Long Term Energy Development Pathways for Nigeria: A Scenario Based Analysis

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Abstract

This research explored several energy solutions for Nigeria in order to have a long range and sustainable power sector. In the research, four deferent scenarios such as Business as usual scenario (BAU), Mild renewable energy scenario (MRES), Extreme renewable energy scenario (ERES) and Total green energy scenario (TGES) were developed using a computer tool kit LEAP from 2018 to 2050. The reference scenario was developed base on governments plan for renewable and sustainable power sector, while the three alternative scenarios were developed base on different policy settings in order to examine the reserves, demands, supply and emission impact of each of the scenarios. Also, the research compared some important energy policies existing in Germany with Nigeria. The results obtained showed that at 2050, the business as usual scenario has the highest energy demand with about 1.3 million GWh , while the total green energy scenario has the least energy demand with about 0.9 million GWh. For the greenhouse gases, the business as usual scenario again has the highest level of greenhouse gases (GHG) with about 231 million ton carbon dioxide equivalent (tCO2e) while the total green energy scenario has the least level of greenhouse gases with about 119 million tCO2e.

Keywords
Energy scenario, LEAP, Renewable energy, Nigeria

1. Introduction

The importance of energy cannot be over emphasized, as it is an integral part in the sustenance of societal development, economy, security and eliminating poverty of a nation. The availability or otherwise of an energy that is environmentally friendly, affordable and accessible naturally affects the total development of a country. Also, there are many issues such climate change, public health which affects a society that is also related to energy (Ramchandra et al. 2011). Strictly speaking, energy is important in all the sectors of a nation the per capita energy consumption, is a measure that is used in measuring the standard of life in any nation. The rise in standard of living and increase in population are the two main reasons that cause energy crises in the world. Ideally, the prosperity of a nation is measured base on its per capita income, which is measured base on the per capita energy consumption (Rai 2004).

Furthermore, domestic activities such as refrigeration, heating, cooking, watching television, lightening, etc., all require energy in various forms for proper utilization and effective working. Major activities such as in transport area, industrial area, mining area, agricultural area, etc. are all not possible without proper utilization of energy from one form to another. In contrast, it can be stated that since every nation requires the aforementioned listed above to be developed, lack of energy in any nation will lead to adverse effect in the economy of the nation there by inducing poverty amongst the citizens of the nation. Increase in productivity and income growth leads to better health and educational services and can only be achieved by energy utilization which will reduce poverty. (Nnaji et al. 2010).

Nigeria as the giant of Africa, is a mono economic country which solidly relies on its non-renewable energy sources such as crude oil and natural gas to generate income that will be used for running the affairs of the government and also boosting the societal development of the country through infrastructural development such as schools, roads, hospitals etc. in order to improve the standard of living of its people. Other sources such as wind, sun, river etc. which are referred to as renewable energy sources are also richly available in Nigeria but are not optimally harnessed. Despite also these renewable energy sources, fossil based fuel such as crude oil, natural gas and coal account for about 80% of the countries utilized energy sources (Awwad et al. 2007). Other sectors such as transport, agricultural, industrial, commercial, health etc. which are the elements used to measure the prosperity of a successful country cannot be developed without proper utilization of the abundant energy resources (Sambo et al. 2009).

Nigeria is a mono economy country which primarily depends on energy products as its source of income. Primary energy sources such as crude oil, natural gas, wind, sun, coal, wood, rivers etc. are all richly available in Nigeria. In Nigeria, energy is the main carrier of its growth and development through international diplomacy and trading. Primary energy sources such as crude oil and natural gas are the major source of income of Nigeria which is used both for capital and recurrent expenditures. Important sectors such as transport, agriculture, health cannot be developed and managed effectively without proper management of energy resources (Sambo et al. 2009) Primary sources of energy such as; natural gas, nuclear fuels, coal, sun, hydro, wind, biomass are all richly available in Nigeria. Despite all these sources, fossil based fuels account for about 80% of the country's utilized energy (Awwad et al. 2007).

Nigeria is endowed with abundant primary energy resource, in 2014, it was estimated that Nigeria has crude oil reserve of about 37 billion barrels. This placed Nigeria at number ten in the world in terms of crude oil reserve. Also, research has shown that Nigeria is more blessed with natural gas rather than crude oil. In 2006 also, it was estimated that Nigeria has about 5.15 trillion $m^3$of natural gas which also placed it among the top ten countries in the world with high natural gas reserve. Even though this are the major primary energy sources in Nigeria, other significant sources include; coal and lignite with a reserve of 2.7 billion tones, tar sands with a reserve of 31 billion barrels of oil equivalent, large hydropower with potential of 11,000 MW.

Nigeria being the most populous country in Africa with an approximate population of 180 million people and richly endowed with primary energy sources cannot provide constant electricity to its citizens (Obadote 2010). This has tremendously affected the socio economic and technological advancement of the country as majority of the citizens live below $1.0 per day (Sambo et al. 2010). According to report from (U N 2017), the population of Nigeria might grow as high as 400 million in 2050, which might made it to slightly beat the United States of America and become the third most populous country in the world after China and India (Mirjat et al. 2018).

About 60% of the population of Nigerians are not connected to the national grid and even the 40% that are connected to the national grid face power interruption about 60% of the time (Obadote 2009). In 2009, industrialist claimed that the industrial sector has been crippled due to inadequate power supply that they need about 2000MW to function optimally. Also, manufacturers association of Nigeria said that it spends more than 11.34 million US $ every week just to run and maintain power using generator sets (ECN 2011). Since energy cost constitutes about 40% of the total cost of production in Nigeria, then his issue has resulted to high cost of products in Nigeria which is about nine times higher than China (Ojo 2009).

