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Integrating Renewable Energy into Nigeria's Energy Supply Mix

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ABSTRACT

In this paper, simulation model for Nigeria's energy system is developed using EnergyPLAN simulation tool to study the structure of the present energy system and explore alternative future scenarios based on renewable energy sources. First, the 2017 reference scenario was developed and validated to reflect Nigeria's energy supply and consumption in 2017. Two other future scenarios were then developed; the 2030 REMP scenario to show a pathway to achieving the Renewable Energy Master Plan target of increasing the supply of renewable electricity by 36% of the total electricity generation by 2030; and the 2050 RE scenario which seeks to increase the share of renewable energy by >70% of the total electricity generation and introduces the concept of electric vehicles and the use of biofuel in the transport sector. Both the 2030 REMP and the 2050 RE scenarios employed the National Energy Master Plan 7% reference growth scenario for all sectors using 2017 as the base year. The study shows that with the abundance of renewable energy sources in Nigeria, it is possible to develop an energy system that is sorely dependent on renewable energy. The 2030 REMP shows that the shift from fossil fuel power plant to renewable energy for electricity generation results in an increase in the share of renewable energy in electricity production from 20.2% in 2017 to 37.88% in 2030 while the 2050 RE shows that the share can go up to 71.20% if proper policies and infrastructures are put in place.

Index Terms: *electricity generation, EnergyPLAN, energy system, modelling, Nigeria*

I. INTRODUCTION

Nigeria's population is rapidly on the rise, and by 2050 Nigeria would account for 4.2% of the total world population, becoming the third most populous country only behind China and India (United Nations, Department of Economic and Social Affairs, Population Division, 2017). Population increase coupled with increase in standard of living would lead to a high demand for energy. Energy security is essential; the economic growth of a nation, as well as its progress and development largely depend on energy (Oyedepo, 2012).

Making energy more affordable, accessible, and environmentally friendly has become a major global topic when discussing energy. For no less than a century, burning fossil fuels has spawned most of the energy required to drive cars, power businesses, and keep the lights on in homes (Denchark, 2018). Even today, oil, coal and gas provide for nearly 80% of the Nigerian energy needs. This dominance is not without a price, as it is associated with environmental and climate challenges. People in Nigeria need to change their energy consumption, and they need to change the way they produce their products and plastics; they need to move away from fossil fuels and they need to do it quickly (Herder, 2019).

An increased popularity in the use of renewable energy technology is perceived as one way of meeting these challenges. A shift towards the use of renewable energy has been a key point on the policy agenda in most countries around the world. More than a few governments have made this a milestone by setting ambitious targets for the implementation of such projects. The level to which these policies have been positive varies between countries (Rolf, et al., 2007). Despites its numerous advantages, the penetration of renewable energy is still faced with barriers such as market failure, market distortion, and technical, financial, economic as well as institutional barriers (Painuly, 2001).

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First, the foremost challenge is to expand the amount of renewable energy in the supply system, particularly the electricity supply (Lund, 2007). Nigeria Renewable Master Plan (REMP) provides a roadmap for increasing the usage of renewable energy in electricity supply. The Master Plan targets to increase the contributions to the electricity supply mix from renewable energy sources (solar, wind, hydro, and biomass) by 23% of total electricity generation in 2025 and 36% in 2030 (ECN, 2005). This study is set out to develop an energy system model for Nigeria which integrates the use of renewable energy, particularly for electricity generation. Firstly, a reference model based on the year 2017 is developed and validated for accuracy. Two models for future scenarios i.e., the 2030 Renewable Energy Master Plan model (hereafter referred to as 2030 REMP) and the 2050 renewable energy scenario (referred to as 2050 RE), are then developed to highlight possible pathway to an efficient utilization of renewable energy sources in energy production. The energy scenarios are an "if-then" analysis and should not be considered as a prediction of what will happen in the future (Teske, et al., 2016).

A. Nigeria Energy Situation

Nigeria is faced with energy crisis and this has been going on for the past five decades. The consequence of this is that many industrial and commercial activities are being affected negatively. There is a significant increase in the number of households, commercial ventures, and industries that consume electricity. This is due to the rapid increase in population and development in industrial and commercial activities. As a result, the demand for electricity has outstripped the supply capacity. The Council for Renewable Energy of Nigeria reports that power outages have caused a loss of about 126 billion naira annually (CREN, 2009). Nnanna and Uzorh (2011) reported that firms spend about 25% to 40% of their initial investment on acquisition of facilities to enhance electricity supply. Aside this negative economic impact, this situation also exposes people to carbon emissions due to the frequent use of generators in different households and business enterprises.

