0	2.9	4.0	5.3	7.1	9.2	11.8
Charcoal	0.3	0.4	0.6	0.8	1.0	1.3	1.7
Sawdust_Plant Residue	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Air Conditioning	0.3	0.6	0.9	1.4	2.1	3.4	5.2
Existing	0.3	0.6	0.9	1.4	2.1	3.4	5.2
Refrigeration	0.5	0.9	1.5	2.4	3.6	6.2	9.8
Existing	0.5	0.9	1.5	2.4	3.6	6.2	9.8
Food Preservation	2.6	3.7	5.1	6.9	9.1	11.8	15.2
Existing	2.6	3.7	5.1	6.9	9.1	11.8	15.2
Water Heating	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Existing	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Electronics	1.0	1.6	2.5	3.6	5.2	7.8	11.3
Existing	1.0	1.6	2.5	3.6	5.2	7.8	11.3
Non_Electrified	137.8	142.9	145.7	145.1	140.0	129.1	110.2
Lighting	61.4	63.5	64.5	64.0	61.6	56.5	47.9
Electric	4.8	5.0	5.0	4.9	4.7	4.3	3.6
Kerosene	56.3	58.3	59.3	58.9	56.7	52.1	44.2
Other	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Cooking	75.0	77.7	79.0	78.5	75.5	69.3	58.9
Kerosene	60.5	62.6	63.7	63.3	60.9	55.9	47.5
Firewood	13.2	13.7	13.9	13.8	13.3	12.2	10.4
Charcoal	1.2	1.3	1.3	1.3	1.2	1.1	1.0
Sawdust_Plant Residue	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Refrigeration	0.4	0.6	0.7	0.9	1.0	1.2	1.2
Existing	0.4	0.6	0.7	0.9	1.0	1.2	1.2
Electronics	1.0	1.2	1.5	1.7	1.9	2.1	2.1
Existing	1.0	1.2	1.5	1.7	1.9	2.1	2.1
Industry	297.0	346.0	403.0	469.5	546.9	637.1	742.2
Industry	297.0	346.0	403.0	469.5	546.9	637.1	742.2
Residual Fuel Oil	11.0	13.6	16.7	20.5	25.0	30.5	37.1
Natural Gas	25.4	33.3	43.2	55.3	70.3	88.7	111.3
Biomass_Waste	247.9	273.8	301.5	330.9	361.8	393.9	426.8
Electricity	11.7	22.9	37.5	56.2	80.1	110.4	148.4
Coal	1.0	2.4	4.2	6.6	9.7	13.6	18.6
Commercial_Service	84.0	112.4	150.4	201.3	269.4	360.5	482.5
Commercial_Service	84.0	112.4	150.4	201.3	269.4	360.5	482.5
Residual Fuel Oil	0.3	0.3	0.5	0.6	0.8	1.1	1.4

Biomass_Waste	64.1	85.8	114.9	153.7	205.7	275.3	368.4
Electricity	19.6	26.2	35.1	47.0	62.9	84.2	112.7
Agriculture	0.4	0.5	0.7	0.9	1.1	1.4	1.8
Agriculture	0.4	0.5	0.7	0.9	1.1	1.4	1.8
Kerosene	0.1	0.1	0.1	0.2	0.2	0.3	0.4
Diesel	0.3	0.4	0.5	0.7	0.9	1.1	1.4
Transport	239.3	277.5	321.7	372.9	432.3	501.1	581.0
Road Vehicles	239.3	277.5	321.7	372.9	432.3	501.1	581.0
Motorcycles	2.4	2.8	3.2	3.7	4.3	5.0	5.8
Gasoline_Moto	2.4	2.8	3.2	3.7	4.3	5.0	5.8
Cars	229.6	266.1	308.5	357.7	414.6	480.7	557.2
Gasoline_Cars	187.7	217.6	252.3	292.4	339.0	393.0	455.6
Diesel_Cars	41.9	48.5	56.2	65.2	75.6	87.6	101.6
Light Goods Vehicles	2.0	2.3	2.7	3.1	3.6	4.2	4.9
Gasoline_LGV	2.0	2.3	2.7	3.1	3.6	4.2	4.9
Heavy Goods Vehicles	0.3	0.4	0.5	0.5	0.6	0.7	0.8
Diesel_HGV	0.3	0.4	0.5	0.5	0.6	0.7	0.8
Urban Bus	1.7	2.0	2.3	2.6	3.1	3.6	4.1
Gasoline_UB	1.7	2.0	2.3	2.6	3.1	3.6	4.1
Long Distance Coach	3.3	3.9	4.5	5.2	6.0	7.0	8.1
Diesel_LDC	3.3	3.9	4.5	5.2	6.0	7.0	8.1
Total	1,039.3	1,238.8	1,478.9	1,768.8	2,119.4	2,550.0	3,075.0

Appendix C2: Low Carbon Moderate Scenario Energy Demand by Sectors

Energy Demand Final Units							
Low Carbon Moderate Scenario, All Fuels							
Branch: Demand							
Units: Petajoules							
Branches	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Households	418.5	496.4	588.2	696.4	823.8	977.3	1,157.4
Urban	207.2	248.5	297.6	355.9	424.7	507.6	604.6
Electrified	173.9	212.9	260.3	317.9	387.7	484.9	604.6
Lighting	33.8	40.3	47.9	56.8	67.2	81.4	98.0
Electric	11.7	13.5	15.5	17.7	19.9	22.8	25.7
LPG	5.0	6.2	7.5	9.2	11.2	14.1	17.6
Kerosene	16.4	19.8	23.8	28.7	34.5	42.5	52.2
Other	0.7	0.8	1.0	1.2	1.5	2.0	2.5
Cooking	93.2	113.9	138.8	169.1	205.7	256.7	319.3
Electric	3.2	4.0	4.9	6.0	7.3	9.1	11.4
Kerosene	53.8	65.0	78.3	94.2	113.2	139.6	171.6
LPG	36.1	44.9	55.6	68.8	85.0	107.8	136.1
Firewood	0.1	0.1	0.1	0.1	0.1	0.2	0.2
Air Conditioning	2.7	3.5	4.6	5.9	7.6	10.1	13.3
Efficient	2.7	3.5	4.6	5.9	7.6	10.1	13.3
Refrigeration	11.3	14.0	17.3	21.4	26.3	33.1	41.5
Efficient	11.3	14.0	17.3	21.4	26.3	33.1	41.5
Food Preservation	23.4	29.2	36.2	44.9	55.6	70.7	89.6
Efficient	23.4	29.2	36.2	44.9	55.6	70.7	89.6
Water Heating	0.1	0.2	0.2	0.2	0.3	0.4	0.4
Efficient	0.1	0.2	0.2	0.2	0.3	0.4	0.4
Electronics	9.3	11.9	15.3	19.5	24.9	32.6	42.5
Efficient	9.3	11.9	15.3	19.5	24.9	32.6	42.5
Non_Electrified	33.3	35.6	37.3	38.0	37.1	22.7	-
Lighting	8.9	9.5	9.8	10.0	9.7	5.8	-
Electric	2.9	3.1	3.2	3.2	3.1	1.9	-
LPG	0.2	0.2	0.3	0.3	0.2	0.2	-
Kerosene	5.7	6.0	6.3	6.4	6.2	3.8	-
Other	0.1	0.1	0.1	0.1	0.1	0.1	-
Cooking	19.4	20.7	21.6	22.0	21.4	13.1	-
Electric	0.4	0.4	0.4	0.4	0.4	0.2	-
Kerosene	12.8	13.7	14.3	14.5	14.1	8.6	-
LPG	6.1	6.5	6.9	7.0	6.9	4.3	-
Firewood	0.1	0.1	0.1	0.1	0.1	0.0	-
Air Conditioning	0.2	0.3	0.3	0.3	0.4	0.3	-
Efficient	0.2	0.3	0.3	0.3	0.4	0.3	-
Refrigeration	0.9	1.1	1.2	1.3	1.3	0.9	-
Efficient	0.9	1.1	1.2	1.3	1.3	0.9	-
Food Preservation	2.9	3.1	3.2	3.2	3.1	1.9	-
Efficient	2.9	3.1	3.2	3.2	3.1	1.9	-
Water Heating	0.0	0.0	0.0	0.0	0.0	0.0	-
Efficient	0.0	0.0	0.0	0.0	0.0	0.0	-
Electronics	0.9	1.0	1.1	1.2	1.2	0.8	-
Efficient	0.9	1.0	1.1	1.2	1.2	0.8	-

Rural	211.4	247.8	290.5	340.6	399.1	469.7	552.8
Electrified	73.6	104.9	144.9	195.5	259.1	340.6	442.7
Lighting	36.5	51.8	71.2	95.7	126.3	164.4	211.6
Electric	3.9	5.5	7.5	10.0	13.1	16.8	21.5
Kerosene	32.5	46.2	63.5	85.4	112.8	147.0	189.5
Other	0.1	0.2	0.2	0.3	0.4	0.5	0.6
Cooking	32.5	46.2	63.6	85.5	112.9	147.1	189.5
Electric	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Kerosene	29.8	42.3	58.2	78.2	103.3	134.6	173.5
LPG	0.4	0.5	0.7	0.9	1.2	1.6	2.1
Firewood	2.0	2.9	4.0	5.3	7.1	9.2	11.8
Charcoal	0.3	0.4	0.6	0.8	1.0	1.3	1.7
Sawdust_Plant Residue	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Air Conditioning	0.3	0.6	0.9	1.4	2.1	3.4	5.2
Efficient	0.3	0.6	0.9	1.4	2.1	3.4	5.2
Refrigeration	0.5	0.9	1.5	2.4	3.6	6.2	9.8
Efficient	0.5	0.9	1.5	2.4	3.6	6.2	9.8
Food Preservation	2.6	3.7	5.1	6.9	9.1	11.8	15.2
Efficient	2.6	3.7	5.1	6.9	9.1	11.8	15.2
Water Heating	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Efficient	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Electronics	1.0	1.6	2.5	3.6	5.2	7.8	11.3
Efficient	1.0	1.6	2.5	3.6	5.2	7.8	11.3
Non_Electrified	137.8	142.9	145.7	145.1	140.0	129.1	110.2
Lighting	61.4	63.5	64.5	64.0	61.6	56.5	47.9
Electric	4.8	5.0	5.0	4.9	4.7	4.3	3.6
Kerosene	56.3	58.3	59.3	58.9	56.7	52.1	44.2
Other	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Cooking	75.0	77.7	79.0	78.5	75.5	69.3	58.9
Kerosene	60.5	62.6	63.7	63.3	60.9	55.9	47.5
Firewood	13.2	13.7	13.9	13.8	13.3	12.2	10.4
Charcoal	1.2	1.3	1.3	1.3	1.2	1.1	1.0
Sawdust_Plant Residue	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Refrigeration	0.4	0.6	0.7	0.9	1.0	1.2	1.2
Efficient	0.4	0.6	0.7	0.9	1.0	1.2	1.2
Electronics	1.0	1.2	1.5	1.7	1.9	2.1	2.1
Efficient	1.0	1.2	1.5	1.7	1.9	2.1	2.1
Industry	297.0	337.4	383.3	435.5	494.8	562.1	638.6
Industry	297.0	337.4	383.3	435.5	494.8	562.1	638.6
Residual Fuel Oil	11.0	13.3	15.9	19.0	22.6	26.9	31.9
Natural Gas	25.4	32.5	41.0	51.3	63.6	78.3	95.8
Biomass_Waste	247.9	267.0	286.8	306.9	327.3	347.5	367.2
Electricity	11.7	22.3	35.6	52.1	72.5	97.4	127.7
Coal	1.0	2.3	4.0	6.1	8.8	12.0	16.0
Commercial_Service	84.0	111.3	147.4	195.4	258.8	342.9	454.3
Commercial_Service	84.0	111.3	147.4	195.4	258.8	342.9	454.3
Residual Fuel Oil	0.3	0.3	0.4	0.6	0.8	1.0	1.4
Biomass_Waste	64.1	82.8	106.9	137.8	177.5	228.5	294.0
Electricity	19.6	28.1	40.2	57.0	80.5	113.4	159.0
Agriculture	0.4	0.5	0.7	0.9	1.1	1.4	1.8

