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The Contribution of Nuclear and Other Low Carbon Electricity Generation Technologies towards Nigeria's Carbon Neutrality Journey

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Abstract

The latest estimate of the United State Energy Information Administration (US-EIA) shows that Nigeria is the largest producer of oil in Africa with largest natural gas reserves on the continent and the fifth–largest exporter of liquefied natural gas (LNG) in the World. In 2017, Nigeria's generation capacity was 12,664 megawatts (MW), with 10,522 MW representing 83% from fossil fuels, 2,110 MW representing 17% from hydropower, and 32 MW accounting for 1% coming from solar, wind, biomass, and other sources. The fossil power plants constitutes the major driver in greenhouse gas emission, therefore reduction in its operation will reduce the rate of carbon emission. To achieve carbon neutrality in line with the Paris agreement of 2015, the need for nuclear and other low carbon emission renewable electricity generation technologies is vital. This study utilizes the International Atomic Energy Agency (IAEA) Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) code in modelling energy supply needs for Nigeria using various electricity generation technologies. By placing the upper limit on carbon emission constraints, discount rate of 11.5% and other electricity generation data obtained from EIA. Using the modelling period of forty-five (45) years with a base year of 2015 the results shows that the contribution of fossil is bound below the upper limit while that of hydro continue to increase from 2016 to the end of the modelling year. Contribution from nuclear power plant starts from 2029, and continue to increase throughout the modeling period which suppressing contribution from fossil below the upper limit of CO_2, The negligible contribution from solar and wind been suppressed by nuclear and hydro power plants. The results shows that nuclear and other low carbon energy technologies are the preeminent alternative for future electricity production in achieving carbon neutrality target.

Keywords: Carbon Emission, Carbon Neutrality, Paris Agreement, Electricity Production, Power Plants.

INTRODUCTION

Nigeria's crude oil and natural gas resources are the mainstay of the country's economy and drives 83% of its electricity from fossil fuel, 17% from hydroelectricity and less than 1% from other sources in 2017 as reported by the Energy Information Administration (EIA) data on electricity generation. Nigeria has set striving goals to upsurge its power generation capacity through construction of nuclear power plants alongside various hydro, wind, and solar power projects partially as a way to mitigate natural gas supply shortages and to increase access to

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electricity in remote and rural communities. Report from EIA on Nigeria Energy Consumption shows that 97% of most primary energy consumption in the country was derived from natural gas, petroleum, and other liquids and 3% from renewable sources in 2017 (US-EIA, 2022). The necessity of renewables and nuclear energy are obvious in the country energy mix, to cope with economic development and provide a reliable basis for African's largest economy. Carbon dioxide (CO_2) emissions result mainly from the burning of fossil fuels, coal and coke, petroleum and other liquid used in manufacturing industries. In 2018, Nigeria recorded 3.83% increase in carbon emissions (101.3014 Metric tons) from 2017. The most recent emission projections, shows that it will continue to increase until 2030 and that reduction will not be enough to meet the upper range of the national mitigation targets (Nigerian Climate Transparency Report, 2020). The objective of this study is to highlight the contribution of nuclear and other low carbon energy technologies in achieving carbon neutrality targets in line with the Paris agreement of 2015. Recent studies suggested that global energy related CO_2 emissions must be cut by 45% below the 2010 levels by 2030 to achieve the Paris agreement on net-zero carbon emission by 2050 (Nigerian Climate Transparency Report, 2020; Joeri et al, 2022). Therefore, Nigeria needs to upsurge its scale of climate action to align with the Paris Agreement temperature goal of limiting the global mean temperature rise to 1.5°C (Paris Agreement, 2015). The IAEA Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) computer code was employed in determining the contribution of nuclear and low carbon emission technologies in achieving carbon neutrality by using the discount rate of 11.5% and other electricity generation data obtained from United State Energy Information Administration (US-EIA) database (US-EIA, 2022; Country Economy, 2022). The role of nuclear and other low-carbon energy production technologies such as hydro, solar, and wind power plants are critical to sustaining economic development and reducing Greenhouse Gas Emissions (GHGE). Nigerian government has laid out plans to include nuclear energy in its electricity generation mix, with a total capacity of 4800 MW to be constructed by the Russian State Atomic Energy Corporation (ROSATOM) (Sambo, 2008). Government, with the help of the World Bank, encourages off-grid solar and wind power initiatives in rural regions to minimize dependency on carbon-emitting energy resources such as kerosene and fossil fuel consumption (Foundation, 2019). According to a recent estimate, Nigeria's outstanding total exploitable hydro potential exceeds 15,000 MW, with large-scale hydropower resource potential above 11, 000 MW and small hydro plant potential exceeding 3500 MW (Fasipe et al., 2015). A research conducted by Sambo in 2008 to match power supply with demand for Nigeria's long-term energy plan and the feasibility of nuclear power resources were simulated using the IAEA MESSAGE code. The result showed that the proportion of large and small-scale hydroelectricity to total installed capacity dropped from 31.30 percent in 2005 to 11 percent in 2030. Consequently, the natural gas–based electrical capacity ratio increased from 68.30 percent in 2005 to 82.15 percent in 2010, before declining to 62.95 percent in 2030.With the rapid population growth and the over dependency on fossil power plants, the need for using low carbon emission technologies is key in achieving carbon neutrality target in line with Paris agreement goal.