According to the International Energy Agency (IEA) estimates (IEA, 2019), the total primary energy supply in Nigeria in 2017 was 1827.50 TWh, in which biofuel/waste had the highest share percentage (74.41%), followed by oil products (14.09%), natural gas (9.01%), crude oil (2.16%), hydro (0.30%) and coal (0.18%). The total final consumption in the same year was 1539.93 TWh. The residential, commercial and public services sectors had the largest share at 80.38%, followed by transport (13.16%), industry (5.43%) and non-energy use (1.04%). The total electricity consumption of Nigeria in 2017 was 25.77 TWh. Nigeria's power generation capacity in 2017 was 12664 MW including 10522 MW from fossil fuels, 2110 MW from hydroelectricity, and 32 MW from solar, wind, biomass and waste. About 83% of fuel mix for power generation was natural gas. For a country with such a large population, the power generated is grossly inadequate. Coupled with the population increase and increased economic activities, the power consumption is expected to radically amplify. The country is in an ominous state vis-à-vis the supply of energy. This translates into low economic growth and development. Therefore, it is pertinent to delve to renewable energy which are in abundance to plan a new future path for Nigeria.

II. METHODOLOGY

A. The EnergyPLAN Simulation Tool

There is a great difficulty in selecting an appropriate energy tool for developing future scenarios of energy system, particularly as it pertains to Nigeria. However, based on the review of 37 computer tools for analysing the integration of renewable energy into various energy systems (Connolly, et al., 2010), the EnergyPLAN simulation tool was chosen for this study. There is no dearth of literature on the use of this simulation model for energy system modelling.

The tool has been used to provide key insight and potentials for neo-carbon energy ecosystem (Abdulganiyu, 2017); to develop an energy system model which integrates all the energy production, conversion and consumption sectors (Ma, et al., 2014); to examine the role of energy storage in high renewable energy systems (Lund & Mathiesen, 2009), as well as to predict the optimization of the combination of various fluctuating renewable energy into the electricity system (Lund, 2006). EnergyPLAN has also been used to effectively analyse energy systems with high share of renewable energy for several countries including Ireland (Connolly, et al.,

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2010), Latvia (Porubova, 2010), United Kingdom (Le & Bhattacharyya, 2011), Macedonia (Ćosić, et al., 2012), Denmark (Kwon & Østergaard, 2012), Kenya and Tanzania (Abdulganiyu, 2017), etc.

The EnergyPLAN model is an input/output simulation model that simulates the performance of a given energy system in hourly steps throughout a year. It was developed purposefully for energy planning strategies on the basis of technical and economic analyses with interest on the penetration of high renewable energy mix. The inputs into the model are demands, renewable energy sources, energy plant capacities, costs and a number of optional different simulation strategies emphasising import/export and excess electricity production. The outputs are energy balances and resulting annual productions, fuel consumption, import/exports and total costs including income from the exchange of electricity (Münster & Lund, 2009; Lund & Thellufsen, 2021). A more detailed overview of the tool can be found in Lund and Thellufsen, (2021) and Connolly (2015).

B. The Energy System Analysis

A reference model of Nigeria's energy system for the year 2017 was created. 2017 was chosen because it is the most recent year with the complete energy data for Nigeria. The inputted data were based on IEA energy balance sheet for Nigeria (IEA, 2019).

The 2030 REMP scenario is in accordance with the Nigeria Renewable Energy Master Plan (ECN, 2005). The Master Plan targets an increase in contribution of renewable energy to electricity generation in Nigeria by 36% in 2030. For other sectors, the reference scenario for the National Energy Master Plan (ECN, 2014) wherein the real GDP grows by a mean of 7% per annum was used to predict energy demand using 2017 as the base year (The National Energy Master Plan used 2009 as the base year). The industry will experience a growth rate of 24.01%, transport 6.46%, household 3.16% and others 6.01%. The electricity supply projection employed in this scenario is also adopted from ECN (2014) (7% growth scenario) and tabulated below.