The sustainable development goals, which were set by the United Nations in 2015 are set of agendas that all member countries are expected to achieve by transforming the world at 2030. The SDGs, which extends from social to economic developmental areas include affordable and clean energy, zero hunger, no poverty, good health and wellbeing, quality education, gender equality, clean water and sanitation, decent work and economic growth, industry, innovation and infrastructure, reduced inequalities, sustainable cities and communities, responsible consumption and production, climate action, life below water, life on land, peace justice and strong institutions and lastly partnership for the goals. If these goals that are set by the United Nations will be achieved by any country, then the country is said to be successful. Without constant electricity supply, it will be very difficult for a country to achieve these goals as they are almost all related to energy. The development of alternative fuels that are reliable and sustainable is been ruin due to the over reliance of the energy sector on petroleum (Julia et al., 2008). In order to have energy security, there is need for the government to diversify the energy sector with other forms of energy in order to have expanded energy supply.

Greenhouse gases (GHG) which are mostly caused by humans are increasing everyday due to increase in population. (OCED/ITF 2009) states that there is about 70% increase in greenhouse gases from 29 GtCO_2 in 1970 to 49 GtCO_2 in 2004 and mostly is as a result of combustion of fossil fuels. Countries such as Mexico, China, and India are concerned about these greenhouse gases because they are large and develop cities that have high level of traffic and as such air pollution might be a problem. Also, the quality of air is highly affected in cities with factories, power plants etc. and if drastic measures are not taken, the level of greenhouse gases will continue increasing every day and as a consequence affect the environment. The greenhouse gases such as carbon dioxide (CO_2), Chlorofluorocarbons (CFC's), Nitrous oxide (N_2O), Perfuorocarbons (PFC's) and Hydrocarbons (HFC's) are everyday affecting the environment as a result of human activities which result to global warming and depletion of Ozone layer (Giwa 2014). Machines that are used in industries are mainly fossil fuel based and burning of firewood mostly in rural areas also contributes to the high increase in GHG's. Inventories for GHG's are mainly used in order to study and track emissions in a particular place so as to come up with strategies and policies on how to reduce it (Aderogba 2011).

In the year 2000, there was 135% increment in GHG's compared to 1990 which indicates increase in industrialization and economic activities in Nigeria. It was also observed that the major share of the GHG's are as a result of energy related activities. About 155.34 MtCO_2 which is 70.4% of the total emission in Nigeria comes from the energy sector (National Communication on Climate Change 2014). Also another addition of GHG's in some of the major cities in Nigeria is from the large number of power generation sets existing now in Nigeria which are mainly fuelled with gasoline and diesel (Ndoke et al. 2005).

2. Methodology

The intricacy and diversity of the energy sector over a very long time lead to the development of computer tools since 1970's simply for the purpose of measuring energy production and energy consumption for either generation systems or to determine the demand and supply for a particular sector (Baughman 1975). Also, (Urban et al. 2007) investigated thoroughly the most common energy modelling approaches used in developing countries which are mostly computer tool based. He identified many computer tools such as WEM (World Energy Model), SGM (Second Generation Model), MiniCAM (Mini Climate Assessment Model), Powerplan, RETScreen (Renewable Energy Technology Screening Model), LEAP (Long Range Energy Alternatives Planning System), MARIA (Multiregional Approach for Resources and Industry Allocation Model), ASF (Atmospheric Stabilization Framework), TIMER (Targets-Image Energy Regional Model) and AIM (AsianPacific Integrated Model). From all the listed computer tools that were identified by (Urban et al. 2007).

The Long-range Energy Alternatives Planning System (LEAP) is a computer software tool that was developed by Stockholm Environment Institute (SEI), a nonprofit independent research institute in Sweden to analyze energy policy and asses climate change mitigation (Cai, 2013). It is used by institutions, non- governmental organizations, government agencies and companies in over 190 countries at different scales for various applications (SEI 2008). Energy consumption, production and resource extraction in all sectors of an economy can be tracked using LEAP. Furthermore, the sources and sinks of greenhouse gases (GHG's) can be accounted for both in the energy sector and non-energy sector with further analysis on emissions of pollutants. The complexity and flexibility in energy analysis using LEAP makes it possible for people from different are of specialization to use it for designing policies for energy systems (SEI 2008).

2.1 Algorithm of the LEAP Model

The framework that LEAP uses for calculating, energy consumption, transformation (electricity generation, oil refinery), greenhouse gas emission and cost of production is presented in the following sections (SEI, 2008).
Energy Consumption
The total energy consumption is obtained through the expression given by (Feng et al. 2012).

$$TEC = \sum_f \sum_t \sum_i AL_{f,t,i} \times EI_{f,t,i}$$

Where *TEC* is the total energy consumption, *AL* is the activation level, *EI* is the energy intensity, *f* is the type of fuel, *t* is the technology and *i* is the sector.
Energy Emission
The total energy emission of carbon from final energy consumption is calculated as shown below.

$$EE = \sum_f \sum_t \sum_i AL_{f,t,i} \times EI_{f,t,i} \times EF_{f,t,i}$$

Where *EE* is the energy emission, *AL* is the activity level, *EI* is the energy intensity, *EF* is the emission factor, *f* is the fuel, *t* is the technology and *i* is the sector.

The total cost involved is to be calculated using the equations shown below:

$$C = \sum_{t}^{n} (Cc_t \times Ca_t) + (Foc_t \times Ca_t) + (Vc_t \times P_t) + (Ce \times T_{GHG})$$

Where *C* is the total cost involved, Cc_t is the capital cost for technology, Ca_t is the installed capacity of technology, Foc_t is the fixed cost of the technology, Vc_t is the operation and maintenance cost of the technology, P_t is the power of the technology, Ce is the cost of emission and T_{GHG} is the emission.

2.2 Cost Benefit Analysis

The cost benefit analysis in LEAP calculates the capital and operating maintenance cost of buying each part of a particular energy system in both the demand and transformation system. The cost benefit analysis can also analyse the cost of emission. It serves as an opportunity cost, the foregone alternative base on the analysis that is carried out in order to give us the opportunity to choose the optimum method to be used. The cost benefit analysis does not provide financial viability but rather guides us on selecting the most acceptable social policy scenario. Now from the scenarios, a detailed analysis will be carried out in order to select the most financially acceptable.