METHODOLOGY

Scenario Description

The summary of scenario description used in this study to model various electricity generation technologies to achieve carbon neutrality targets in line with the Paris agreement of 2015 is presented in figure 1.

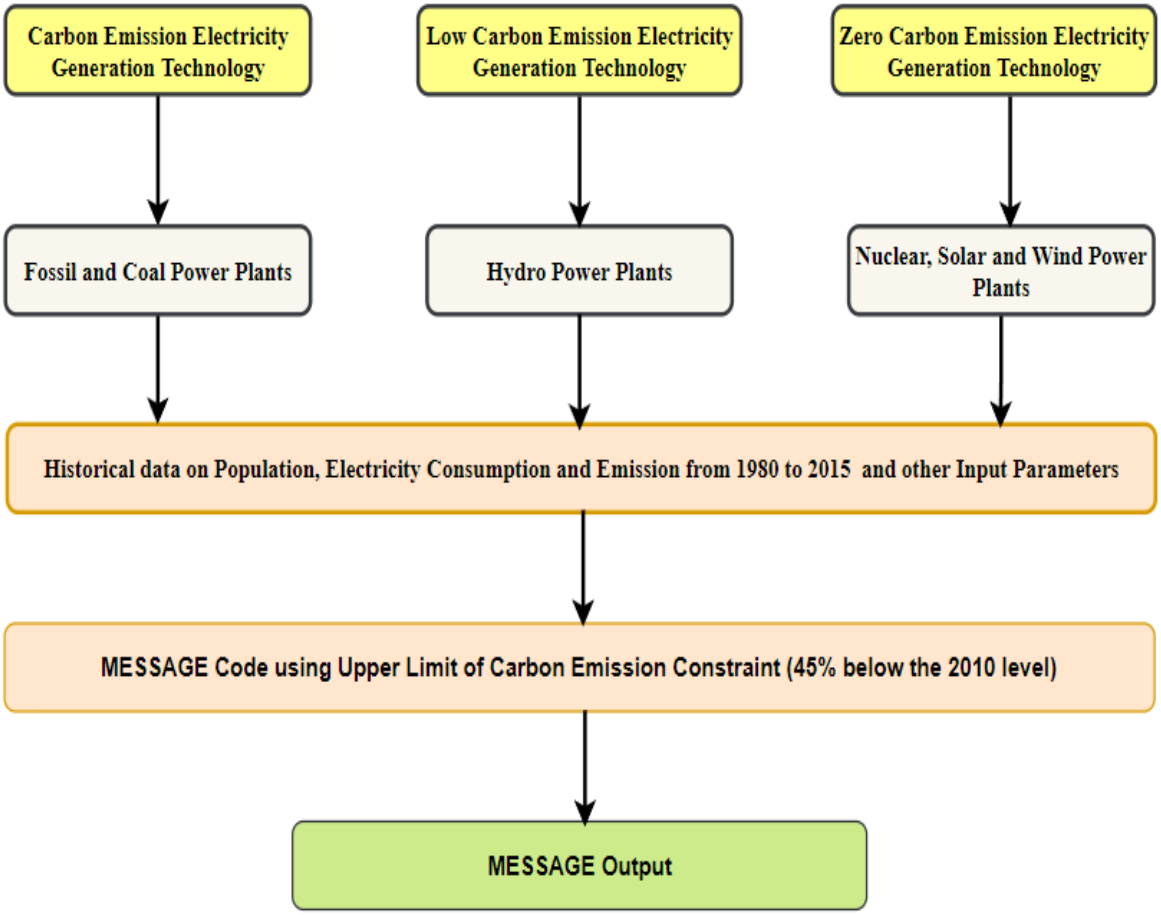

Figure 1. Scenario Description used in MESSAGE code

MESSAGE Code.

Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) code is a graphic user interphase and a system engineering optimization model that optimizes a linear objective function based on decision variables under specific linear equalities and inequalities. The code is an energy modeling computer code designed by the International Atomic Energy Agency (IAEA) to determine the best expansion path for developing country energy systems, planning, policy analysis, and scenario development. It also aids in the development of an energy system. The objective function is calculated using the total system cost throughout each period ("p"), subject to some set of constraints defined by equation 1 and 2 according to (IAEA, 2017; Kim *et al.,* 2021).

$$\text{Total system cost} \sum_{p=1}^{T} \gamma r \sum_{j=1}^{n} A_{pj} \times B_{pj} \quad (1)$$

Where

$\sum_{j=1}^{n} A_{pj} \times B_{pj}$ is the costs incurred over period (p) and $\gamma r = \frac{1}{1+j}$ and (j) represent discount rate.

MESSAGE code was used to model the energy supply systems in Nigeria by placing the upper limit of constraints. An important constraint in MESSAGE is the satisfaction of demand, which can be expressed as final and useful energy, and the constraints must be equal to the demand. The constraint is that the supply must be at least equal to the demand in each period t given by

$$\sum_{i=1}^{i=T} SUP_{ij} \times ACT_{it} \geq DM_t \quad (2)$$

Where

DM_{jt} represents the energy demand form for j at period t, ACT_{it} represents the activity of various generation technology i at period t, and SUP_{ij} is the generating technology i energy form j.

The input data used in IAEA MESSAGE code is shown in Table 1.

Table 1. Input data used in MESSAGE Code.

Parameters	Input Data
Base Year	2015
Modelling Period	2015 - 2060
Discount Rate used	11.5%. Country Economy, (2022).
Resources used	Oil, Gas, Nuclear, Hydro, Solar and Wind.
Upper limit of CO2 emission	21.98355. Nigeria Climate Report, (2020).
Historical Capacity Data for resources used	Obtained from US-EIA, (2022).

The input data use for the analysis are based on the current economy rate of Nigeria which employs a discount rate of 11.5% and the upper limit of CO_2 emission reported in the Nigeria Climate Transparency report 2020 towards achieving net zero carbon emission target by 2045. The historical data of various energy resources (fossil, nuclear, hydro, solar and wind) obtained from EIA were also used as input to the MESSAGE code for prediction future electricity demand and assessing the contribution of each energy resource towards achieving carbon neutrality target. No historical data on coal since Nigeria does not produce electricity from coal.

Historical Population data of Nigeria from 1980 to 2015.

Historical population data of Nigeria obtained from EIA database from 1980 to 2015 (base year) were used as an input parameters in MESSAGE code to predict the future population growth throughout the modeling period. The period of 2015 represents the base year for the modeling. The Historical population data for Nigeria used as input in MESSAGE code is presented in Figure 2.