TABLE I
ELECTRICITY SUPPLY PROJECTION FOR 2030

Fuel Type	Capacity (MW)
Coal	10984
Natural gas	80560
Solar	25917
Hydro	6533
Wind	29
Biomass	54
Nuclear	3500

Source: ECN (2014)

Lastly, the model for the 2050 RE scenario was created. The scenario is aimed at increasing the percentage contribution of renewable energy to electricity supply by > 70%. The energy demand for other sectors was also predicted using the National Energy Master Plan's reference growth scenario. However, the scenario was modified through several steps of iteration to reduce the use of fossil by approximately 30% in the transport sector. This is replaced by the used of biofuel and electric vehicles. The following are the key assumptions made in the design of this scenario:

1. Solar capacity was set at 70 GW, wind 25 GW and hydro 17759.4 MW
2. Natural gas-powered plant capacity for the National Energy Master Plan 7% growth for 2030 was maintained. However, it is assumed there will be construction of new biomass plants and the use of coal is assumed to have phaseout.
3. The transport sector is set to grow according the National Energy Master Plan 7% growth scenario. It is assumed that the number of vehicles per 1000 people will increase from 60 in 2018 (National Bureau of Statistics/ Federal Road Safety Corps, 2018) to 200 in 2050. About 4 million of these vehicles will be electrically powered.
4. 20% of the fuel mix in the transport sector will be biofuel. This is set based on preliminary studies of some literatures (NNPC, 2007; Abila, 2010; Agba, et al., 2010; Ohimain, 2013).

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The electricity demand for 2030 and 2050 was projected based on forecast of population growth (United Nations, Department of Economic and Social Affairs, Population Division, 2017) and power demand estimates in literatures (Olayande & Rogo, 2008; World Bank, 2013; Ezennaya, et al., 2014; GIZ, 2015).

TABLE II
PROJECTED POPULATION AND ELECTRICITY DEMAND FOR NIGERIA

Year	2017	2030	2050
Population (million)*	190.886	264.068	410.638
Electricity demand (TWh)	25.77**	131.50[a]	410.64[a]

*Source: * United Nations, DESA, Population Division (2017)*
*** IEA, 2019*
*[a] Calculations based on * and power demand estimates from literatures*

All the above data considerations were inputted into EnergyPLAN for technical simulation. Østergaard (2009) gives some framework of optimization measures for energy system analyses of renewable energy integration. This study focuses on particularly on electricity generation.

III. RESULTS AND DISCUSSION

A. Reference Model Verification and Validation

A comparison was made between the reference model created in EnergyPLAN, and the actual data of the Nigeria's energy system in 2017 obtained from IEA (2019). This is necessary to ensure that EnergyPLAN can be used to generate accurate simulation result. The validation procedure employed by Ma et al. (2014) and Abdulganiyu (2017) was used in this study. First, the sources of electricity consumed were compared. As shown Table III, it can be observed that there is only a slight difference between the Energy PLAN's simulation result and the actual data from IEA (2019).

TABLE III
COMPARISON OF ELECTRICITY GENERATION BETWEEN EnergyPLAN MODEL AND ACTUAL DATA IN 2017 (TWh)

Production mode	Electricity production (TWh)		Difference	
	Actual 2017	EnergyPLAN 2017	TWh	%
Hydropower	5.52	5.56	-0.04	0.72
Solar PV	0.02	0.02	0.00	0.00
Condensing Power	20.25*	20.19	0.06	0.30
Import/Export	0.00	0.00	0.00	0.00
Total Production	25.79	25.77	0.02	0.08

**Excluding 6.65 TWh which accounts for statistical differences (0.45TWh), energy own use (1.16 TWh) and losses (4.84 TWh)*

Table IV compares total fuel consumption by source obtained from the EnergyPLAN model simulation result and the values in the Nigeria energy balance (IEA, 2019).

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TABLE IV
COMPARISON OF TOTAL FUEL CONSUMPTION IN 2017 AND THE EnergyPLAN

Consumption Mode	Total fuel consumption (TWh)		Differences	
	Actual 2017	EnergyPLAN 2017	TWh	%
Coal	0.34	0.34	0.00	0.00
Oil	219.94	219.96	-0.02	0.01
Natural gas	81.13	85.06	-3.93	4.84
Biofuel/waste	1253.59	1253.57	0.02	0.00
Total fuel consumption	1555.00	1558.93	-3.93	0.25

As can be seen on Table IV, the Energy PLAN data agrees to a large extent with the actual 2017 data. The only observable difference is natural gas consumption which differs by 4.84%. The verification of the reference model developed shows that Energy PLAN can simulate Nigeria's energy system effectively and is therefore, employed to simulate the 2030 and 2050 future scenarios.