2.3 The Nigerian LEAP Model

LEAP is generally used for modelling of different forms of energy analysis. This makes it have a very low initial data requirement. The designed LEAP model was used for the energy analysis of Nigeria's power generation. 2018 being the recent year will be used as the base year for the analysis. This is in order to use current data for the analysis. Some of the data required for the Nigerian LEAP model include; demographic data, economic data, demand data, transformation data etc.

2.3.1 Scenario Analysis

In this research, four (4) different scenarios were developed i.e. the business as usual scenario (BAUS), the mild renewable energy scenario (MRES), the extreme renewable energy scenario (ERES) and the total green energy scenario (TGES). The business as usual scenario was used as a reference to develop the three other different scenarios. The reference scenario was made using documents obtained from the NEP, NREEE and NEMP all in (ECN 2014). It was assumed that the guidelines and policies stated by the Nigerian government are strictly adhered to and that the goals setup by the Nigerian government will be achieved by 2050.

2.3.2 Business as usual Scenario

The reference scenario which is the base year because it is the most recent as such, it will give us current information about Nigeria's economic and energy status. Nigeria's GDP as at 2018 stood at with an annual average growth rate of 1.5% (World Bank, 2018). There are about 40 million households in Nigeria that is growing as the population is growing (NBS, 2018). The scenario assumes business as usual; transformations are strictly base on the already established plans by the Nigerian government through different forms of Acts and policies such as the presidential advisory committee on electricity (2006), National Energy master plan, National energy security etc. Power generation is mainly from thermal and hydro stations and presently, Nigeria is operating at negative reserve in terms of electricity, the demand for electricity is by far greater than the supply.

2.3.3 Mild Renewable Energy Scenario

This scenario concentrates on the implementation of renewable energy technology at a moderate level so as to reduce GHG emission at a moderate level compared to the reference scenario. It is expected that in this scenario, low carbon technologies are introduced in households. The use of incandescent for lighting in households is slightly reduces to an approximate 20% while CFL which lower energy intensity will reach 80% by 2050. According to (Anumaka, 2012), Improvement in national grid, generation and distribution system will reduce transmission and distribution loses to about 8%. It is expected that if electricity generation using solar reach about 10% of total electricity generation in Nigeria, GHG emission will reduce (Yohanna et al., 2010). Solar, hydro and wind energy sources are harnessed in order to boost the capacity of renewable energy to about 50% at 2050. According to National Energy Master Plan in (ECN, 2014), Energy demand in Nigeria in 2030 will be, Natural gas 115,086 MW, Coal 15,691 MW, Hydro 9,332 MW, Biomass 77 MW, Solar 370,225 MW, Wind 42 MW, Small hydro 2,694 MW, nuclear 3,500 MW.

2.3.4 Extreme Renewable Energy Scenario

This scenario tries to explore renewable energy at an advance stage using aggressive strategies for policies in energy in order to reduce the effect of GHG gases which causes change in climate, rise in sea-level etc. Due to increase in household appliances, it is expected that the energy intensity of electrical appliances will drastically be reduced to 50% of the initial intensity (Momodu et al. 2012). LED bulb which consumes only 30% of CFL is introduced in order to reduce energy consumption. The use of LPG for cooking in household is increased to about 40% in order to reduce the use of firewood and coal so as to reduce emission. According to (Julius, 2013) and (Maduka, 2011), public awareness and orientation are the key things that can help in popularize the use of LPG rather than firewood and coal in order to reduce risk of contracting lung related illness. The emission produced by countries is greatly reduced by using LPG as a substitute to firewood and coal (Kojima 2011).

2.3.5 Total Green Energy Scenario

This scenario explores renewable energy at full capacity. This is because with rate at which Nigeria's population is growing, it is not possible for the fossil based fuel to cater for the demand of energy in Nigeria. According to (United Nations 2018), Nigeria's population is expected to grow and can even become the third most populous country in the world by 2050. By exploring the renewable energy sources we have in Nigeria, we might be able to meet the expected demand in the future (Oyedepo 2012). Also, it can open a window for creating jobs and eradicating poverty (Bowen 2012).

3. Results and Discussion

The results for the demand, transformation and distribution, energy resources and greenhouse gases emission were obtained by grouping them into four different scenarios i.e. the business as usual scenario, mild renewable energy scenario, extreme renewable energy scenario and total optimistic energy scenario to obtain the results. An energy modelling software LEAP was used for the simulation in order to obtain the results.

3.1 The Business as Usual Scenario (BAUS)

The business as usual scenario is the first scenario assumes that government continues with its planned system of development which includes finishing of ongoing electricity projects and there is no any energy emission reduction target. The total final energy demand under the business as usal scenario which comprises of four different sectors is about 647.8 million MWh in the year 2018 and it is expected that by 2050, the final energy demand will be 1,399.2 million MWh as shown in Figure 1 below. The current electricity generation capacity in Nigeria in 2018 is about 10,900 MW and is expected to rise to 21,900 MW by the year 2050 (Figure 2). The increase in energy demand is directly proportional to increase in greenhouse gases. The current greenhouse gases emission level at 2018 is about 106.2 billion kgCO2 and it is expected that by 2050, it will rise to 231 billion kgCO2 (Figure 3).