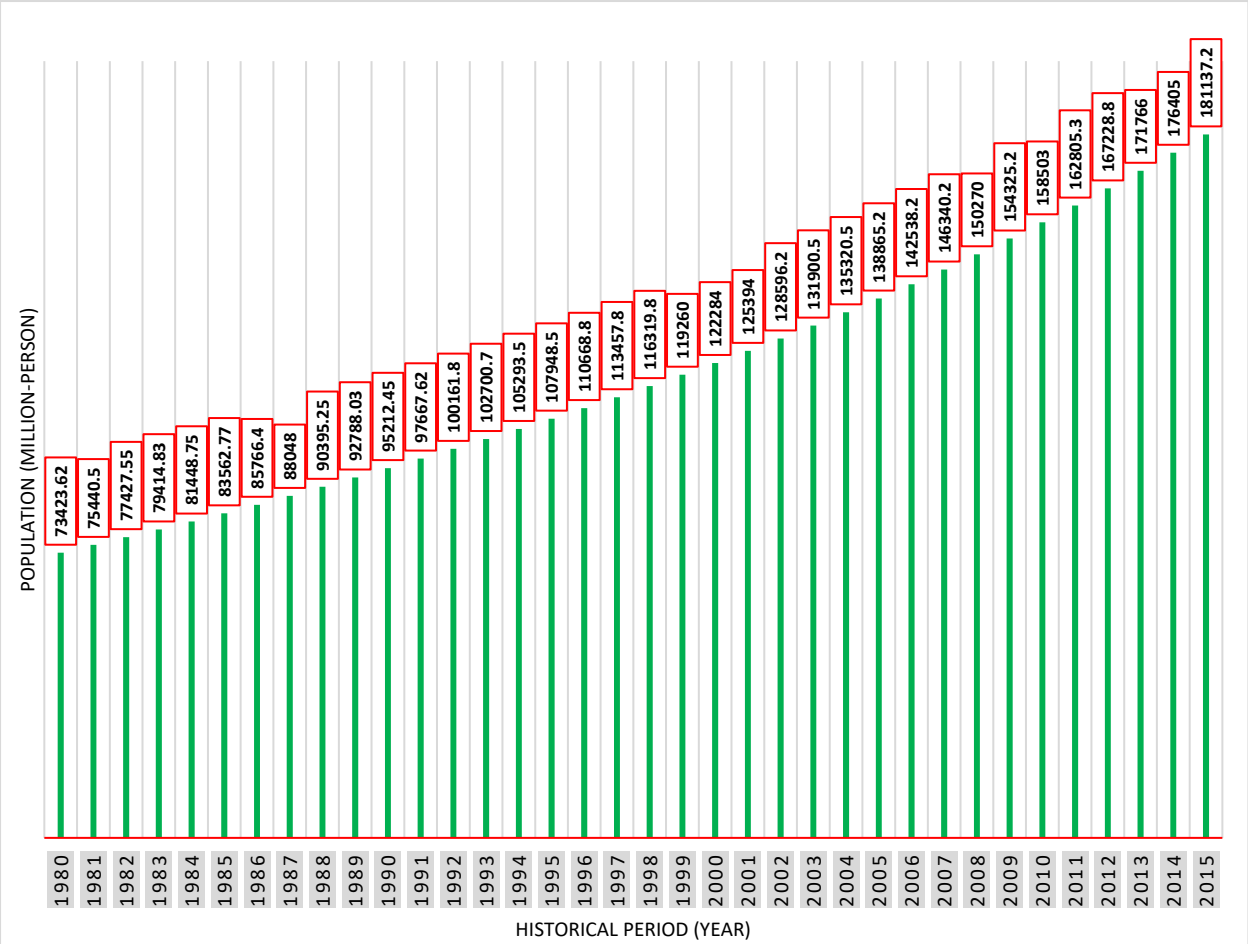

Figure 2. Historical Population from 1980 to 2015

Historical Electricity Consumption data of Nigeria from 1980 to 2015.

The History of electricity consumption data of Nigeria obtained from US-EIA database from 1980 to 2015 used as input in MESSAGE code in modelling future electricity demand are presented in Figure 3. The energy consumption witnessed a decline in 2009 due to global recession as reported by the British Petroleum statistical review of the World energy (2010). The period of 2015 represent the base year used in the code for predicting future electricity consumption.