Agriculture	0.4	0.5	0.7	0.9	1.1	1.4	1.8
Kerosene	0.1	0.1	0.1	0.2	0.2	0.3	0.4
Diesel	0.3	0.4	0.5	0.7	0.9	1.1	1.4
Transport	239.3	285.7	340.9	406.6	484.8	577.8	688.3
Road Vehicles	239.3	285.7	340.9	406.6	484.8	577.8	688.3
Motorcycles	2.4	2.8	3.4	4.0	4.8	5.7	6.7
Gasoline_Moto	2.4	2.8	3.3	3.9	4.5	5.3	6.2
Bio_Moto	-	0.0	0.1	0.1	0.2	0.3	0.5
Cars	229.6	273.9	326.8	389.7	464.4	553.3	658.9
Gasoline_Cars	187.7	212.7	239.7	268.5	298.4	328.7	358.1
Diesel_Cars	41.9	48.1	55.1	62.8	71.3	80.6	90.5
Bio_Cars	-	13.1	32.0	58.4	94.7	144.0	210.3
Light Goods Vehicles	2.0	2.4	2.9	3.5	4.3	5.2	6.2
Gasoline_LGV	2.0	2.3	2.7	3.1	3.5	4.0	4.6
Bio_LGV	-	0.1	0.3	0.5	0.8	1.2	1.7
Heavy Goods Vehicles	0.3	0.4	0.5	0.6	0.7	0.9	1.0
Diesel_HGV	0.3	0.4	0.4	0.5	0.6	0.6	0.7
Bio_HGV	-	0.0	0.1	0.1	0.2	0.2	0.4
Urban Bus	1.7	2.0	2.5	3.0	3.6	4.3	5.2
Gasoline_UB	1.7	1.9	2.1	2.3	2.5	2.6	2.8
Bio_UB	-	0.2	0.4	0.7	1.1	1.7	2.5
Long Distance Coach	3.3	4.0	4.8	5.8	7.0	8.5	10.2
Diesel_LDC	3.3	3.8	4.3	4.8	5.4	5.9	6.5
Bio_LDC	-	0.2	0.6	1.0	1.7	2.5	3.7
Total	1,039.3	1,231.3	1,460.6	1,734.8	2,063.3	2,461.6	2,940.5

Appendix C3: Low Carbon Advance Scenario Energy Demand by Sectors

Energy Demand Final Units							
Low Carbon Advance Scenario, All Fuels							
Branch: Demand							
Units: Petajoules							
Branches	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Households	418.5	506.4	608.6	723.7	848.6	925.1	948.3
Urban	207.2	261.6	323.6	390.5	458.1	464.2	403.6
Electrified	173.9	189.9	211.8	240.3	276.8	333.0	403.6
Lighting	33.8	39.2	45.3	52.1	59.7	70.0	81.4
Electric	11.7	12.8	13.8	14.6	15.2	15.7	15.6
LPG	5.0	6.2	7.6	9.4	11.5	14.6	18.3
Kerosene	16.4	19.4	22.9	27.0	31.7	38.2	45.8
Other	0.7	0.8	0.9	1.1	1.3	1.5	1.8
Cooking	93.2	96.9	104.0	115.1	131.1	158.2	194.4
Electric	3.2	4.0	5.0	6.3	7.8	9.5	11.4
Kerosene	53.8	47.0	41.1	35.8	31.1	27.8	24.8
LPG	36.1	45.8	57.8	73.0	92.1	120.9	158.2
Firewood	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Air Conditioning	2.7	2.7	2.7	2.7	2.7	2.9	3.0
Efficient	2.7	2.7	2.7	2.7	2.7	2.9	3.0
Refrigeration	11.3	10.8	10.4	9.9	9.4	9.3	9.2
Efficient	11.3	10.8	10.4	9.9	9.4	9.3	9.2
Food Preservation	23.4	28.7	35.1	42.9	52.4	65.6	81.8
Efficient	23.4	28.7	35.1	42.9	52.4	65.6	81.8
Water Heating	0.1	0.2	0.2	0.2	0.3	0.3	0.4
Efficient	0.1	0.2	0.2	0.2	0.3	0.3	0.4
Electronics	9.3	11.4	14.1	17.3	21.2	26.6	33.3
Efficient	9.3	11.4	14.1	17.3	21.2	26.6	33.3
Non_Electrified	33.3	71.7	111.8	150.2	181.3	131.2	-
Lighting	8.9	45.5	84.4	122.2	153.9	114.4	-
Electric	2.9	39.2	77.7	115.5	147.3	110.4	-
LPG	0.2	0.2	0.3	0.3	0.2	0.2	-
Kerosene	5.7	6.0	6.3	6.4	6.2	3.8	-
Other	0.1	0.1	0.1	0.1	0.1	0.1	-
Cooking	19.4	20.7	21.6	22.0	21.4	13.1	-
Electric	0.4	0.4	0.4	0.4	0.4	0.2	-
Kerosene	12.8	13.7	14.3	14.5	14.1	8.6	-
LPG	6.1	6.5	6.9	7.0	6.9	4.3	-
Firewood	0.1	0.1	0.1	0.1	0.1	0.0	-
Air Conditioning	0.2	0.3	0.3	0.3	0.4	0.3	-
Efficient	0.2	0.3	0.3	0.3	0.4	0.3	-
Refrigeration	0.9	1.1	1.2	1.3	1.3	0.9	-
Efficient	0.9	1.1	1.2	1.3	1.3	0.9	-
Food Preservation	2.9	3.1	3.2	3.2	3.1	1.9	-
Efficient	2.9	3.1	3.2	3.2	3.1	1.9	-
Water Heating	0.0	0.0	0.0	0.0	0.0	0.0	-
Efficient	0.0	0.0	0.0	0.0	0.0	0.0	-
Electronics	0.9	1.0	1.1	1.2	1.2	0.8	-
Efficient	0.9	1.0	1.1	1.2	1.2	0.8	-

Rural	211.4	244.7	285.0	333.1	390.6	460.9	544.7
Electrified	73.6	104.9	144.9	195.5	259.1	340.6	442.7
Lighting	36.5	51.8	71.2	95.7	126.3	164.4	211.6
Electric	3.9	5.5	7.5	10.0	13.1	16.8	21.5
Kerosene	32.5	46.2	63.5	85.4	112.8	147.0	189.5
Other	0.1	0.2	0.2	0.3	0.4	0.5	0.6
Cooking	32.5	46.2	63.6	85.5	112.9	147.1	189.5
Electric	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Kerosene	29.8	42.3	58.2	78.2	103.3	134.6	173.5
LPG	0.4	0.5	0.7	0.9	1.2	1.6	2.1
Firewood	2.0	2.9	4.0	5.3	7.1	9.2	11.8
Charcoal	0.3	0.4	0.6	0.8	1.0	1.3	1.7
Sawdust_Plant Residue	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Air Conditioning	0.3	0.6	0.9	1.4	2.1	3.4	5.2
Efficient	0.3	0.6	0.9	1.4	2.1	3.4	5.2
Refrigeration	0.5	0.9	1.5	2.4	3.6	6.2	9.8
Efficient	0.5	0.9	1.5	2.4	3.6	6.2	9.8
Food Preservation	2.6	3.7	5.1	6.9	9.1	11.8	15.2
Efficient	2.6	3.7	5.1	6.9	9.1	11.8	15.2
Water Heating	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Efficient	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Electronics	1.0	1.6	2.5	3.6	5.2	7.8	11.3
Efficient	1.0	1.6	2.5	3.6	5.2	7.8	11.3
Non_Electrified	137.8	139.8	140.1	137.7	131.4	120.3	102.0
Lighting	61.4	63.5	64.5	64.0	61.6	56.5	47.9
Electric	4.8	5.0	5.0	4.9	4.7	4.3	3.6
Kerosene	56.3	58.3	59.3	58.9	56.7	52.1	44.2
Other	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Cooking	75.0	74.6	73.4	71.1	67.0	60.5	50.7
Kerosene	60.5	62.6	63.7	63.3	60.9	55.9	47.5
Firewood	13.2	10.6	8.3	6.4	4.8	3.4	2.2
Charcoal	1.2	1.3	1.3	1.3	1.2	1.1	1.0
Sawdust_Plant Residue	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Refrigeration	0.4	0.6	0.7	0.9	1.0	1.2	1.2
Efficient	0.4	0.6	0.7	0.9	1.0	1.2	1.2
Electronics	1.0	1.2	1.5	1.7	1.9	2.1	2.1
Efficient	1.0	1.2	1.5	1.7	1.9	2.1	2.1
Industry	297.0	320.8	346.5	374.3	404.3	436.6	471.6
Industry	297.0	320.8	346.5	374.3	404.3	436.6	471.6
Residual Fuel Oil	11.0	12.6	14.4	16.3	18.5	20.9	23.6
Natural Gas	25.4	36.3	48.6	62.8	78.9	97.2	117.9
Biomass_Waste	247.9	238.1	225.1	208.6	187.9	162.6	132.1
Electricity	11.7	31.9	55.3	82.2	113.1	148.4	188.7
Coal	1.0	1.9	3.0	4.3	5.8	7.5	9.4
Commercial_Service	84.0	111.3	147.4	195.4	258.8	342.9	454.3
Commercial_Service	84.0	111.3	147.4	195.4	258.8	342.9	454.3
Residual Fuel Oil	0.3	0.4	0.6	0.9	1.3	1.9	2.7
Biomass_Waste	64.1	80.4	100.5	125.1	155.1	191.4	234.9
Electricity	19.6	30.5	46.4	69.4	102.5	149.7	216.7