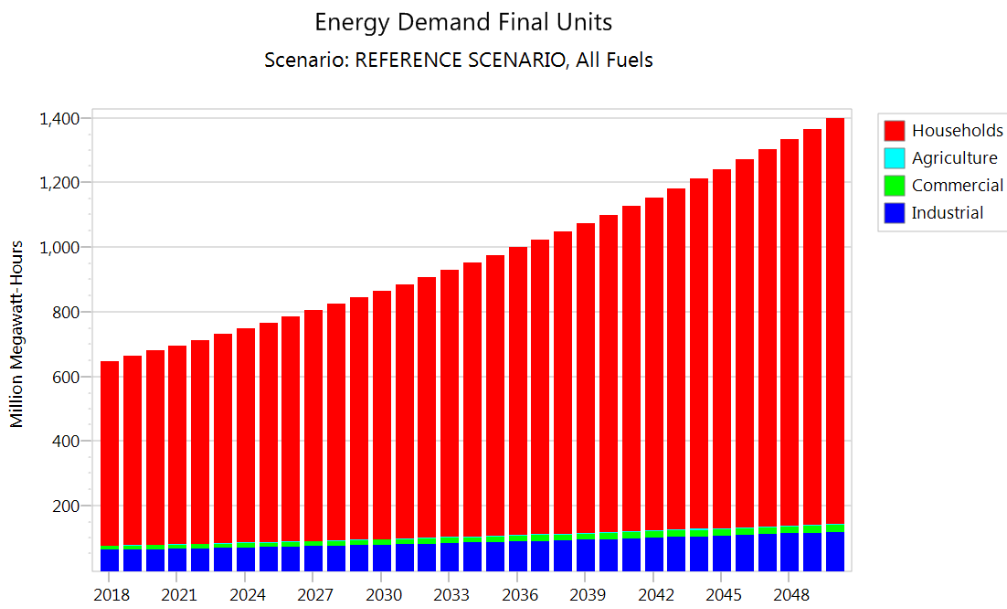

Figure 1. Total energy demand under BAU Scenario

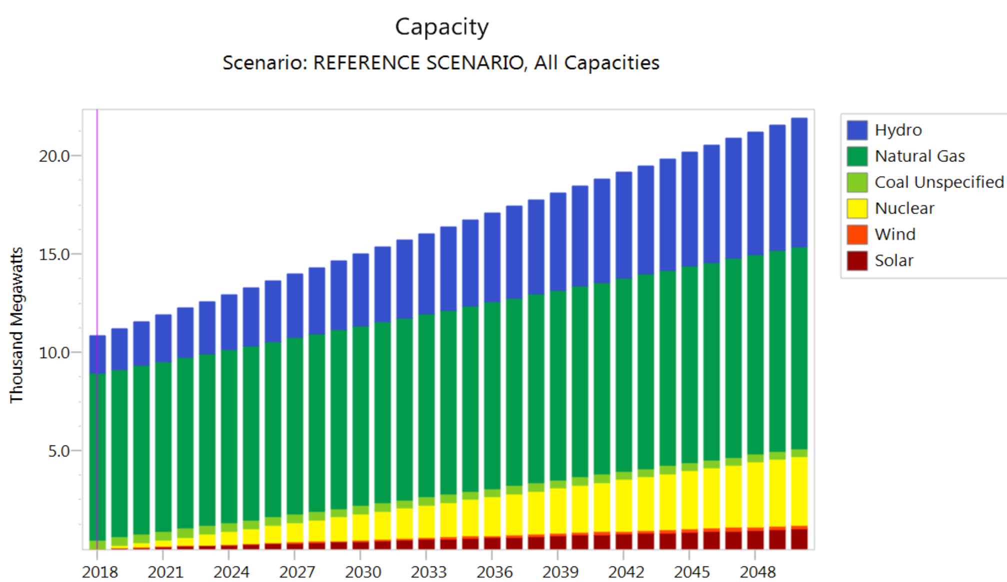

Figure 2. Electricity Generation capacity under REF Scenario

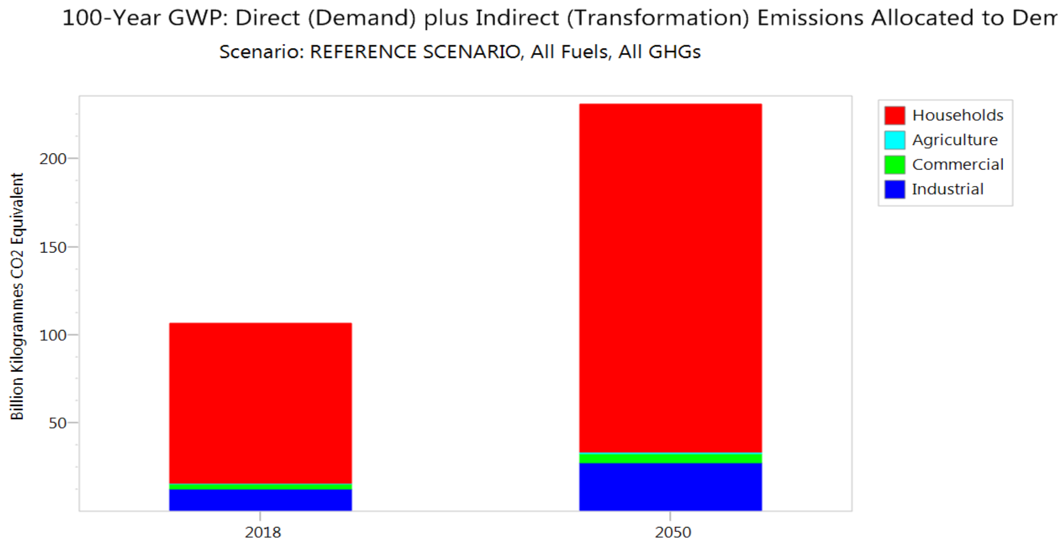

Figure 3. GHG Emission under REF Scenario

3.2 The Mild Renewable Energy Scenario (MRES)

In the mild renewable energy scenario, there is a moderate level of renewable energy in the country's energy sector such as electricity generation and usage in different sectors. Energy efficiency is implemented moderately in order to reduce the demand for energy and GHG as the population is growing. The total final energy demand under the moderate renewable energy scenario at 2050 for the four sectors, households, commercial, industrial and agricultural is expected to be 1,288.1 million MWh which is lower than the final energy demand in the business as usual scenario which has a value of about 1,399.2 million MWh (Figure 4). The reduction in energy demand is attributed with slight reduction in population and moderate level of energy efficiency implementation in all the sectors. Figure 4 below, shows the total energy demand under the mild renewable energy scenario. The total electricity generation capacity under the mild renewable energy is expected to be 34,100 MW by 2050 (Figure 5). This is higher than the electricity generation capacity under the business as usual scenario which is expected to be 21,900 MW by 2050 because under the mild renewable energy scenario, renewable energy sources such as solar, wind etc. are explored at a moderate level there by increasing the generating capacity. The chart below shows the electricity generation capacity from 2018 to 2050 under the mild renewable energy scenario. The total greenhouse gases emitted under the mild renewable energy scenario is expected to be about 213.2 billion $kgCO2$ by 2050, which is less than the total greenhouse gases under the business as usual scenario which is about 231 billion $kgCO2$ by 2050 (Figure 6). The reduction in the level of GHG is due to implementation of energy policies in order to moderately regulate emission.