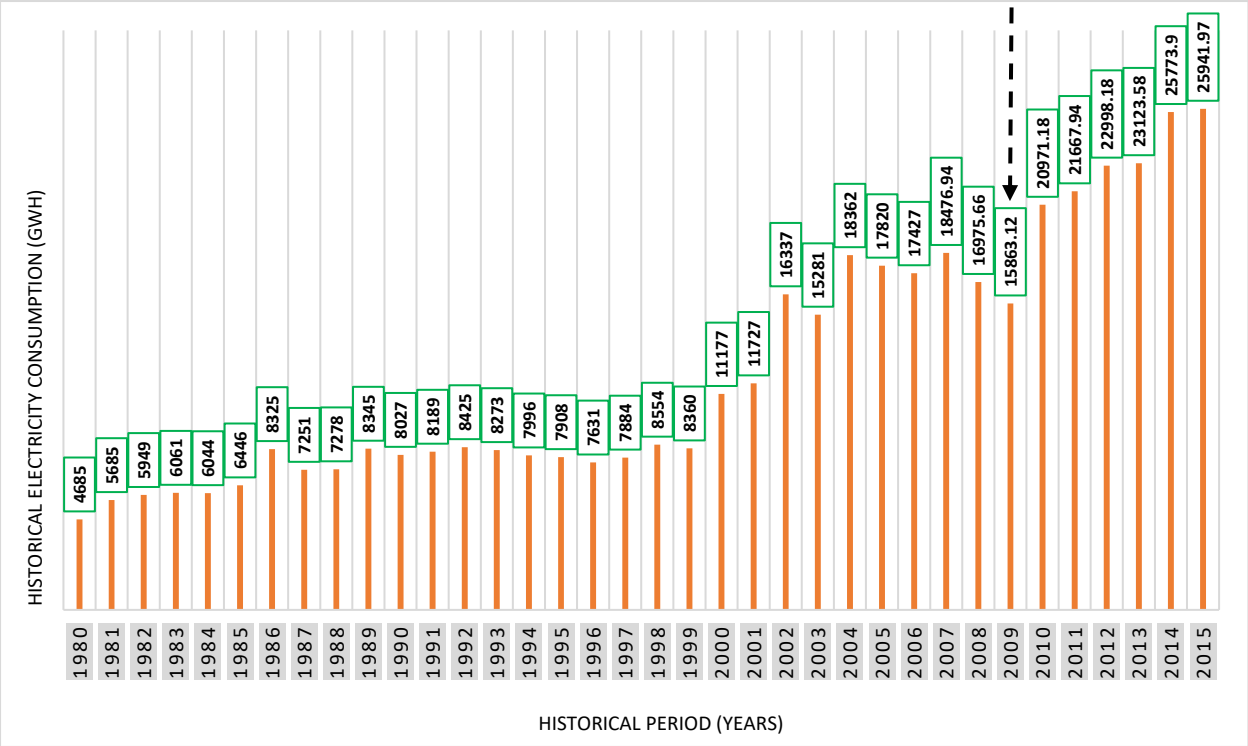

Figure 3. Historical electricity consumption in Nigeria from 1980 to 2015

Carbon Emission History in Nigeria 1980 to 2018.

Nigeria's GHG emissions have increased by 11% from 1990 to 2018 according the Nigerian Climate Transparency report of 2020 (Nigerian Climate Transparency Report, 2020). The history of emission from various energy sources in Nigeria obtained from United State Energy Information Administration Database from 1980 to 2018 are presented in Figure 4. The trend of electricity consumption and the resulting carbon emission from 1980 to 2018 shows a sharp deterioration in 2009 due to reduction in the consumption of natural gas during the period resulting from world energy crisis as reported by the British Petroleum statistical energy review and other agitations in the northern and southern region of the country. CO_2 emission from Nigeria comes from different sources. The largest driver of overall CO_2 emissions comes from fuel combustion. Nigeria does not produce electricity from coal (Sunday, 2012). Since majority of the country's electricity comes from fossil power plants, thus the reason for the emission from natural gas. The upper limit of carbon emission constraint was calculated from the total emission based on the suggested study that global CO_2 emissions must be cut by 45% below the 2010 levels by 2030 to achieve the Paris agreement on net-zero by 2060 (Nigerian Climate Transparency Report, 2020).