Agriculture	0.4	0.5	0.7	0.9	1.1	1.4	1.8
Agriculture	0.4	0.5	0.7	0.9	1.1	1.4	1.8
Kerosene	0.1	0.1	0.1	0.2	0.2	0.3	0.4
Diesel	0.3	0.4	0.5	0.7	0.9	1.1	1.4
Transport	239.3	280.9	329.3	385.5	450.5	525.7	612.2
Road Vehicles	239.3	280.9	329.3	385.5	450.5	525.7	612.2
Motorcycles	2.4	2.8	3.3	3.9	4.5	5.3	6.2
Gasoline_Moto	2.4	2.8	3.2	3.7	4.2	4.8	5.4
Bio_Moto	-	0.0	0.1	0.2	0.3	0.5	0.7
Cars	229.6	269.4	315.7	369.5	431.7	503.5	586.2
Gasoline_Cars	187.7	205.1	221.2	234.7	243.6	245.3	236.4
Diesel_Cars	41.9	46.4	50.9	55.3	59.1	62.0	63.3
Bio_Cars	-	9.9	24.0	43.8	71.0	108.0	157.7
LPG_Cars	-	8.1	19.6	35.8	58.0	88.2	128.8
Light Goods Vehicles	2.0	2.4	2.8	3.3	3.9	4.6	5.4
Gasoline_LGV	2.0	2.2	2.3	2.3	2.3	2.2	2.0
Bio_LGV	-	0.1	0.3	0.5	0.8	1.2	1.7
LPG_LGV	-	0.1	0.3	0.5	0.8	1.2	1.7
Heavy Goods Vehicles	0.3	0.4	0.5	0.6	0.7	0.9	1.0
Diesel_HGV	0.3	0.4	0.4	0.5	0.5	0.5	0.6
Bio_HGV	-	0.0	0.1	0.1	0.2	0.3	0.5
Urban Bus	1.7	2.0	2.4	2.8	3.4	4.0	4.7
Gasoline_UB	1.7	1.9	2.0	2.1	2.2	2.3	2.2
Bio_UB	-	0.1	0.2	0.4	0.7	1.0	1.5
LPG_UB	-	0.1	0.2	0.3	0.4	0.7	1.0
Long Distance Coach	3.3	3.9	4.6	5.4	6.4	7.5	8.7
Diesel_LDC	3.3	3.6	3.9	4.1	4.1	4.1	3.8
Bio_LDC	-	0.2	0.4	0.8	1.2	1.9	2.8
LPG_LDC	-	0.1	0.3	0.6	1.0	1.5	2.2
Total	1,039.3	1,219.9	1,432.5	1,679.7	1,963.4	2,231.7	2,488.3

Appendix C4: Green Optimistic Scenario Energy Demand by Sectors

Energy Demand Final Units							
GO Scenario, All Fuels							
Branch: Demand							
Units: Petajoules							
Branches	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**
Households	418.5	459.6	510.1	570.9	643.4	732.4	836.0
Urban	207.2	211.8	219.5	230.4	244.3	262.6	283.1
Electrified	173.9	181.6	191.9	205.3	221.9	249.8	283.1
Lighting	33.8	36.4	39.1	41.9	44.7	48.9	53.0
Electric	11.7	11.4	11.0	10.4	9.7	9.0	8.0
LPG	5.0	6.6	8.6	11.1	14.2	18.6	24.2
Kerosene	16.4	17.6	18.7	19.5	19.9	20.2	19.7
Other	0.7	0.7	0.8	0.9	1.0	1.1	1.1
Cooking	93.2	92.4	93.2	95.6	99.7	109.2	120.9
Electric	3.2	3.9	4.8	5.8	7.1	8.4	9.8
Kerosene	53.8	47.0	41.1	35.8	31.1	27.8	24.8
LPG	36.1	41.4	47.3	53.9	61.5	73.0	86.3
Firewood	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Air Conditioning	2.7	2.6	2.4	2.3	2.2	2.2	2.2
Efficient	2.7	2.6	2.4	2.3	2.2	2.2	2.2
Refrigeration	11.3	11.1	10.6	9.9	8.9	8.0	6.8
Efficient	11.3	11.1	10.6	9.9	8.9	8.0	6.8
Food Preservation	23.4	28.7	35.1	42.9	52.4	65.6	81.8
Efficient	23.4	28.7	35.1	42.9	52.4	65.6	81.8
Water Heating	0.1	0.2	0.2	0.2	0.3	0.3	0.4
Efficient	0.1	0.2	0.2	0.2	0.3	0.3	0.4
Electronics	9.3	10.2	11.3	12.4	13.7	15.8	18.1
Efficient	9.3	10.2	11.3	12.4	13.7	15.8	18.1
Non_Electrified	33.3	30.2	27.6	25.1	22.4	12.8	-
Lighting	8.9	9.5	9.8	10.0	9.7	5.8	-
Electric	2.9	3.1	3.2	3.2	3.1	1.9	-
LPG	0.2	0.2	0.3	0.3	0.2	0.2	-
Kerosene	5.7	6.0	6.3	6.4	6.2	3.8	-
Other	0.1	0.1	0.1	0.1	0.1	0.1	-
Cooking	19.4	15.3	11.9	9.1	6.8	3.2	-
Electric	0.4	0.4	0.4	0.4	0.4	0.2	-
Kerosene	12.8	9.5	6.9	4.9	3.3	1.4	-
LPG	6.1	5.3	4.6	3.8	3.1	1.5	-
Firewood	0.1	0.0	0.0	0.0	0.0	0.0	-
Air Conditioning	0.2	0.3	0.3	0.3	0.4	0.3	-
Efficient	0.2	0.3	0.3	0.3	0.4	0.3	-
Refrigeration	0.9	1.1	1.2	1.3	1.3	0.9	-
Efficient	0.9	1.1	1.2	1.3	1.3	0.9	-
Food Preservation	2.9	3.1	3.2	3.2	3.1	1.9	-
Efficient	2.9	3.1	3.2	3.2	3.1	1.9	-
Water Heating	0.0	0.0	0.0	0.0	0.0	0.0	-
Efficient	0.0	0.0	0.0	0.0	0.0	0.0	-
Electronics	0.9	1.0	1.1	1.2	1.2	0.8	-
Efficient	0.9	1.0	1.1	1.2	1.2	0.8	-

Rural	211.4	247.8	290.5	340.6	399.1	469.7	552.8
Electrified	73.6	104.9	144.9	195.5	259.1	340.6	442.7
Lighting	36.5	51.8	71.2	95.7	126.3	164.4	211.6
Electric	3.9	5.5	7.5	10.0	13.1	16.8	21.5
Kerosene	32.5	46.2	63.5	85.4	112.8	147.0	189.5
Other	0.1	0.2	0.2	0.3	0.4	0.5	0.6
Cooking	32.5	46.2	63.6	85.5	112.9	147.1	189.5
Electric	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Kerosene	29.8	42.3	58.2	78.2	103.3	134.6	173.5
LPG	0.4	0.5	0.7	0.9	1.2	1.6	2.1
Firewood	2.0	2.9	4.0	5.3	7.1	9.2	11.8
Charcoal	0.3	0.4	0.6	0.8	1.0	1.3	1.7
Sawdust_Plant Residue	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Air Conditioning	0.3	0.6	0.9	1.4	2.1	3.4	5.2
Efficient	0.3	0.6	0.9	1.4	2.1	3.4	5.2
Refrigeration	0.5	0.9	1.5	2.4	3.6	6.2	9.8
Efficient	0.5	0.9	1.5	2.4	3.6	6.2	9.8
Food Preservation	2.6	3.7	5.1	6.9	9.1	11.8	15.2
Efficient	2.6	3.7	5.1	6.9	9.1	11.8	15.2
Water Heating	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Efficient	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Electronics	1.0	1.6	2.5	3.6	5.2	7.8	11.3
Efficient	1.0	1.6	2.5	3.6	5.2	7.8	11.3
Non_Electrified	137.8	142.9	145.7	145.1	140.0	129.1	110.2
Lighting	61.4	63.5	64.5	64.0	61.6	56.5	47.9
Electric	4.8	5.0	5.0	4.9	4.7	4.3	3.6
Kerosene	56.3	58.3	59.3	58.9	56.7	52.1	44.2
Other	0.2	0.2	0.2	0.2	0.2	0.2	0.1
Cooking	75.0	77.7	79.0	78.5	75.5	69.3	58.9
Kerosene	60.5	62.6	63.7	63.3	60.9	55.9	47.5
Firewood	13.2	13.7	13.9	13.8	13.3	12.2	10.4
Charcoal	1.2	1.3	1.3	1.3	1.2	1.1	1.0
Sawdust_Plant Residue	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Refrigeration	0.4	0.6	0.7	0.9	1.0	1.2	1.2
Efficient	0.4	0.6	0.7	0.9	1.0	1.2	1.2
Electronics	1.0	1.2	1.5	1.7	1.9	2.1	2.1
Efficient	1.0	1.2	1.5	1.7	1.9	2.1	2.1
Industry	297.0	312.7	329.3	346.8	365.1	384.5	404.9
Industry	297.0	312.7	329.3	346.8	365.1	384.5	404.9
Residual Fuel Oil	11.0	10.7	10.4	9.9	9.4	8.8	8.1
Natural Gas	25.4	37.9	51.7	66.9	83.4	101.6	121.5
Biomass_Waste	247.9	225.8	200.8	172.4	140.5	104.7	64.8
Electricity	11.7	36.3	63.5	93.5	126.5	162.7	202.4
Coal	1.0	1.9	2.9	4.0	5.3	6.6	8.1
Commercial_Service	84.0	111.3	147.4	195.4	258.8	342.9	454.3
Commercial_Service	84.0	111.3	147.4	195.4	258.8	342.9	454.3
Residual Fuel Oil	0.3	0.5	0.9	1.6	2.5	3.9	5.9
Biomass_Waste	64.1	77.3	92.3	108.8	126.3	143.7	159.0
Electricity	19.6	33.5	54.3	85.0	130.1	195.4	289.4

Agriculture	0.4	0.5	0.7	0.9	1.1	1.4	1.8
Agriculture	0.4	0.5	0.7	0.9	1.1	1.4	1.8
Kerosene	0.1	0.1	0.1	0.2	0.2	0.3	0.4
Diesel	0.3	0.4	0.5	0.7	0.9	1.1	1.4
Transport	239.3	277.2	320.2	368.8	423.5	484.6	552.2
Road Vehicles	239.3	277.2	320.2	368.8	423.5	484.6	552.2
Motorcycles	2.4	2.8	3.2	3.7	4.3	4.9	5.6
Gasoline_Moto	2.4	2.7	3.1	3.4	3.8	4.3	4.7
Bio_Moto	-	0.1	0.2	0.3	0.4	0.7	1.0
Cars	229.6	265.8	306.9	353.4	405.6	463.9	528.4
Gasoline_Cars	187.7	199.7	208.1	210.8	204.8	186.4	150.4
Diesel_Cars	41.9	44.7	46.8	47.7	46.9	43.4	36.2
Bio_Cars	-	9.9	24.0	43.8	71.0	108.0	157.7
LPG_Cars	-	6.7	16.3	29.8	48.3	73.5	107.3
CNG_Cars	-	4.8	11.7	21.3	34.5	52.5	76.7
Light Goods Vehicles	2.0	2.4	2.8	3.2	3.8	4.4	5.1
Gasoline_LGV	2.0	2.2	2.3	2.3	2.3	2.2	2.0
Bio_LGV	-	0.1	0.2	0.3	0.5	0.8	1.1
LPG_LGV	-	0.1	0.2	0.3	0.5	0.7	1.1
CNG_LGV	-	0.1	0.1	0.3	0.4	0.7	1.0
Heavy Goods Vehicles	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Diesel_HGV	0.3	0.4	0.4	0.4	0.4	0.4	0.4
Bio_HGV	-	0.0	0.0	0.1	0.1	0.2	0.3
CNG_HGV	-	0.0	0.0	0.1	0.1	0.2	0.2
Urban Bus	1.7	2.0	2.3	2.7	3.1	3.6	4.2
Gasoline_UB	1.7	1.8	1.9	2.0	2.0	1.9	1.7
Bio_UB	-	0.1	0.2	0.3	0.4	0.7	1.0
LPG_UB	-	0.1	0.1	0.2	0.4	0.6	0.8
CNG_UB	-	0.0	0.1	0.2	0.3	0.5	0.7
Long Distance Coach	3.3	3.9	4.5	5.2	6.0	6.9	8.0
Diesel_LDC	3.3	3.6	3.8	3.9	3.9	3.7	3.3
Bio_LDC	-	0.1	0.3	0.5	0.8	1.3	1.8
LPG_LDC	-	0.1	0.2	0.4	0.7	1.1	1.5
CNG_LDC	-	0.1	0.2	0.4	0.6	0.9	1.3
Total	1,039.3	1,161.4	1,307.7	1,482.7	1,692.0	1,945.8	2,249.2