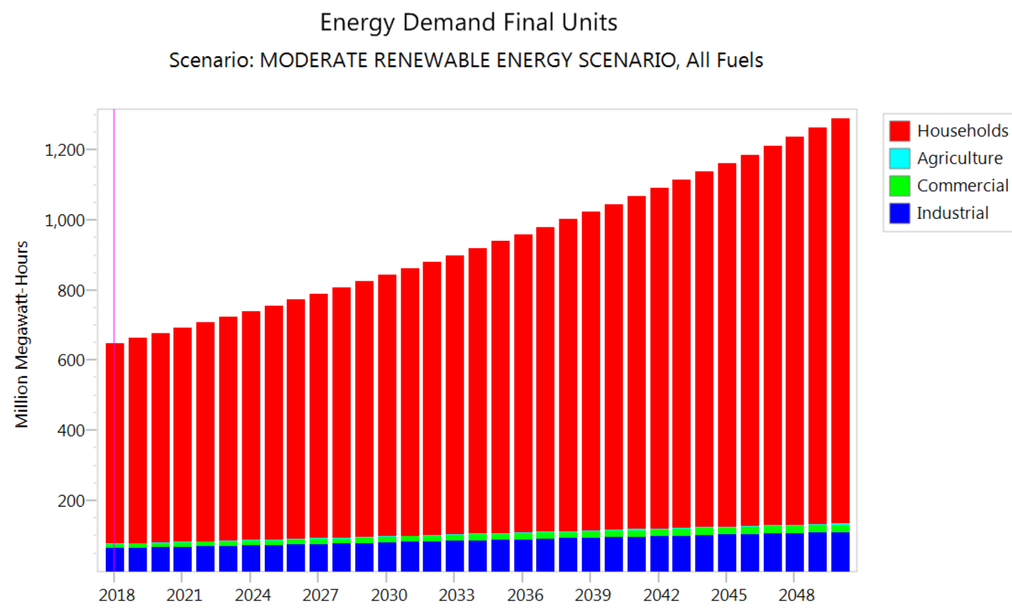

Figure 4. Total energy demand under MRE Scenario

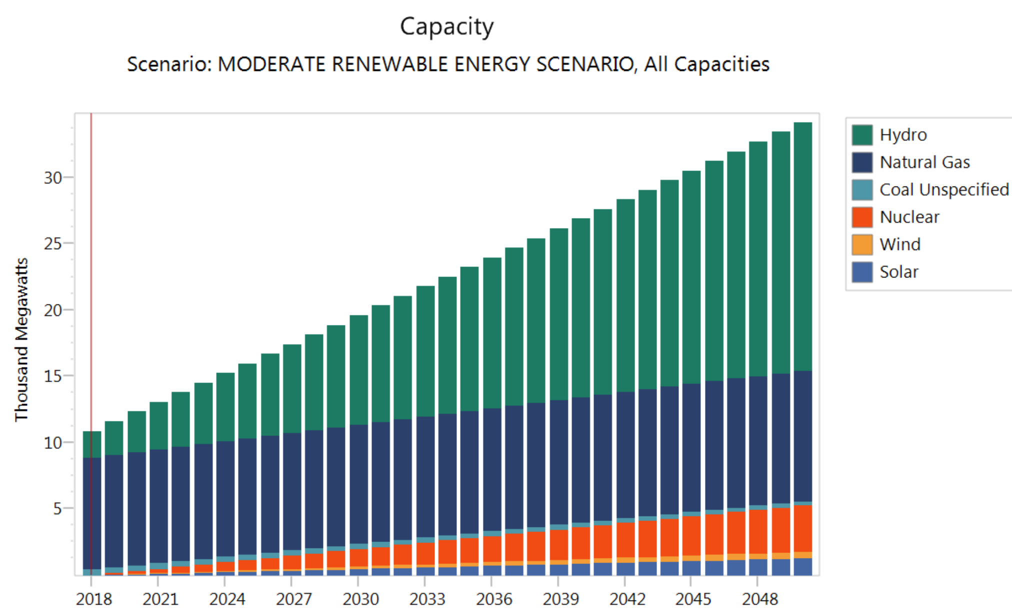

Figure 5. Electricity generation capacity under MRE Scenario

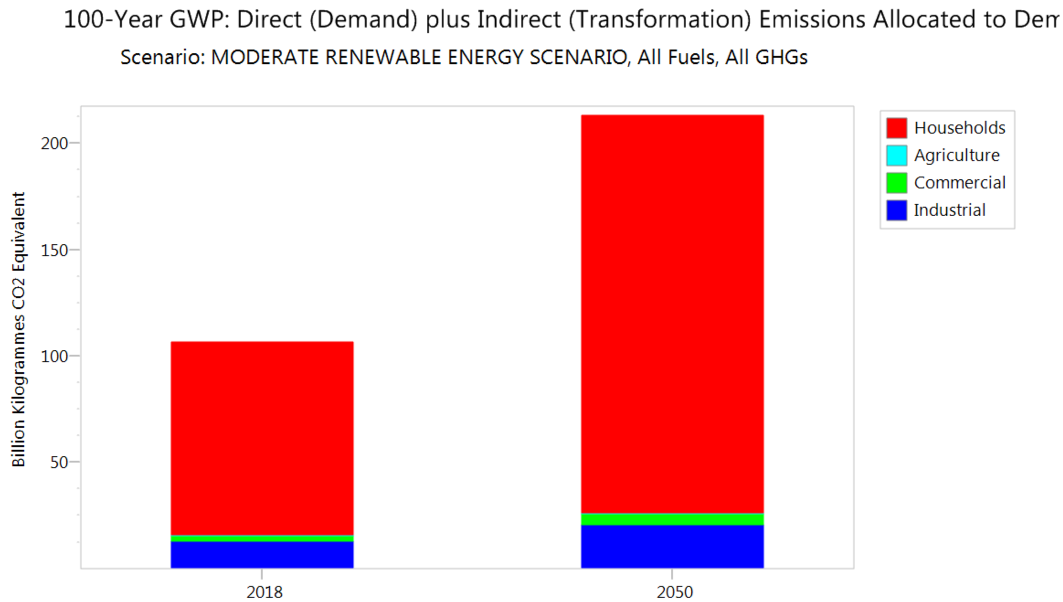

Figure 6. GHG emission under MRE Scenario

3.3 The Extreme Renewable Energy Scenario (ERES)

In the extreme renewable energy scenario, there is implementation of the government's renewable energy policies at an extreme level. The use renewable energy is fully utilized with retirement of majority of the fossil based fuel systems. The total final energy demand under the extreme renewable energy scenario at 2050 is estimated to be about 1,046 million MWh which is by far less than the total energy demand for the mild renewable energy scenario which is 1,288.1 million MWh (Figure 7). The high reduction in energy demand is due to extreme level of implementation of renewable energy policies as outlined in Renewable Energy Master plan in (ECN, 2014) and the implementation of energy efficiency. The chart below shows the total energy demand under the extreme renewable energy scenario. The total electricity capacity under the extreme renewable energy scenario at 2050 is expected to rise to 69,900 MW which is approximately twice the expected electricity generation under the mild renewable energy scenario which is 34,100 MW at 2050 (Figure 8). The increase in electricity generation capacity is associated with extreme level of exploration of renewable energy sources such as wind, solar and hydro in order to increase the electricity generation so as to able to satisfy the growing population. The chart below shows the electricity generation capacity from 2018 to 2050 under the extreme renewable energy scenario. The level of greenhouse gases emission under the extreme renewable energy scenario is expected to drop from 213.2 billion kgCO2 under the moderate renewable energy scenario to about 156.1 billion kgCO2 (Figure 9). The decrease in the GHG level is due to the reduction in usage of fossil based fuels at an advance stage most especially in the household and industrial sectors. The chart below shows the GHG emission level from 2018 to 2050.