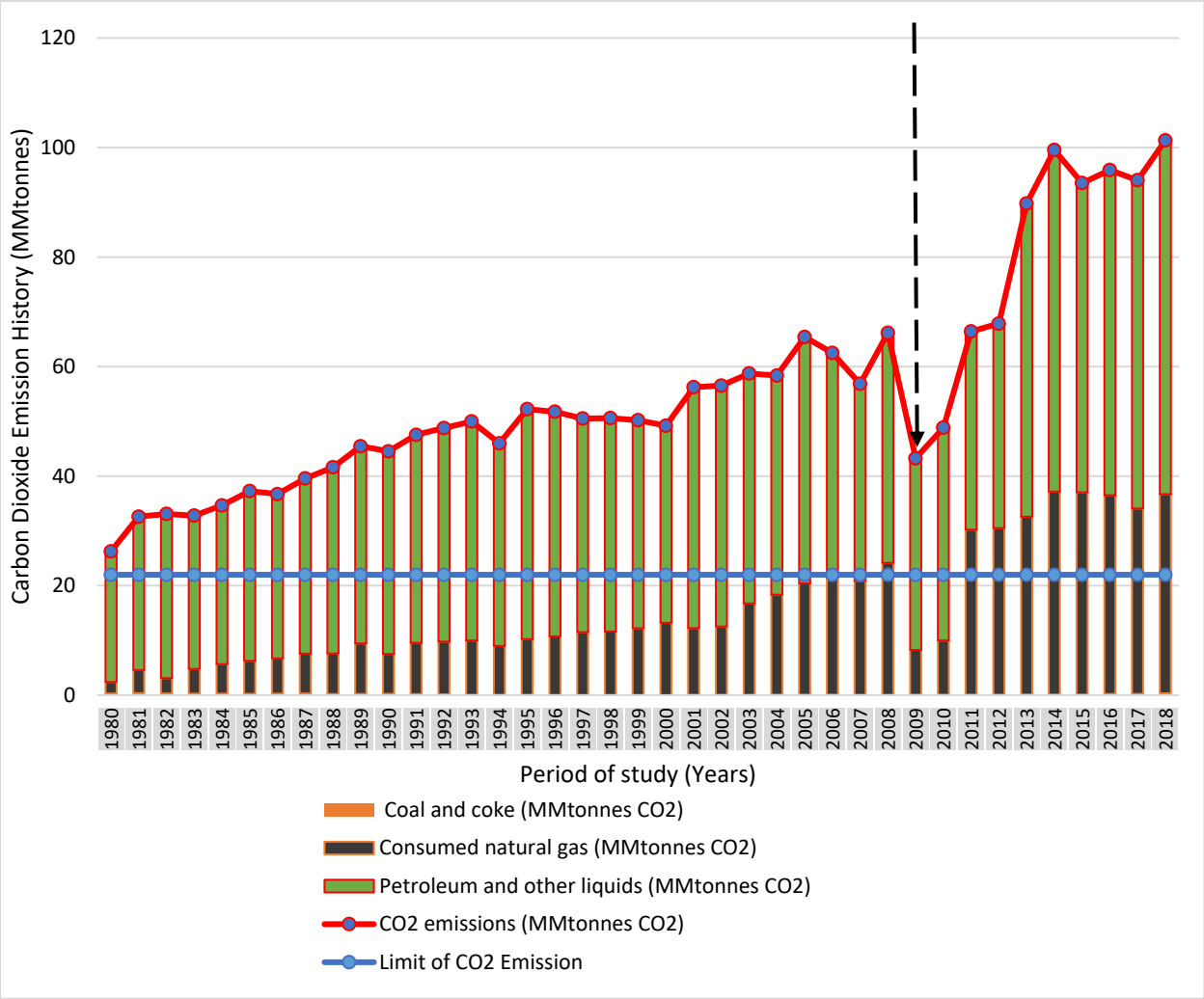

Figure 4. Carbon Dioxide Emission in Nigeria.

RESULTS AND DISCUSSION

Prediction of Future Electricity Demand and Population Growth in Nigeria.

The historical electricity consumption and population data of Nigeria from 1980 to 2015 (base year) obtained from EIA were used to predict the future electricity demand and the future population growth of Nigeria using IAEA MESSAGE Code. The result shows exponential population growth with increasing electricity demand throughout the modeling period as presented in figure 5. The constant increase in electricity consumption with population growth throughout the modeling period represent the increasing demand of electricity consumption as the population increase. Thus, the need to scale up electricity production by introducing nuclear and expanding the existing renewables and other low carbon electricity generation technologies to meet the growing population and increasing demand as well as highlighting their contributions in achieving carbon neutrality is key.