Appendix D: Primary and Secondary Energy Supply by Scenarios

Appendix D1: Total Primary Energy Requirements by Scenarios

Primary Requirements							
All Fuels							
Branch: Resources							
Units: Million Gigajoules							
Scenarios	2010	2015	2020	2025	2030	2035	2040
GO	1,270.6	1,568.0	1,801.2	2,139.0	2,504.8	2,968.5	3,507.5
Low Carbon Advance	1,270.6	1,601.3	1,934.1	2,337.8	2,795.7	3,185.7	3,486.7
Low Carbon Moderate	1,270.6	1,584.5	1,872.4	2,221.4	2,669.0	3,202.5	3,868.9
Reference	1,270.6	1,631.2	1,930.6	2,309.7	2,755.9	3,326.3	3,998.0
Total	5,082.4	6,385.0	7,538.4	9,007.8	10,725.5	12,683.0	14,861.0

Appendix D2: Reference Scenario Fuel Supply

Energy Demand Final Units							
Reference Scenario							
Branch: Demand							
Units: Petajoules							
Fuels	2010	2015	2020	2025	2030	2035	2040
Electricity	116.2	155.1	204.6	267.5	347.0	450.9	582.5
Natural Gas	25.4	33.3	43.2	55.3	70.3	88.7	111.3
Gasoline	193.8	224.7	260.5	301.9	350.0	405.8	470.4
Kerosene	267.9	317.4	376.0	445.5	527.8	625.2	740.6
Diesel	45.9	53.2	61.7	71.6	83.1	96.5	112.0
Residual Fuel Oil	11.3	13.9	17.2	21.1	25.8	31.6	38.6
LPG	47.8	59.4	73.6	91.2	112.9	141.5	177.2
Coal Sub bituminous	1.0	2.4	4.2	6.6	9.7	13.6	18.6
Wood	15.4	16.7	18.0	19.3	20.6	21.6	22.5
Charcoal	1.5	1.7	1.9	2.1	2.3	2.5	2.7
Vegetal Wastes	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Solar	1.0	1.2	1.3	1.5	1.6	1.8	1.9
Biomass	312.0	359.6	416.4	484.6	567.5	669.2	795.1
Total	1,039.3	1,238.8	1,478.9	1,768.8	2,119.4	2,550.0	3,075.0

Appendix D3: Low Carbon Moderate Scenario Fuel Supply

Energy Demand Final Units							
Low Carbon Moderate Scenario							
Branch: Demand							
Units: Petajoules							
Fuels	2010	2015	2020	2025	2030	2035	2040
Electricity	116.2	155.0	204.1	266.3	345.2	449.2	581.3
Natural Gas	25.4	32.5	41.0	51.3	63.6	78.3	95.8
Gasoline	193.8	219.7	247.8	277.7	308.9	340.7	371.6
Kerosene	267.9	313.9	367.5	429.8	502.0	584.4	678.8
Diesel	45.9	52.7	60.3	68.8	78.1	88.3	99.1
Residual Fuel Oil	11.3	13.6	16.3	19.6	23.4	27.9	33.3
LPG	47.8	58.3	71.0	86.2	104.7	127.9	155.8
Coal Sub bituminous	1.0	2.3	4.0	6.1	8.8	12.0	16.0
Wood	15.4	16.7	18.0	19.3	20.5	21.6	22.4
Charcoal	1.5	1.7	1.9	2.1	2.3	2.5	2.7
Vegetal Wastes	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Solar	1.0	1.2	1.4	1.6	1.9	2.2	2.6
Biomass	312.0	363.5	426.9	505.5	603.5	726.1	880.1
Total	1,039.3	1,231.3	1,460.6	1,734.8	2,063.3	2,461.6	2,940.5

Appendix D4: Low Carbon Advance Scenario Fuel Supply

Energy Demand Final Units							
Low Carbon Advance Scenario							
Branch: Demand							
Units: Petajoules							
Fuels	2010	2015	2020	2025	2030	2035	2040
Electricity	116.2	197.4	291.9	399.4	518.9	596.1	630.4
Natural Gas	25.4	36.3	48.6	62.8	78.9	97.2	117.9
Gasoline	193.8	211.9	228.7	242.8	252.3	254.6	246.0
Kerosene	267.9	295.7	329.4	369.7	417.2	468.3	525.5
Diesel	45.9	50.8	55.8	60.5	64.6	67.7	69.2
Residual Fuel Oil	11.3	13.0	15.0	17.2	19.8	22.8	26.3
LPG	47.8	67.6	93.7	127.8	172.2	233.1	312.2
Coal Sub bituminous	1.0	1.9	3.0	4.3	5.8	7.5	9.4
Wood	15.4	13.6	12.4	11.8	11.9	12.6	14.1
Charcoal	1.5	1.7	1.9	2.1	2.3	2.5	2.7
Vegetal Wastes	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Solar	1.0	1.2	1.5	1.8	2.2	2.7	3.3
Biomass	312.0	328.8	350.7	379.4	417.3	466.9	531.8
Total	1,039.3	1,219.9	1,432.5	1,679.7	1,963.4	2,231.7	2,488.3

Appendix D5: Green Optimistic Scenario Fuel Supply

Energy Demand Final Units							
Green Optimistic Advance Scenario							
Branch: Demand							
Units: Petajoules							
Fuels	2010	2015	2020	2025	2030	2035	2040
Electricity	116.2	166.1	227.6	304.1	400.9	526.9	689.1
Natural Gas	25.4	37.9	51.7	66.9	83.4	101.6	121.5
Gasoline	193.8	206.4	215.4	218.6	213.0	194.8	158.7
Kerosene	267.9	289.7	317.8	352.5	394.5	443.1	499.4
Diesel	45.9	49.1	51.5	52.8	52.1	48.7	41.3
Residual Fuel Oil	11.3	11.3	11.3	11.5	11.9	12.7	14.0
LPG	47.8	61.0	78.2	100.8	130.2	170.8	223.3
Coal Sub bituminous	1.0	1.9	2.9	4.0	5.3	6.6	8.1
Wood	15.4	16.7	18.0	19.2	20.4	21.4	22.2
Charcoal	1.5	1.7	1.9	2.1	2.3	2.5	2.7
Vegetal Wastes	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Solar	1.0	1.3	1.5	1.9	2.3	2.8	3.4
Biomass	312.0	313.3	317.8	326.4	340.2	360.0	386.7
CNG	-	5.0	12.2	22.2	36.0	54.8	80.0
Total	1,039.3	1,161.4	1,307.7	1,482.7	1,692.0	1,945.8	2,249.2

Appendix E: Total Electricity Supply by Scenarios

Appendix E1: Reference Scenario Electricity Supply

Outputs by Feedstock Fuel							
Reference Scenario, All Fuels, Primary Outputs							
Branch: Transformation\Electricity Generation\Processes							
Units: Million Megawatt-Hours							
Branches	2010	2015	2020	2025	2030	2035	2040
Hydropower_1	7.4	3.1	6.0	7.4	7.0	7.2	9.3
Coal_Steam	-	0.7	1.2	4.0	5.0	9.5	13.4
Nuclear	-	0.8	1.3	1.9	2.8	3.8	4.6
On_Shore Wind	-	-	0.0	0.0	0.0	0.0	0.0
Biomass	-	0.0	0.0	0.0	0.0	0.0	0.1
Solar PV	-	0.0	0.0	0.1	0.1	0.1	0.2
Solar Thermal	-	0.0	0.0	0.0	0.0	0.0	0.0
SCGT_1	11.2	29.7	33.7	38.6	45.3	55.8	64.2
CCGT_1	6.2	3.5	5.0	6.8	17.9	23.8	32.2
Diesel Gen_Off Grid	-	8.3	9.5	13.5	16.0	22.2	30.4
Gasoline Gen_Off Grid	-	4.7	5.6	7.0	6.8	7.0	8.9
Gas Turbine_Off Grid	-	1.9	5.9	8.0	10.1	12.4	16.5
Total	24.8	52.8	68.2	87.4	111.2	141.8	179.8

Appendix E2: Low Carbon Moderate Scenario Electricity Supply

Outputs by Feedstock Fuel							
Low Carbon Moderate Scenario, All Fuels, Primary Outputs							
Branch: Transformation\Electricity Generation\Processes							
Units: Million Megawatt-Hours							
Branches	2010	2015	2020	2025	2030	2035	2040
Hydropower_1	7.4	3.9	4.6	6.0	7.7	8.8	9.7
Coal_Steam	-	1.3	2.3	3.3	6.6	8.3	13.6
Nuclear	-	0.7	1.3	2.4	3.7	4.6	5.5
On_Shore Wind	-	0.0	0.0	0.0	0.0	0.0	0.1
Biomass	-	0.3	0.5	0.9	1.1	1.6	2.0
Solar PV	-	0.0	0.0	0.6	1.2	2.0	2.7
Solar Thermal	-	0.0	0.1	0.1	0.3	0.4	0.5
Coal_Super_Critical	-	0.7	1.2	1.7	4.7	7.7	11.4
Solar PV_Off Grid	-	0.0	0.1	0.2	0.5	0.9	1.3
Small Hydropower_Off Grid	-	1.1	2.0	2.3	2.9	3.3	3.5
SCGT_1	11.2	17.4	18.2	19.6	21.0	27.9	38.3
CCGT_1	6.2	13.8	17.8	19.4	22.2	23.3	28.9
Diesel Gen_Off Grid	-	7.3	8.5	12.0	13.5	19.0	20.2
Gasoline Gen_Off Grid	-	4.1	6.4	8.0	11.5	13.9	16.7
Gas Turbine_Off Grid	-	1.7	4.0	8.5	10.4	14.5	17.5
Total	24.8	52.3	67.0	85.0	107.3	136.1	171.8

Appendix E3: Low Carbon Advance Scenario Electricity Supply

Outputs by Feedstock Fuel							
Low Carbon Advance Scenario, All Fuels, Primary Outputs							
Branch: Transformation\Electricity Generation\Processes							
Units: Million Megawatt-Hours							
Branches	2010	2015	2020	2025	2030	2035	2040
Hydropower_1	7.4	16.3	17.6	16.6	16.7	15.5	15.4
Nuclear	-	1.3	2.5	6.2	9.4	14.3	18.6
On_Shore Wind	-	0.0	0.1	1.5	2.7	3.8	4.7
Biomass	-	0.6	1.1	3.8	6.9	7.3	8.6
Solar PV	-	0.2	0.3	1.3	1.8	3.1	4.2
Solar Thermal	-	0.2	0.3	0.8	2.2	4.1	5.2
Coal_IGCC	-	1.2	2.3	7.8	12.4	13.5	15.2
Coal_CFB	-	2.5	7.0	9.8	12.4	15.0	16.4
Solar PV_Off Grid	-	0.2	0.4	0.5	1.7	2.2	2.1
Small Hydropower_Off Grid	-	2.5	4.7	6.9	8.0	9.0	8.8
On_Shore Wind_Off Grid	-	0.3	0.6	1.8	2.7	3.4	3.9
SCGT_1	11.2	18.3	19.8	18.7	18.8	17.5	14.9
CCGT_1	6.2	16.6	23.5	30.6	37.7	41.9	39.3
Gas Turbine_Off Grid	-	2.3	6.6	9.2	11.7	12.7	12.1
SCGT_Off Grid	-	3.9	8.6	11.4	15.0	15.9	14.9
Total	24.8	66.5	95.4	126.8	160.2	179.0	184.3