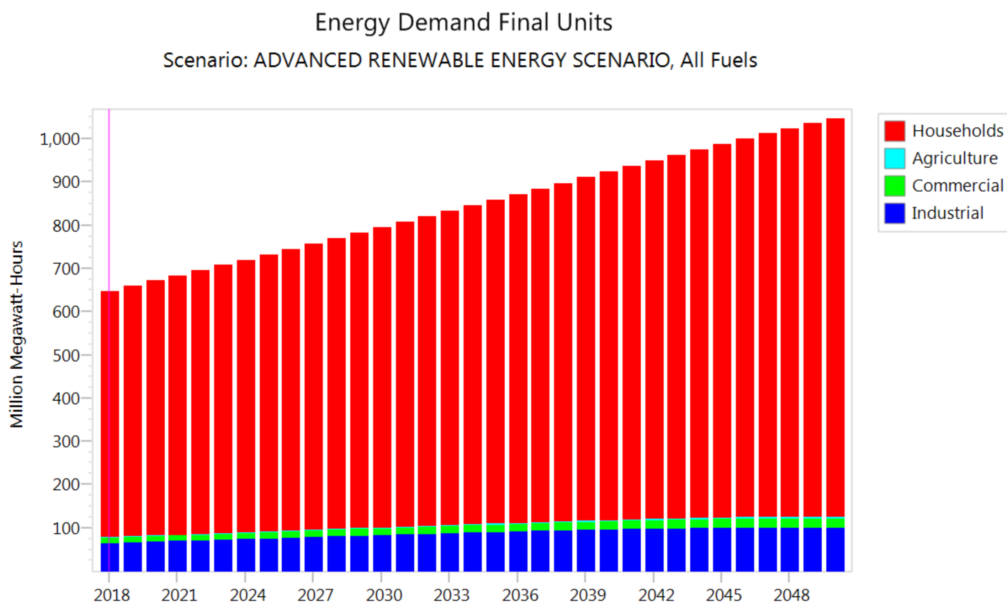

Figure 7. Total energy demand under ERE Scenario

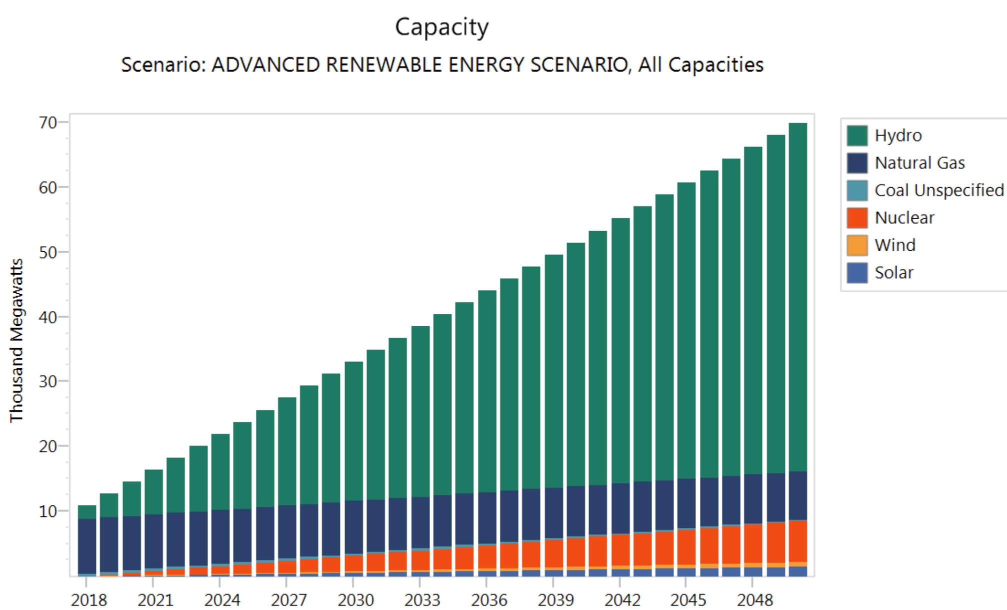

Figure 8. Electricity generation capacity under ERE Scenario

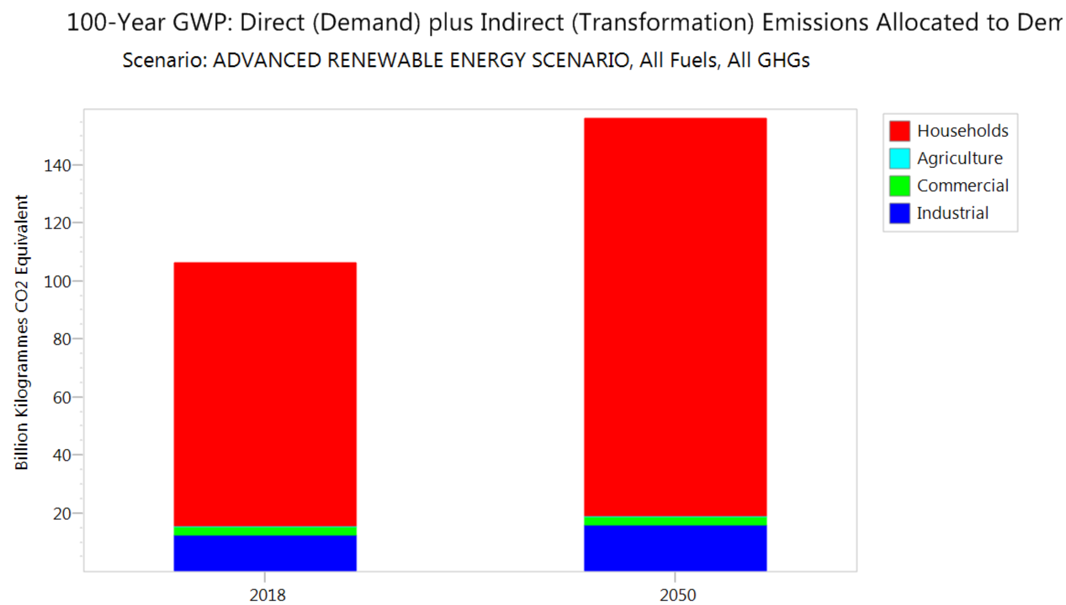

Figure 9. GHG emission under ERE Scenario

3.4 The Total Green Energy Scenario (TGES)

The total green energy scenario focused much on the implementation of energy efficiency in order to reduce energy demand and also to reduce the effect of global warming as it affects climate change. The final energy demand under the total green energy scenario is expected to be 936.9 million MWh by 2050 which is less than the energy demand under the extreme renewable energy scenario which is about 1,046.7 million MWh in 2050 due to nearly retirement of all fossil based fuel energy sources in order to reduce emission and great implementation of energy efficiency in all the four energy demand sectors (Figure 10). The renewable energy master plan as prepared by (ECN, 2014) is fully implemented. The chart below shows the total energy demand under the total green energy scenario. The total electricity generation capacity under the total green energy scenario has full implementation of the renewable energy policies. Renewable sources such as hydro, solar, wind dominated the generation. By 2050 the total generation capacity will be 71,100 MW greater than the 69,900 MW of the extreme renewable energy scenario (Figure 11). The chart below shows the electricity generation capacity of each process. The greenhouse gases level under the green optimistic scenario is reduced to a low level due to the nearly retirement of the fossil based fuels and such diesel, kerosene and natural gas. It is expected that at 2050, the GHG level be 119.3 billion kgCO2which is lower than the GHG level in 2050 under the extreme renewable energy scenario which is about 156.1 billion kgCO2 (Figure 12).