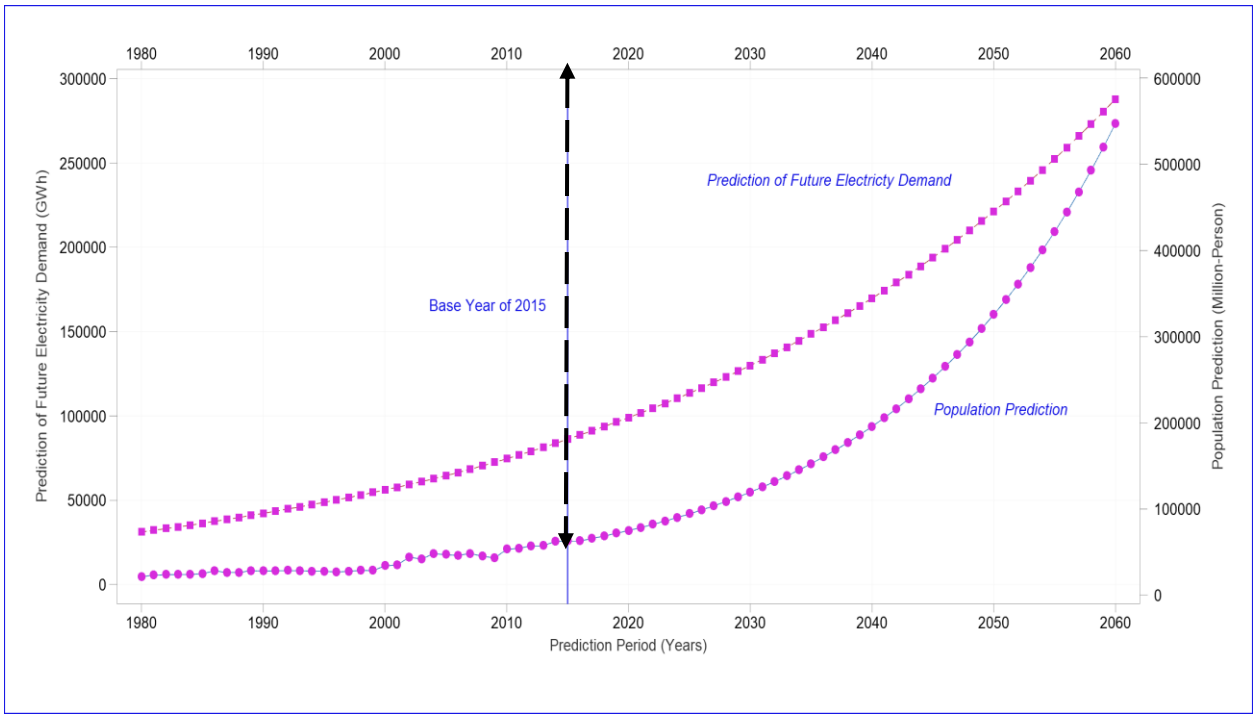

Figure 5: Prediction of Future Electricity Demand and Population Growth in Nigeria

Prediction of Electricity Production from Various Technologies in Nigeria.

The results from modelling various electricity generation technologies in Nigeria using IAEA MESSAGE code and placing the upper limit on the CO_2 constraint is shown in Figure 6.

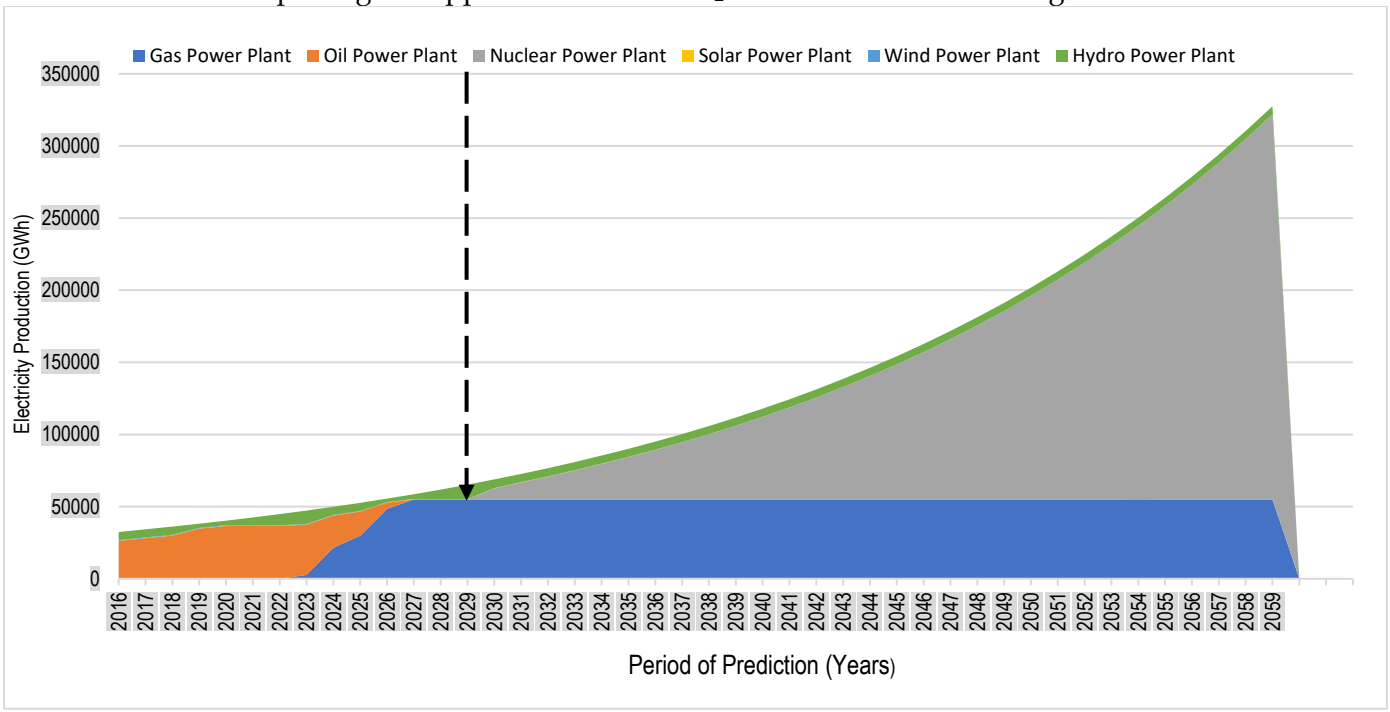

Figure 6: Result from MESSAGE code.