Appendix E4: Green Optimistic Scenario Electricity Supply

Outputs by Feedstock Fuel							
GO Scenario, All Fuels, Primary Outputs							
Branch: Transformation\Electricity Generation\Processes							
Units: Million Megawatt-Hours							
Branches	2010	2015	2020	2025	2030	2035	2040
Hydropower_1	7.4	6.4	11.2	11.6	12.8	16.3	20.1
Nuclear	-	2.4	4.2	9.8	14.4	19.8	26.2
On_Shore Wind	-	0.0	0.5	3.1	4.8	6.8	8.3
Biomass	-	0.9	1.6	3.8	6.0	8.5	10.7
Solar PV	-	0.9	1.5	2.4	3.2	5.2	6.1
Solar Thermal	-	1.1	2.0	3.8	4.7	5.9	7.5
Coal_IGCC	-	1.1	2.0	3.1	5.4	8.0	11.0
Coal_Super_Critical	-	1.1	2.0	3.1	4.1	5.3	6.9
Coal_CFB	-	2.3	5.0	6.2	8.2	9.3	13.1
Off_Shore Wind	-	0.1	0.1	1.6	3.6	4.9	6.6
Geothermal	-	1.2	2.1	4.1	5.8	8.5	12.4
Solar PV_Off Grid	-	0.3	0.5	1.2	1.8	2.4	3.2
Small Hydropower_Off Grid	-	2.3	4.0	5.4	7.5	9.1	11.0
On_Shore Wind_Off Grid	-	0.3	0.5	1.6	2.8	4.1	5.6
Biomass_Off Grid	-	0.6	1.0	3.0	4.7	5.9	8.1
SCGT_1	11.2	16.1	14.7	11.9	11.3	11.3	12.4
CCGT_1	6.2	15.2	17.7	17.2	18.3	20.9	24.6
SCGT_Off Grid	-	3.6	3.6	3.3	3.6	4.7	5.8
Total	24.8	55.8	74.1	96.0	122.8	156.8	199.4

Appendix F: Total Electricity Demand, Supply and Primary Resources Requirements by Scenarios

Appendix F1: Total Electricity Demand

Energy Demand Final Units							
Electricity							
Branch: Demand							
Units: Million Megawatt-Hours							
Scenarios	2010	2015	2020	2025	2030	2035	2040
GO	32.3	46.2	63.2	84.5	111.4	146.3	191.4
Low Carbon Advance	32.3	54.8	81.1	111.0	144.1	165.6	175.1
Low Carbon Moderate	32.3	43.0	56.7	74.0	95.9	124.8	161.5
Reference	32.3	43.1	56.8	74.3	96.4	125.2	161.8
Total	129.1	187.1	257.8	343.7	447.8	561.9	689.8

Appendix F2: Total Electricity Supply

Outputs by Feedstock Fuel							
All Fuels, Primary Outputs							
Branch: Transformation\Electricity Generation							
Units: Million Megawatt-Hours							
Scenarios	2010	2015	2020	2025	2030	2035	2040
GO	24.8	55.8	74.1	96.0	122.8	156.8	199.4
Low Carbon Advance	24.8	66.5	95.4	126.8	160.2	179.0	184.3
Low Carbon Moderate	24.8	52.3	67.0	85.0	107.3	136.1	171.8
Reference	24.8	52.8	68.2	87.4	111.2	141.8	179.8
Total	99.1	227.3	304.6	395.3	501.5	613.7	735.3

Appendix F3: Primary Resource Requirements

Primary Requirements							
All Fuels							
Branch: Resources							
Units: Petajoules							
Scenarios	2010	2015	2020	2025	2030	2035	2040
GO	1,270.6	1,568.0	1,801.2	2,139.0	2,504.8	2,968.5	3,507.5
Low Carbon Advance	1,270.6	1,601.3	1,934.1	2,337.8	2,795.7	3,185.7	3,486.7
Low Carbon Moderate	1,270.6	1,584.5	1,872.4	2,221.4	2,669.0	3,202.5	3,868.9
Reference	1,270.6	1,631.2	1,930.6	2,309.7	2,755.9	3,326.3	3,998.0
Total	5,082.4	6,385.0	7,538.4	9,007.8	10,725.5	12,683.0	14,861.0

Appendix G: Green House Gas (GHG) Emissions by Scenarios

Appendix G1: GHGs in Reference Scenario

One Hundred Year Global Warming Potential							
Reference Scenario, All Fuels, All GHGs							
Branch: Demand							
Units: Million Metric Tonnes CO2 Equivalent							
Branches	2010	2015	2020	2025	2030	2035	2040
Households	22.3	26.6	31.7	37.7	45.0	53.7	64.1
Urban	9.1	11.2	13.6	16.7	20.4	25.0	30.6
Rural	13.2	15.4	18.0	21.1	24.6	28.7	33.5
Industry	2.8	3.6	4.6	5.8	7.3	9.2	11.5
Industry	2.8	3.6	4.6	5.8	7.3	9.2	11.5
Commercial_Service	0.5	0.7	0.9	1.2	1.6	2.2	2.9
Commercial_Service	0.5	0.7	0.9	1.2	1.6	2.2	2.9
Agriculture	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Agriculture	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Transport	16.8	19.4	22.5	26.1	30.3	35.1	40.7
Road Vehicles	16.8	19.4	22.5	26.1	30.3	35.1	40.7
Total	42.4	50.3	59.7	70.9	84.2	100.2	119.2

Appendix G2: GHGs in Low Carbon Moderate Scenario

One Hundred Year Global Warming Potential							
Low Carbon Moderate Scenario, All Fuels, All GHGs							
Branch: Demand							
Units: Million Metric Tonnes CO2 Equivalent							
Branches	2010	2015	2020	2025	2030	2035	2040
Households	22.3	26.3	30.9	36.3	42.6	49.9	58.4
Urban	9.1	10.9	12.9	15.3	18.0	21.2	24.9
Rural	13.2	15.4	18.0	21.1	24.6	28.7	33.5
Industry	2.8	3.5	4.4	5.4	6.6	8.1	9.9
Industry	2.8	3.5	4.4	5.4	6.6	8.1	9.9
Commercial_Service	0.5	0.6	0.8	1.1	1.4	1.8	2.3
Commercial_Service	0.5	0.6	0.8	1.1	1.4	1.8	2.3
Agriculture	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Agriculture	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Transport	16.8	19.1	21.8	24.7	27.8	31.1	34.5
Road Vehicles	16.8	19.1	21.8	24.7	27.8	31.1	34.5
Total	42.4	49.6	58.0	67.5	78.5	91.0	105.2

Appendix G3: GHGs in Low Advance Moderate Scenario

One Hundred Year Global Warming Potential							
Low Carbon Advance Scenario, All Fuels, All GHGs							
Branch: Demand							
Units: Million Metric Tonnes CO2 Equivalent							
Branches	2010	2015	2020	2025	2030	2035	2040
Households	22.3	25.0	28.2	32.1	36.8	42.2	48.4
Urban	9.1	9.6	10.2	11.1	12.3	13.5	15.0
Rural	13.2	15.4	18.0	21.0	24.5	28.6	33.4
Industry	2.8	3.6	4.5	5.5	6.7	8.0	9.4
Industry	2.8	3.6	4.5	5.5	6.7	8.0	9.4
Commercial_Service	0.5	0.6	0.8	1.0	1.3	1.6	2.0
Commercial_Service	0.5	0.6	0.8	1.0	1.3	1.6	2.0
Agriculture	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Agriculture	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Transport	16.8	18.9	21.2	23.6	26.1	28.6	30.8
Road Vehicles	16.8	18.9	21.2	23.6	26.1	28.6	30.8
Total	42.4	48.1	54.8	62.3	70.9	80.4	90.8

Appendix G4: GHGs in Green Optimistic Scenario

One Hundred Year Global Warming Potential							
Green Optimistic Scenario, All Fuels, All GHGs							
Branch: Demand							
Units: Million Metric Tonnes CO2 Equivalent							
Branches	2010	2015	2020	2025	2030	2035	2040
Households	22.3	24.3	26.7	29.8	33.4	37.8	42.9
Urban	9.1	8.8	8.7	8.7	8.8	9.1	9.4
Rural	13.2	15.4	18.0	21.1	24.6	28.7	33.5
Industry	2.8	3.5	4.3	5.2	6.1	7.1	8.3
Industry	2.8	3.5	4.3	5.2	6.1	7.1	8.3
Commercial_Service	0.5	0.6	0.8	0.9	1.1	1.4	1.6
Commercial_Service	0.5	0.6	0.8	0.9	1.1	1.4	1.6
Agriculture	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Agriculture	0.0	0.0	0.0	0.1	0.1	0.1	0.1
Transport	16.8	18.6	20.5	22.3	23.9	25.2	26.0
Road Vehicles	16.8	18.6	20.5	22.3	23.9	25.2	26.0
Total	42.4	47.1	52.3	58.2	64.7	71.6	78.9

Appendix G5: GHG from Electricity Generation in Reference Scenario

One Hundred Year Global Warming Potential							
Reference Scenario, All Fuels, All GHGs							
Branch: Transformation\Electricity Generation\Processes							
Units: Million Metric Tonnes CO2 Equivalent							
Branches	2010	2015	2020	2025	2030	2035	2040
Coal_Steam	-	0.8	1.3	4.5	5.6	10.7	15.0
Biomass	-	0.0	0.0	0.0	0.0	0.0	0.0
SCGT_1	5.6	14.9	16.9	19.4	22.8	28.0	32.3
CCGT_1	2.1	1.2	1.7	2.4	6.2	8.2	11.2
Diesel Gen_Off Grid	-	3.1	3.6	5.0	6.0	8.3	11.3
Gasoline Gen_Off Grid	-	3.5	4.2	5.3	5.1	5.2	6.6
Gas Turbine_Off Grid	-	0.6	2.0	2.7	3.4	4.2	5.5
Total	7.8	24.2	29.7	39.2	49.1	64.6	81.9

Appendix G6: GHG from Electricity Generation in Low Carbon Moderate Scenario

One Hundred Year Global Warming Potential							
Low Carbon Moderate Scenario, All Fuels, All GHGs							
Branch: Transformation\Electricity Generation\Processes							
Units: Million Metric Tonnes CO2 Equivalent							
Branches	2010	2015	2020	2025	2030	2035	2040
Coal_Steam	-	1.4	2.6	3.7	7.4	9.2	15.2
Biomass	-	0.0	0.0	0.0	0.0	0.0	0.0
Coal_Super_Critical	-	0.6	1.1	1.5	4.0	6.6	9.8
SCGT_1	5.6	8.7	9.1	9.8	10.6	14.0	19.2
CCGT_1	2.1	4.8	6.2	6.7	7.7	8.1	10.0
Diesel Gen_Off Grid	-	2.7	3.2	4.5	5.0	7.1	7.6
Gasoline Gen_Off Grid	-	3.1	4.8	6.0	8.6	10.4	12.5
Gas Turbine_Off Grid	-	0.6	1.4	2.8	3.5	4.8	5.9
Total	7.8	21.9	28.2	35.0	46.8	60.3	80.1