B. The 2030 REMP Scenario

This scenario takes into account the Renewable Energy Master Plan targets wherein renewable energy is to account for 36% of the total electricity generation capacity by 2030. The energy demand and supply for the other sectors (industry, transport, household and others) is projected according to the National Energy Master Plan's 7% growth scenario while using 2017 as the base year. The electricity supply is also projected based on the National Energy Master Plan's 7% growth scenario. These data were inputted into EnergyPLAN model, and the results are tabulated below.

TABLE V
FUEL MIX IN THE 2030 REMP SCENARIO

2030 REMP		Total fuel consumption (TWh)	Fuel for power generation (TWh)
Coal		157.21	152.06
Oil		566.31	-
Natural gas		497.65	26.70
Biomass		2639.57	0.47
Renewables	Hydro	24.5	24.5
	Solar	27.4	27.4
	Wind	0.09	0.09
Nuclear		7.26	7.26
Total		3919.99	238.48

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From Table V, about 6.59% of the fuel consumption is for power generation. The main driver of growth in this scenario is industry (construction, manufacturing, mining, etc.) with annual growth rate of 24.01%. The transport, household and others (commercial and public services) will be having growth rates of 6.46%, 3.16% and 6.01%, respectively. As can be observed, aside biomass, oil still accounts for the highest share of fuel used in this scenario.

Table VI shows the simulation result for power production. The shift from fossil fuel power plant to renewable energy for electricity generation will result in an increase in the share of renewable energy in electricity production from 20.2% in 2017 (IEA, 2019) to 37.88% in 2030. This is 1.88% more than the Renewable Energy Master Plan target for 2030 (ECN, 2005). In addition, 5.6% of the electricity production will be from nuclear power plant. This is in line with the National Energy Master Plan projection for the year 2030 (ECN, 2014).

TABLE VI
SIMULATION RESULT FOR POWER PRODUCTION 2030 REMP SCENARIO

2030 REMP	Electricity Production (TWh)
Condensing Power Plant	78.55
Nuclear	7.26
Solar	27.40
Hydro	24.50
Wind	0.09
Biomass	0.33
Total	138.13

C. The 2050 RE Scenario

This scenario is focused on achieving >70% contribution of renewable energy to power generation and the introduction of electric vehicles and biofuels in the transport sector. The scenario was designed considering the availability of renewable sources in Nigeria (Sambo, 2009), and renewable energy technologies assessment based on several critical sustainability indicators (Evans, et al., 2009). The electricity production was from natural gas power plant, biomass power plant, solar, hydro and wind. Coal-powered plant was assumed to have phaseout due to CO2 content (95 kg/kJ). The simulation result for the power production is shown in Fig. 1. 71.20% of the total electricity production is from renewable energy sources (excluding biomass plants). Fig. 2 shows EnergyPLAN electricity production for a month in 2050.

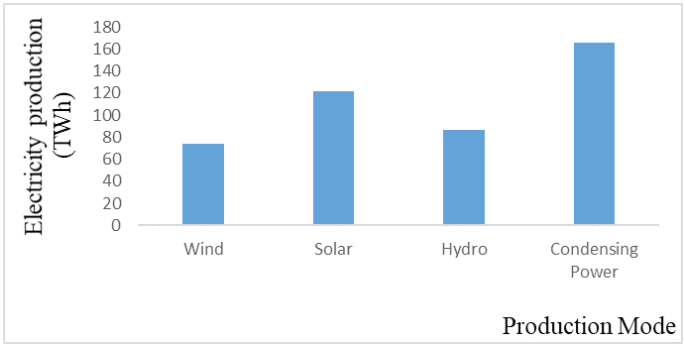

Fig. 1: Simulation result for power production 2050 RE scenario

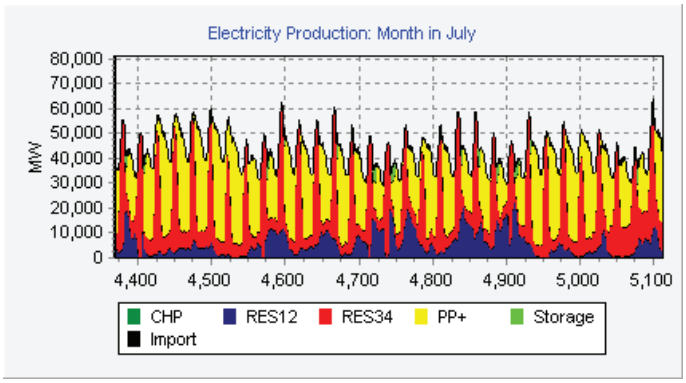

Fig. 2: EnergyPLAN electricity production output in a typical month

RES12–Wind RES34 - Solar PV; PP+- Large hydropower plants + Natural gas plant + biomass plant; Storage– Electricity production from storage and vehicle to grid transportation