Resources used are existing energy resources of oil and gas, nuclear and renewables such as hydro, wind and solar electricity. Data on historical capacity for each resources obtained from US-EIA from 1980 to 2015, which was used for prediction of future electricity demand from various technologies, and the upper value of the CO_2 constraint is calculated based on the 45% global reduction of carbon emissions below the 2010 levels by 2030 to achieve carbon

neutrality by 2060. Modeling period from 2015 to 2060 with 2015 as the base year and a discount rate of 11.5%. The results shows that by placing the upper limit on CO_2 emission and introduction of nuclear power plant by 2028, the contribution of hydro continues to increase from 2016 to the end of the modelling year. Nuclear power plant starts from 2029, and continue to increase thereby suppressing contribution from fossil technology, which later disappear after the end of the modelling period. However, negligible contribution from solar and wind which has been suppressed by nuclear and hydro power plants. The United State energy data of 2019 reported that total power generation capacities for Nuclear, fossil, hydro, wind, and solar power generation capacities amounted to 93.5 percent, 56.8 percent, 39.1 percent, 34.8 percent, and 24.5 percent, respectively with nuclear generation capacity approximately double renewables and three times wind and solar power. The limit placed on carbon emission constraints suppressed the electricity contribution from Gas and Oil (combined cycle) power plants to 45% below the 2010 carbon emission level as recommended by the Nigerian Climate Transparency report of 2020. Due to increasing population, the demand of electricity continue to increase throughout the modeling period with significant contributions from low carbon emission technologies including nuclear, hydro, solar and wind which makes it dominant energy resources towards achieving carbon neutrality target. Although contribution from fossil is vital in meeting the future electricity demand in Nigeria, the contribution are been bounded below the limit on CO_2 constraints since fossil and coal are the major drivers of carbon emission technologies. There is no historical data on electricity production from coal since Nigeria does not produce electricity from coal, and hence was not used in the modeling prediction. Although the Paris Agreement aims towards achieving the carbon neutrality and also limiting the global mean temperature rise to 1.5°C by 2050, the contribution of oil and gas power plants is vital in meeting future electricity demand of Nigeria.

CONCLUSION.

The contribution of nuclear and other low carbon emission generation technologies in achieving carbon neutrality target in line with the Paris agreement goal of 2015 was modelled in this study using the IAEA energy-modeling tool. Nuclear power plants are the most environmentally beneficial technology, with zero carbon emissions, reliable baseload power and long operation lifespan, due to their negligible environmental impacts during normal operation. Hydropower produces low-cost electricity, and has a long lifespan when compared to other energy sources and produces methane gases during its life cycle. Its other benefits include flood control, agricultural support, and pure drinking water. Solar power is environmentally friendly with no GHGE and minimal maintenance cost, other benefits includes off grid power source which uses batteries to store energy to use at night, and can be installed anywhere. Wind power provides clean and sustainable sources of energy with zero carbon emission; it can be constructed on farms or ranches where wind is abundant. Equally, fossil power plants constitutes the major driver of carbon emission. Nigeria's ongoing efforts to include nuclear energy in its electricity generation mix, the off-grid solar and wind power initiatives in rural districts and its efforts towards exploiting hydropower resources are great steps towards reducing carbon emission and achieving carbon neutrality in line with Paris agreement. From figure 6, which places the upper limit of CO_2 constraints in line with the Nigeria's climate transparency report 2020, contribution from Oil and gas for electricity generation been curbed below the carbon emission limit of 2010 emission level given way for other low carbon energy technologies. Such measures will results to drastic decrease in the country's CO_2 emission and will greatly help in achieving carbon neutrality in line with Paris agreement target. This study employs the International Atomic Energy Agency (IAEA) energy-modelling tool in modelling energy supply needs for Nigeria using various electricity

generation technologies by placing the upper limit on carbon emission constraints. The study can serve as a reference point towards reducing carbon emission from electricity generation technologies in Nigeria and in determining the contribution of nuclear and other low carbon emission technologies towards achieving carbon neutrality and meeting the future electricity demand in Nigeria.

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