Appendix G7: GHG from Electricity Generation in Low carbon Advance Scenario

One Hundred Year Global Warming Potential							
Low Carbon Academic Scenario, All Fuels, All GHGs							
Branch: Transformation\Electricity Generation\Processes							
Units: Million Metric Tonnes CO2 Equivalent							
Branches	2010	2015	2020	2025	2030	2035	2040
Biomass	-	0.0	0.0	0.0	0.1	0.1	0.1
Coal_IGCC	-	0.9	1.7	5.8	9.2	10.0	11.3
Coal_CFB	-	2.6	7.3	10.3	13.0	15.7	17.2
SCGT_1	5.6	9.2	9.9	9.4	9.4	8.8	7.5
CCGT_1	2.1	5.8	8.1	10.6	13.1	14.5	13.6
Gas Turbine_Off Grid	-	0.8	2.2	3.1	3.9	4.3	4.1
SCGT_Off Grid	-	2.0	4.3	5.7	7.6	8.0	7.5
Total	7.8	21.2	33.7	44.9	56.3	61.3	61.2

Appendix G8: GHG from Electricity Generation in Green Optimistic Scenario

One Hundred Year Global Warming Potential							
Green Optimistic Scenario, All Fuels, All GHGs							
Branch: Transformation\Electricity Generation\Processes							
Units: Million Metric Tonnes CO2 Equivalent							
Branches	2010	2015	2020	2025	2030	2035	2040
Biomass	-	0.0	0.0	0.0	0.1	0.1	0.1
Coal_IGCC	-	0.8	1.5	2.3	4.1	6.0	8.2
Coal_Super_Critical	-	1.0	1.7	2.6	3.5	4.6	5.9
Coal_CFB	-	2.4	5.2	6.5	8.6	9.8	13.7
SCGT_1	5.6	8.1	7.4	6.0	5.7	5.7	6.2
CCGT_1	2.1	5.3	6.1	6.0	6.3	7.2	8.5
SCGT_Off Grid		1.8	1.8	1.6	1.8	2.3	2.9
Total	7.8	19.4	23.7	25.0	30.0	35.7	45.6

Appendix H: Energy Balance by Scenarios

Appendix H1: Reference Scenario Energy Balance in Base Year (2010)

Energy Balance for Area "Nigeria"																			
Scenario: Reference, Year: 2010, Units: Petajoule	Electricity	Natural Gas	Gasoline	Kerosene	Diesel	Residual Fuel Oil	LPG	Crude Oil	Coal Sub bituminous	Wood	Charcoal	Vegetal Wastes	Solar	Hydro	Lubricants	Biomass	Avgas	CNG	Total
Production	-	186.1	-	-	-	-	-	963.9	0.8	23.0	-	0.1	1.0	28.1	-	312.0	-	-	1,515.0
Imports	56.0	-	85.4	159.5	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	301.2
Exports	-	-	-	-	-62.6	-97.1	-60.6	-	-	-	-	-	-	-	-108.4	-	-108.4	-108.4	-545.6
Total Primary Supply	56.0	186.1	85.4	159.5	-62.6	-97.1	-60.6	963.9	1.1	23.0	-	0.1	1.0	28.1	-108.4	312.0	-108.4	-108.4	1,270.6
Coal Mining	-	-	-	-	-	-	-	-	-0.2	-	-	-	-	-	-	-	-	-	-0.2
Oil Refining	-	-	108.4	108.4	108.4	108.4	108.4	-963.9	-	-	-	-	-	-	108.4	-	108.4	108.4	-96.4
Charcoal Production	-	-	-	-	-	-	-	-	-	-7.6	1.5	-	-	-	-	-	-	-	-6.1
Electricity Generation	89.2	-139.0	-	-	-	-	-	-	-	-	-	-	-	-28.1	-	-	-	-	-77.9
Transmission and Distribution	-29.0	-21.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-50.7
Total Transformation	60.1	-160.7	108.4	108.4	108.4	108.4	108.4	-963.9	-0.2	-7.6	1.5	-	-	-28.1	108.4	-	108.4	108.4	-231.3
Households	84.9	-	-	267.8	-	-	47.8	-	-	15.4	1.5	0.1	1.0	-	-	-	-	-	418.5
Industry	11.7	25.4	-	-	-	11.0	-	-	1.0	-	-	-	-	-	-	247.9	-	-	297.0
Commercial_Service	19.6	-	-	-	-	0.3	-	-	-	-	-	-	-	-	-	64.1	-	-	84.0
Agriculture	-	-	-	0.1	0.3	-	-	-	-	-	-	-	-	-	-	-	-	-	0.4
Transport	-	-	193.8	-	45.5	-	-	-	-	-	-	-	-	-	-	-	-	-	239.3
Total Demand	116.2	25.4	193.8	267.9	45.9	11.3	47.8	-	1.0	15.4	1.5	0.1	1.0	-	-	312.0	-	-	1,039.3
Unmet Requirements (Waste)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix H2: Reference Scenario Energy Balance in 2040

Energy Balance for Area "Nigeria"																					
Scenario: Reference, Year: 2040, Units: Petajoule	Electricity	Natural Gas	Gasoline	Kerosene	Diesel	Residual Fuel Oil	LPG	Crude Oil	Coal Sub bituminous	Wood	Charcoal	Vegetal Wastes	Wind	Solar	Hydro	Nuclear	Lubricants	Biomass	Avgas	CNG	Total
Production	-	1,016.1	-	-	-	-	-	963.9	0.8	34.6	-	0.2	0.2	7.8	35.2	-	-	795.4	-	-	2,854.1
Imports	-	-	453.0	632.1	159.7	-	68.8	-	179.0	-	-	-	-	-	-	46.5	-	-	-	-	1,539.1
Exports	-	-	-	-	-	-69.9	-	-	-	-	-	-	-	-	-	-	-108.4	-	-108.4	-108.4	-395.2
Total Primary Supply	-	1,016.1	453.0	632.1	159.7	-69.9	68.8	963.9	179.8	34.6	-	0.2	0.2	7.8	35.2	46.5	-108.4	795.4	-108.4	-108.4	3,998.0
Coal Mining	-	-	-	-	-	-	-	-	-0.2	-	-	-	-	-	-	-	-	-	-	-	-0.2
Oil Refining	-	-	108.4	108.4	108.4	108.4	108.4	-963.9	-	-	-	-	-	-	-	-	108.4	-	108.4	108.4	-96.4
Charcoal Production	-	-	-	-	-	-	-	-	-	-12.1	2.7	-	-	-	-	-	-	-	-	-	-9.4
Electricity Generation	647.2	-876.9	-91.1	-	-156.1	-	-	-	-161.1	-	-	-	-0.2	-4.4	-35.2	-46.5	-	-0.3	-	-	-724.5
Transmission and Distribution	-64.7	-27.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-92.6
Total Transformation	582.5	-904.7	17.4	108.4	-47.7	108.4	108.4	-963.9	-161.2	-12.1	2.7	-	-0.2	-4.4	-35.2	-46.5	108.4	-0.3	108.4	108.4	-923.0
Households	321.4	-	-	740.2	-	-	177.2	-	-	22.5	2.7	0.2	-	3.4	-	-	-	-	-	-	1,267.6
Industry	148.4	111.3	-	-	-	37.1	-	-	18.6	-	-	-	-	-	-	-	-	426.8	-	-	742.2
Commercial_Service	112.7	-	-	-	-	1.4	-	-	-	-	-	-	-	-	-	-	-	368.4	-	-	482.5
Agriculture	-	-	-	0.4	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8
Transport	-	-	470.4	-	110.5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	581.0
Total Demand	582.5	111.3	470.4	740.6	112.0	38.6	177.2	-	18.6	22.5	2.7	0.2	-	3.4	-	-	-	795.1	-	-	3,075.0
Unmet Requirements (Waste)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix H3: Low Carbon Moderate Scenario Energy Balance in 2040

Energy Balance for Area "Nigeria"																					
Scenario: Low Carbon Moderate, Year: 2040, Units: Petajoule	Electricity	Natural Gas	Gasoline	Kerosene	Diesel	Residual Fuel Oil	LPG	Crude Oil	Coal Sub bituminous	Wood	Charcoal	Vegetal Wastes	Wind	Solar	Hydro	Nuclear	Lubricants	Biomass	Avgas	CNG	Total
Production	-	738.6	-	-	-	-	-	963.9	0.8	32.2	-	0.2	0.7	107.5	50.9	-	-	889.2	-	-	2,784.0
Imports	-	-	434.7	570.4	94.8	-	47.3	-	283.5	-	-	-	-	-	-	54.7	-	-	-	-	1,485.3
Exports	-	-	-	-	-	-75.1	-	-	-	-	-	-	-	-	-	-	-108.4	-	-108.4	-108.4	-400.5
Total Primary Supply	-	738.6	434.7	570.4	94.8	-75.1	47.3	963.9	284.3	32.2	-	0.2	0.7	107.5	50.9	54.7	-108.4	889.2	-108.4	-108.4	3,868.9
Coal Mining	-	-	-	-	-	-	-	-	-0.2	-	-	-	-	-	-	-	-	-	-	-	-0.2
Oil Refining	-	-	108.4	108.4	108.4	108.4	108.4	-963.9	-	-	-	-	-	-	-	-	108.4	-	108.4	108.4	-96.4
Charcoal Production	-	-	-	-	-	-	-	-	-	-9.8	2.7	-	-	-	-	-	-	-	-	-	-7.1
Electricity Generation	618.4	-628.5	-171.5	-	-104.1	-	-	-	-268.2	-	-	-	-0.7	-104.2	-50.9	-54.7	-	-9.1	-	-	-773.3
Transmission and Distribution	-37.1	-14.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-51.4
Total Transformation	581.3	-642.8	-63.0	108.4	4.3	108.4	108.4	-963.9	-268.3	-9.8	2.7	-	-0.7	-104.2	-50.9	-54.7	108.4	-9.1	108.4	108.4	-928.4
Households	294.6	-	-	678.5	-	-	155.8	-	-	22.4	2.7	0.2	-	3.3	-	-	-	-	-	-	1,157.4
Industry	127.7	95.8	-	-	-	31.9	-	-	16.0	-	-	-	-	-	-	-	-	367.2	-	-	638.6
Commercial_Service	159.0	-	-	-	-	1.4	-	-	-	-	-	-	-	-	-	-	-	294.0	-	-	454.3
Agriculture	-	-	-	0.4	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8
Transport	-	-	371.6	-	97.7	-	-	-	-	-	-	-	-	-	-	-	-	219.0	-	-	688.3
Total Demand	581.3	95.8	371.6	678.8	99.1	33.3	155.8	-	16.0	22.4	2.7	0.2	-	3.3	-	-	-	880.1	-	-	2,940.5
Unmet Requirements (Waste)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix H4: Low Carbon Advance Scenario Energy Balance in 2040