In the transport sector, it is assumed there would be four million battery electric vehicles (BEVs) each having 50 KWh rechargeable battery packs, an equivalent of 200 GWh capacity in total. An estimated electricity demand of 24 TWh was set for the BEVs of which 75% would be for dump charge and the remaining 25% would be for smart charge. The maximum share of cars during peak demand was set at 20% and the share of cars that will be grid connected was set at 70%. Table VII shows the fuel consumption in the transport sector for the year 2050.

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TABLE VII
FUEL CONSUMPTION IN THE TRANSPORT SECTOR 2050 RE SCENARIO

2030 REMP	Electricity Production (TWh)
Condensing Power Plant	78.55
Nuclear	7.26
Solar	27.40
Hydro	24.50
Wind	0.09
Biomass	0.33
Total	138.13

It can be observed that fossil fuel still dominates the share of fuel mix used in transport sector in the 2050 RE scenario. This is because vehicles stay on the road for up to 40 years in Nigeria (Maduekwe, et al., 2020) and there is still an increasing market for fossil fuel vehicles, so, therefore, replacing the already existing fossil fuel vehicles would be impractical.

D. Comparison of Electricity Production between the Scenarios

The annual electricity generation in each of the three scenarios is shown in Fig. 3. There is a substantial shift in the generation capacities from fossil fuel power plant-dependent to Renewable energy-dependent. In the 2017 reference scenario, the electricity production from condensing power is 20.19 TWh, 5.56 TWh from hydropower, and 0.02 TWh from solar. Renewable energy account to about 20% of the electricity generation in 2017. In the 2030 REMP scenario, production from condensing power plant is 78.55 TWh, 7.26 TWh from nuclear power plant and 52.32 TWh from renewable energy sources. Renewable energy in this scenario accounts for 37.88% of the total power production. In the 2050 RE scenario, renewable energy share in power generation is increased to 71.20%.

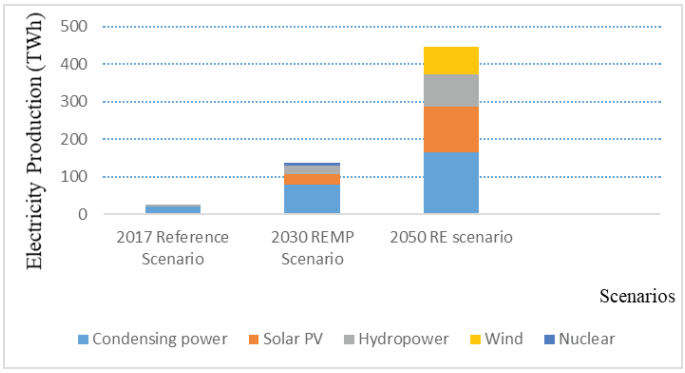

Fig. 3: Electricity generation by source in different scenarios

IV. CONCLUSION

It is evident that Nigeria's energy demand would continue to increase due to the rapid growth in population and the economy. However, the supply which is still dominated by fossil fuel is not sufficient enough to meet such increasing demand. It is pertinent to introduce renewable energy sources which the country has in abundance into the supply mix. In this study, a reference scenario and two energy system scenarios for Nigeria were technically designed and simulated. The 2017 reference scenario was designed to reflect Nigeria's energy supply and consumption in 2017; the 2030 REMP scenario was designed to show a pathway to achieving the Renewable Energy Master Plan target of increasing the supply of renewable electricity by 36% of the total electricity generation by 2030.

The 2050 RE scenario seeks to increase the share of renewable energy by >70% of the total electricity generation; it also introduces the concept of electric vehicles and the use of biofuel in the transport sector. Both the 2030 REMP and the 2050 RE scenarios employed the National Energy Master Plan 7% reference growth scenario for all sectors using 2017 as the base year.

The study shows that with the abundance renewable energy sources in the country, it is possible to develop an energy system whose supply is based on renewable energy. The 2030 REMP shows the shift from fossil fuel power plant to renewable energy for electricity generation will result in an increase in the share of renewable energy in electricity production from 20.2% in 2017 to 37.88% in 2030 while the 2050 RE shows that the share can go up to 71.20% if proper infrastructures and policies are put in place.

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