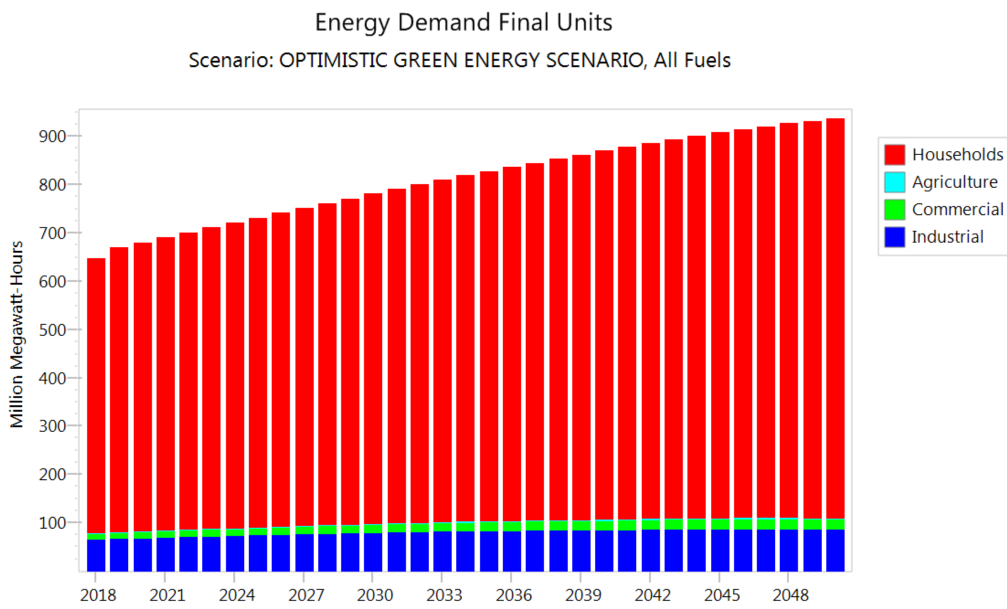

Figure 10. Total energy demand under TGE Scenario

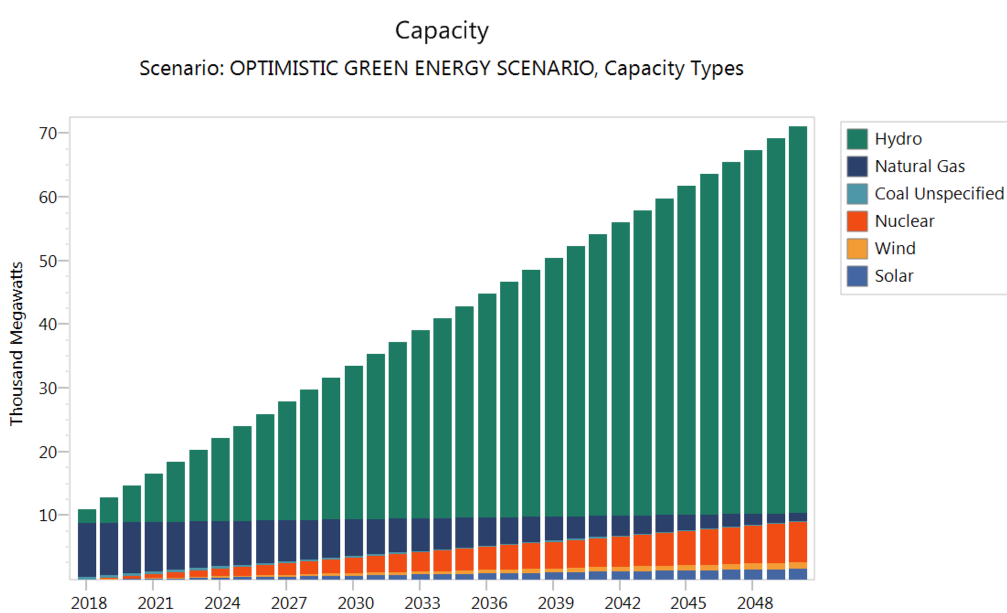

Figure 11. Electricity generation capacity under TGE Scenario

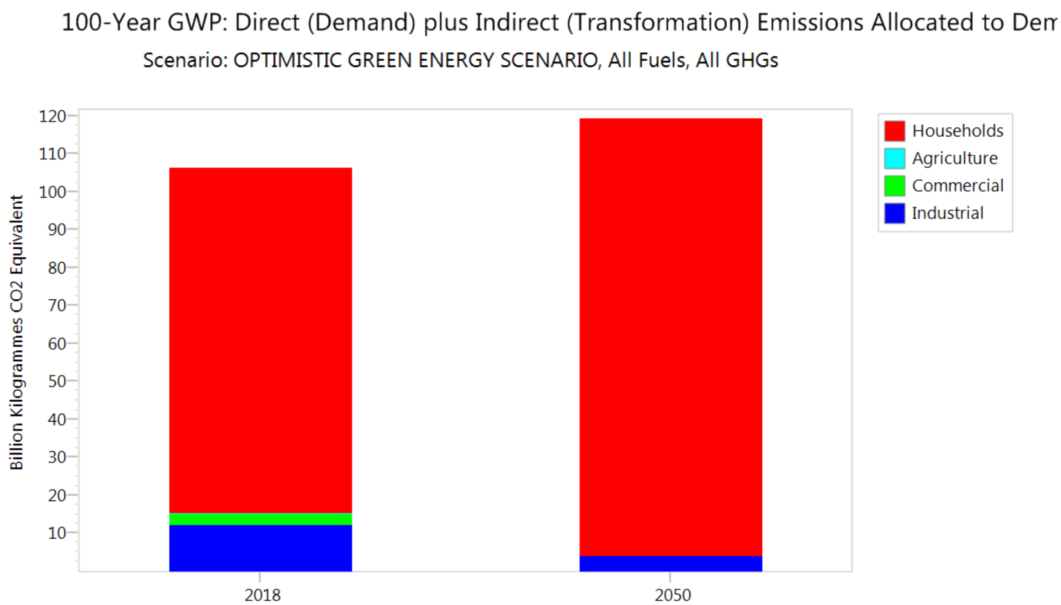

Figure 12. GHG emission under TGE Scenario

4. Conclusions

This research work developed four different scenarios namely the Business as usual, Mild renewable energy, Extreme renewable energy, and Total green energy scenarios based on different policy settings to make a comprehensive forecast report on the energy sector in Nigeria. The demand, supply and emission impact of each of the scenarios was examined under different scenarios. The results obtained from each of the scenarios showed that by 2050, business as usual scenario will have the highest energy demand, followed by the mild renewable energy scenario and extreme renewable energy scenario while the total green energy scenario has the least energy demand due to high level of implementation of renewable energy policies and energy efficiency techniques being adopted in all the four sectors i.e. residential, industrial, commercial and agricultural sectors. Also, the level of GHG emission was observed to be very high in the reference scenario while the green optimistic energy scenario has a very low level of GHG emission in 2050 due to aggressive policies taking by government in retirement of fossil based fuel technologies and full implementation of energy efficiency in virtually all sectors.

Acknowledgement

The authors are grateful to Universiti Teknologi Malaysia (UTM) and Ministry of Education, Malaysia (MOE) for providing financial support through UTMER grant **Q.J130000.2651.18J48** for proving funding for conducting this research.

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