Energy Balance for Area "Nigeria"																					
Scenario: Low Carbon Advance, Year: 2040, Units: Petajoule	Electricity	Natural Gas	Gasoline	Kerosene	Diesel	Residual Fuel Oil	LPG	Crude Oil	Coal Sub bituminous	Wood	Charcoal	Vegetal Wastes	Wind	Solar	Hydro	Nuclear	Lubricants	Biomass	Avgas	CNG	Total
Production	-	715.3	-	-	-	-	-	963.9	0.8	22.3	-	0.2	114.5	236.9	93.6	-	-	570.4	-	-	2,717.9
Imports	-	-	137.5	417.1	-	-	203.8	-	271.1	-	-	-	-	-	-	186.0	-	-	-	-	1,215.5
Exports	-	-	-	-	-39.3	-82.1	-	-	-	-	-	-	-	-	-	-	-108.4	-	-108.4	-108.4	-446.7
Total Primary Supply	-	715.3	137.5	417.1	-39.3	-82.1	203.8	963.9	271.9	22.3	-	0.2	114.5	236.9	93.6	186.0	-108.4	570.4	-108.4	-108.4	3,486.7
Coal Mining	-	-	-	-	-	-	-	-	-0.2	-	-	-	-	-	-	-	-	-	-	-	-0.2
Oil Refining	-	-	108.4	108.4	108.4	108.4	108.4	-963.9	-	-	-	-	-	-	-	-	108.4	-	108.4	108.4	-96.4
Charcoal Production	-	-	-	-	-	-	-	-	-	-8.2	2.7	-	-	-	-	-	-	-	-	-	-5.5
Electricity Generation	663.5	-584.3	-	-	-	-	-	-	-262.3	-	-	-	-114.5	-234.3	-93.6	-186.0	-	-38.6	-	-	-850.1
Transmission and Distribution	-33.2	-13.1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-46.3
Total Transformation	630.4	-597.4	108.4	108.4	108.4	108.4	108.4	-963.9	-262.5	-8.2	2.7	-	-114.5	-234.3	-93.6	-186.0	108.4	-38.6	108.4	108.4	-998.4
Households	225.0	-	-	525.1	-	-	178.6	-	-	14.1	2.7	0.2	-	2.6	-	-	-	-	-	-	948.3
Industry	188.7	117.9	-	-	-	23.6	-	-	9.4	-	-	-	-	-	-	-	-	132.1	-	-	471.6
Commercial_Service	216.7	-	-	-	-	2.7	-	-	-	-	-	-	-	-	-	-	-	234.9	-	-	454.3
Agriculture	-	-	-	0.4	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8
Transport	-	-	246.0	-	67.7	-	133.7	-	-	-	-	-	-	-	-	-	-	164.9	-	-	612.2
Total Demand	630.4	117.9	246.0	525.5	69.2	26.3	312.2	-	9.4	14.1	2.7	0.2	-	2.6	-	-	-	531.8	-	-	2,488.3
Unmet Requirements (Waste)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix H5: Green Optimistic Scenario Energy Balance in 2040

Energy Balance for Area "Nigeria"

Scenario: GO, Year: 2040, Units: Petajoule	Electricity	Natural Gas	Gasoline	Kerosene	Diesel	Residual Fuel Oil	LPG	Crude Oil	Coal Sub bituminous	Wood	Charcoal	Vegetal Wastes	Wind	Solar	Hydro	Geothermal	Nuclear	Lubricants	Biomass	Avgas	CNG	Total
Production	-	445.7	-	-	-	-	-	963.9	0.7	29.7	-	0.2	240.4	341.1	120.0	212.2	-	-	471.3	-	-	2,825.2
Imports	-	-	50.2	391.0	-	-	114.9	-	271.0	-	-	-	-	-	-	-	262.1	-	-	-	-	1,089.2
Exports	-	-	-	-	-67.1	-94.4	-	-	-	-	-	-	-	-	-	-	-	-108.4	-	-108.4	-28.4	-406.9
Total Primary Supply	-	445.7	50.2	391.0	-67.1	-94.4	114.9	963.9	271.7	29.7	-	0.2	240.4	341.1	120.0	212.2	262.1	-108.4	471.3	-108.4	-28.4	3,507.5
Coal Mining	-	-	-	-	-	-	-	-	-0.1	-	-	-	-	-	-	-	-	-	-	-	-	-0.1
Oil Refining	-	-	108.4	108.4	108.4	108.4	108.4	-963.9	-	-	-	-	-	-	-	-	-	108.4	-	108.4	108.4	-96.4
Charcoal Production	-	-	-	-	-	-	-	-	-	-7.4	2.7	-	-	-	-	-	-	-	-	-	-	-4.7
Electricity Generation	717.9	-316.5	-	-	-	-	-	-	-263.5	-	-	-	-240.4	-339.1	-120.0	-212.2	-262.1	-	-84.6	-	-	-1,120.7
Transmission and Distribution	-28.7	-7.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-36.5
Total Transformation	689.1	-324.2	108.4	108.4	108.4	108.4	108.4	-963.9	-263.6	-7.4	2.7	-	-240.4	-339.1	-120.0	-212.2	-262.1	108.4	-84.6	108.4	108.4	-1,258.3
Households	197.3	-	-	499.1	-	-	112.6	-	-	22.2	2.7	0.2	-	1.9	-	-	-	-	-	-	-	836.0
Industry	202.4	121.5	-	-	-	8.1	-	-	8.1	-	-	-	-	-	-	-	-	-	64.8	-	-	404.9
Commercial_Service	289.4	-	-	-	-	5.9	-	-	-	-	-	-	-	-	-	-	-	-	159.0	-	-	454.3
Agriculture	-	-	-	0.4	1.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.8
Transport	-	-	158.7	-	39.8	-	110.8	-	-	-	-	-	-	-	-	-	-	-	162.9	-	80.0	552.2
Total Demand	689.1	121.5	158.7	499.4	41.3	14.0	223.3	-	8.1	22.2	2.7	0.2	-	1.9	-	-	-	-	386.7	-	80.0	2,249.2
Unmet Requirements (Waste)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Appendix I: Results for Least-Cost Electricity Generation

Appendix I1: Least-Cost Electricity Generation 2015

Social Costs																		
2015																		
Branch: Nigeria Electricity Optimization																		
Units: Discounted 2010 Cumulative Million U.S. Dollars. Discounted to Year: 2010.																		
Cost Categories	Biomass Only	CCGT Only	CO2 Limit	Coal CFB Only	Coal IGCC Only	Coal Steam Only	Coal Super-critical Only	Geothermal Only	Large Hydro-power Only	Nuclear Only	Off Shore Wind Only	On Shore Wind Only	Optimization	SCGT Only	Small Hydro-power Only	Solar PV Only	Solar Thermal Only	Total
Transformation Capital	1.0	0.4	1.9	0.6	0.8	0.6	0.6	0.6	0.5	1.1	2.9	0.9	1.9	0.4	1.1	2.9	1.7	19.9
Transformation Fixed O&M	0.5	0.2	0.2	0.4	0.4	0.1	0.3	0.4	0.1	1.1	0.5	0.3	0.2	0.1	0.1	0.1	0.6	5.6
Transformation Variable O&M	573.7	367.9	-	362.7	580.4	281.5	507.8	441.3	27.7	367.8	-	-	-	220.7	-	-	-	3,731.5
Fuel Production	-	3,466.5	-	3,307.5	3,087.0	4,491.4	3,157.2	-	-	-	-	-	-	5,024.7	-	-	-	22,534.3
Environmental Externalities	543.7	494.2	-	1,417.3	1,862.2	2,709.4	1,904.5	-	-	-	-	-	-	716.4	-	-	-	9,647.8
Total	1,119.0	4,329.2	2.1	5,088.6	5,530.8	7,482.9	5,570.4	442.4	28.4	369.9	3.4	1.2	2.1	5,962.3	1.2	3.0	2.2	35,939.1

Appendix I2: Least-Cost Electricity Generation 2020

Social Costs																		
2020																		
Branch: Nigeria Electricity Optimization																		
Units: Discounted 2010 Cumulative Million U.S. Dollars. Discounted to Year: 2010.																		
Cost Categories	Biomass Only	CCGT Only	CO2 Limit	Coal CFB Only	Coal IGCC Only	Coal Steam Only	Coal Super-critical Only	Geothermal Only	Large Hydro-power Only	Nuclear Only	Off Shore Wind Only	On Shore Wind Only	Optimization	SCGT Only	Small Hydro-power Only	Solar PV Only	Solar Thermal Only	Total
Transformation Capital	3.2	1.3	6.0	1.9	2.6	1.8	2.0	1.9	1.7	3.3	8.9	2.8	6.0	1.2	3.3	8.9	5.2	62.1
Transformation Fixed O&M	1.6	0.5	0.7	1.3	1.1	0.3	0.9	1.3	0.4	3.3	1.5	0.8	0.7	0.4	0.4	0.4	1.7	17.3
Transformation Variable O&M	1,790.5	1,152.7	-	1,132.9	1,812.7	878.1	1,586.1	1,382.1	86.2	1,151.8	-	-	-	691.1	-	-	-	11,664.2
Fuel Production	-	10,861.4	-	10,330.7	9,641.9	14,012.9	9,861.1	-	-	-	-	-	-	15,735.9	-	-	-	70,443.9
Environmental Externalities	1,696.8	1,548.6	-	4,426.9	5,816.4	8,453.2	5,948.6	-	-	-	-	-	-	2,243.5	-	-	-	30,134.0
Total	3,492.1	13,564.5	6.7	15,893.7	17,274.8	23,346.3	17,398.6	1,385.3	88.3	1,158.3	10.5	3.7	6.7	18,672.0	3.7	9.3	7.0	112,321.5

Appendix I3: Least-Cost Electricity Generation 2025

Social Costs																		
2025																		
Branch: Nigeria Electricity Optimization																		
Units: Discounted 2010 Cumulative Million U.S. Dollars. Discounted to Year: 2010.																		
Cost Categories	Biomass Only	CCGT Only	CO2 Limit	Coal CFB Only	Coal IGCC Only	Coal Steam Only	Coal Super-critical Only	Geothermal Only	Large Hydro-power Only	Nuclear Only	Off Shore Wind Only	On Shore Wind Only	Optimization	SCGT Only	Small Hydro-power Only	Solar PV Only	Solar Thermal Only	Total
Transformation Capital	6.0	2.4	11.3	3.5	4.8	3.4	3.7	3.5	3.1	6.1	16.7	5.3	11.3	2.3	6.2	16.6	9.8	115.8
Transformation Fixed O&M	3.1	1.0	1.3	2.4	2.1	0.5	1.6	2.4	0.8	6.1	2.8	1.5	1.3	0.7	0.7	0.7	3.2	32.2
Transformation Variable O&M	3,344.6	2,156.8	-	2,116.7	3,386.7	1,640.3	2,963.4	2,585.0	160.7	2,154.2	-	-	-	1,292.5	-	-	-	21,801.0
Fuel Production	-	20,321.6	-	19,301.3	18,014.5	26,175.2	18,423.9	-	-	-	-	-	-	29,431.2	-	-	-	131,667.6
Environmental Externalities	3,169.7	2,897.3	-	8,271.0	10,867.1	15,790.0	11,114.1	-	-	-	-	-	-	4,196.1	-	-	-	56,305.3
Total	6,523.4	25,379.0	12.6	29,694.8	32,275.2	43,609.3	32,506.6	2,591.0	164.6	2,166.4	19.5	6.8	12.6	34,922.7	7.0	17.3	13.0	209,921.9

Appendix I4: Least-Cost Electricity Generation 2030

Social Costs																		
2030																		
Branch: Nigeria Electricity Optimization																		
Units: Discounted 2010 Cumulative Million U.S. Dollars. Discounted to Year: 2010.																		
Cost Categories	Biomass Only	CCGT Only	CO2 Limit	Coal CFB Only	Coal IGCC Only	Coal Steam Only	Coal Super-critical Only	Geothermal Only	Large Hydro-power Only	Nuclear Only	Off Shore Wind Only	On Shore Wind Only	Optimization	SCGT Only	Small Hydro-power Only	Solar PV Only	Solar Thermal Only	Total
Transformation Capital	9.0	3.6	17.0	5.2	7.2	5.1	5.5	5.2	4.6	9.2	25.1	8.0	17.0	3.4	9.4	25.0	14.7	174.2
Transformation Fixed O&M	4.6	1.5	2.0	3.6	3.1	0.7	2.4	3.7	1.2	9.2	4.2	2.3	2.0	1.0	1.1	1.0	4.9	48.5
Transformation Variable O&M	5,033.3	3,248.3	-	3,185.6	5,097.0	2,468.4	4,459.8	3,892.4	241.7	3,243.7	-	-	-	1,946.2	-	-	-	32,816.4
Fuel Production	-	30,606.3	-	29,048.1	27,111.5	39,390.0	27,727.7	-	-	-	-	-	-	44,315.6	-	-	-	198,199.2
Environmental Externalities	4,770.0	4,363.6	-	12,447.7	16,354.8	23,761.7	16,726.5	-	-	-	-	-	-	6,318.2	-	-	-	84,742.7
Total	9,816.9	38,223.2	19.0	44,690.2	48,573.6	65,626.1	48,921.9	3,901.3	247.5	3,262.1	29.3	10.3	19.0	52,584.5	10.5	26.0	19.6	315,981.0

Appendix I5: Least-Cost Electricity Generation 2035

Social Costs																		
2035																		
Branch: Nigeria Electricity Optimization																		
Units: Discounted 2010 Cumulative Million U.S. Dollars. Discounted to Year: 2010.																		
Cost Categories	Biomass Only	CCGT Only	CO2 Limit	Coal CFB Only	Coal IGCC Only	Coal Steam Only	Coal Super-critical Only	Geothermal Only	Large Hydro-power Only	Nuclear Only	Off Shore Wind Only	On Shore Wind Only	Optimization	SCGT Only	Small Hydro-power Only	Solar PV Only	Solar Thermal Only	Total
Transformation Capital	12.0	4.8	22.7	7.0	9.6	6.8	7.3	7.0	6.2	12.3	33.5	10.7	22.7	4.5	12.5	33.4	19.6	232.7
Transformation Fixed O&M	6.1	2.0	2.7	4.8	4.2	1.0	3.2	4.9	1.6	12.3	5.7	3.1	2.7	1.4	1.5	1.4	6.5	64.8
Transformation Variable O&M	6,726.1	4,342.4	-	4,257.2	6,811.4	3,298.6	5,960.0	5,202.9	322.9	4,335.8	-	-	-	2,601.5	-	-	-	43,858.7
Fuel Production	-	40,915.2	-	38,819.0	36,231.1	52,637.6	37,054.5	-	-	-	-	-	-	59,236.1	-	-	-	264,893.5
Environmental Externalities	6,374.3	5,833.4	-	16,634.8	21,856.1	31,753.2	22,352.8	-	-	-	-	-	-	8,445.5	-	-	-	113,250.2
Total	13,118.6	51,097.7	25.3	59,722.7	64,912.4	87,697.2	65,377.9	5,214.8	330.7	4,360.4	39.2	13.7	25.3	70,289.0	14.0	34.7	26.2	422,299.9

Appendix I6: Least-Cost Electricity Generation 2040

Social Costs																		
2040																		
Branch: Nigeria Electricity Optimization																		
Units: Discounted 2010 Cumulative Million U.S. Dollars. Discounted to Year: 2010.																		
Cost Categories	Biomass Only	CCGT Only	CO2 Limit	Coal CFB Only	Coal IGCC Only	Coal Steam Only	Coal Super-critical Only	Geothermal Only	Large Hydro-power Only	Nuclear Only	Off Shore Wind Only	On Shore Wind Only	Optimization	SCGT Only	Small Hydro-power Only	Solar PV Only	Solar Thermal Only	Total
Transformation Capital	14.9	5.9	28.1	8.7	12.0	8.5	9.1	8.7	7.7	15.3	41.5	13.2	28.1	5.6	15.5	41.4	24.3	288.6
Transformation Fixed O&M	7.6	2.4	3.3	5.9	5.2	1.2	4.0	6.1	2.0	15.2	7.0	3.8	3.3	1.7	1.8	1.7	8.1	80.3
Transformation Variable O&M	8,340.8	5,386.8	-	5,279.2	8,446.8	4,090.5	7,390.9	6,453.4	400.2	5,377.8	-	-	-	3,226.7	-	-	-	54,393.2
Fuel Production	-	50,755.9	-	48,138.8	44,929.6	65,273.8	45,950.7	-	-	-	-	-	-	73,473.1	-	-	-	328,521.9
Environmental Externalities	7,904.6	7,236.4	-	20,628.6	27,103.4	39,375.9	27,719.4	-	-	-	-	-	-	10,475.3	-	-	-	140,443.5
Total	16,267.9	63,387.5	31.4	74,061.2	80,496.9	108,749.8	81,074.1	6,468.1	409.9	5,408.3	48.6	17.0	31.4	87,182.5	17.4	43.0	32.4	523,727.5

Appendix I7: Power Plant Specific GHGs

	Biomass Only			CCGT only			Coal CFB Only			Coal IGCC Only		
	2020	2030	2040	2020	2030	2040	2020	2030	2040	2020	2030	2040
Carbon Dioxide Non Biogenic	0	0	0	20.77363	41.54727	62.3209	46.7535	93.21135	139.9648	43.6366	86.99726	130.6339
Methane	0.164804	0.328578	0.493382	0.007821	0.015641	0.023462	0.010598	0.021129	0.031726	0.009891	0.01972	0.029611
Nitrous Oxide	0.324377	0.646725	0.971102	0.011545	0.02309	0.034634	15.01859	29.9422	44.96079	0.20442	0.407547	0.611966
Total	0.489181	0.975303	1.464484	20.793	41.586	62.379	61.78268	123.1747	184.9574	43.85091	87.42453	131.2754

Appendix I8: Power Plants Specific GHGs

	Coal Steam Only			Coal Supercritical Only			SCGT Only		
	2020	2030	2040	2020	2030	2040	2020	2030	2040
Carbon Dioxide Non Biogenic	63.38541	126.3813	189.7667	44.62834	88.97447	133.6028	30.0966	60.09453	90.19113
Methane	0.014368	0.028647	0.043015	0.010116	0.020168	0.030284	0.011331	0.022624	0.033954
Nitrous Oxide	0.296935	0.592045	0.888979	0.209066	0.416809	0.625875	0.016726	0.033397	0.050123
Total	63.69671	127.002	190.6987	44.84752	89.41145	134.259	30.12466	60.15055	90.27521

발췌문

나이지리아의 지속 가능한 국가 전략 마련을
위한 장기 에너지 분석: LEAP 모델을 이용하여

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본 연구는 나이지리아 경제체제를 대상으로 미래 에너지 시스템에 영향을 줄 수 있는 주요 요소들을 선별하여, 시나리오를 설계하고 이에 따른 효과를 분석하는 데 목적이 있다. 나이지리아 경제체제를 대상으로 LEAP (Long-Range Alternative Planning System) 모델링 방법론을 적용용함으로써, 설계 시나리오를 바탕으로 비용-편익 분석, 및 최소비용 발전기술 옵션에 대한 분석을 실시하였다. 이와 같은 에너지 수요에 대한 예측 및 에너지 수요 충족을 위한 최소비용 에너지 기술 조합 등을 파악함으로써 향후 나이지리아의 저탄소 경제성장을 이룩하기 위한 거시적 에너지정책 수립을 위한 시사점을 도출하고자 한다.

분석을 위해 미래 에너지 시스템 및 에너지 수요에 영향을 줄 수 있는 주요 변수로서는 경제성장 (GDP) 성장률, 가계 및 인구 성장률, 도시화 정도 (urbanization rate), 그리고 에너지 집약산업의 성장 정도 등을 고려하였고 이를 바탕으로 네 개의 분석 시나리오를 설계하였다 (REF: Reference 시나리오, LCM: Low carbon moderate 시나리오, LCA: Low carbon advance 시나리오, GO: Green optimistic 시나리오). 분석을 위한 시나리오는 에너지 수요 및 공급 부문을 종합적으로 고려하여 설계되었으며, 특히 에너지 공급 부문의 기술적 요소의 특이성을 강조하여 분석 시나리오를 구성하였다.

분석 결과, 에너지에 대한 수요는 연 평균 약 3.56% (REF 시나리오), 3.53% (LCM), 2.95% (LCA), 그리고 2.61% (GO)의 성장률을 보이는 것으로 확인되었다. 그리고 REF 시나리오 하에서 2040년 3,075PJ의 가장 높은 에너지 수요를 가져오는 반면, GO 시나리오 하에서는 가장 낮은 2,248.2PJ의 에너지 수요가 있을 것으로 전망되었다. 더불어, GO 시나리오 하에서, 다른 시나리오들에 비해 온실가스 배출 정도가 가장 낮은 것 (124.4 MMTCDE)으로 확인되었는데 이는 에너지 믹스 내 높은 수준의 신재생에너지 기술 진입으로 인한 것으로 파악하였다.

또한 본 연구는 시나리오 별로 다양한 에너지 정책의 수준 정도를 반영하였는데, 예로 에너지 효율, 연료 및 에너지 기술 전환정도 등을 시나리오에 반영함으로써 개별 시나리오의 비용 편익 분석도 함께 실시하였다. 분석 결과, LCM, LCA, GO 시나리오 하에서 약 $ 1.69 billion,

$ 23.8 billion, $ 41.4billion 의 비용이 발생함을 추정할 수 있었다. 더불어 최소 비용의 발전 기술 조합에 대한 분석을 실시하여, 풍력 발전 및 소규모 수력발전이 가장 낮은 비용의 발전 비용을 수반하는 것을 확인하였으며, 화석연료 기반 발전에 대해서는 CCGT 기반 발전기술이 가장 낮은 비용을 가져오는 것을 확인할 수 있었다. 이와 같은 분석을 통해 본 연구는 나이지리아 내 저탄소 경제체제로의 전환을 위해서는 저탄소 및 신재생에너지의 역할이 매우 중요함을 파악할 수 있었다.

이와 같은 일련의 분석을 통해 본 연구는 나이지리아의 녹색성장을 견인할 수 있는 저탄소 에너지 정책에 대한 시사점을 도출할 수 있었다. 이를 통해 도출한 정책적 시사점은, 녹색 성장에 대한 개념 정리화, 에너지 정책 개편, 장기간 시각에 근거한 에너지 계획 수립, 환경세 개편, 에너지 규제 및 표준 수립, 그리고 에너지 및 교통 부문 내 효율성 증대 등으로 정리할 수 있었다. 이처럼 본 연구는 향후 나이지리아의 기후변화 대응 및 녹색성장을 위한 에너지 정책 부문에 있어서의 정책적 시사점을 도출하였다는 점에서 연구적 의의가 있다.

주요어 : 나이지리아 LEAP 모델; 시나리오 분석; 최소 비용 발전 기술; 비용 편익 분석; 지속가능한 발전; 저탄소 경제성장
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