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Towards 2060 Net Zero Emission: Marching the Electricity Demand with Supply in Nigeria Using NEECAL2060

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ABSTRACT

The gap between energy demand and supply in Nigeria creates a great hindrance to the country's sustainable development agenda and the realization of its 2060 net zero emissions. The objective of the study reported in this article was to model the electricity demand and supply using the Nigeria Energy and Emissions Calculator (NEECAL2060) which develops consistent scenarios of energy supply to meet energy demand projections. The choices that lead in this direction vary, reflecting the different resource endowments and starting points across a very diverse Nigerian energy landscape. For Nigeria to use the enormous potential of its energy resources given its drive to match electricity demand with supply, and its vision towards 2060 net zero agenda, the barriers to achieving these must be eliminated through significant investment in R&D, the building of indigenous human and manufacturing capacities and intensification of the on-going economic reform to create an investor-friendly environment.

Keywords: Energy Demand and Supply Projections; Electricity Projections; Emissions Mitigation Pathways; Energy Resources; 2060 Net Zero Pledge

INTRODUCTION

Access to a stable and secure supply of energy is a fundamental driver of economic growth. Several sub-Saharan African countries are amongst the least developed economies in the world. A large proportion of the population in the region lacks access to electricity and other modern energy services, while those who have access face frequent outages.

More than two-thirds of the population, approximately 600 million people, in sub-Saharan Africa lacked access to electricity (Pappis et al., 2019). North Africa reached almost universal access to electricity by 2018, but the electrification rate in sub-Saharan Africa was 45 % that year. Electrification levels in sub-Saharan Africa remain very low compared to the levels in other developing parts of the world, most notably the 94% rate reached on average across developing countries in Asia. Lack of electricity often obliges households, small businesses, and community services that can afford it to use inefficient, polluting, and expensive alternative solutions for essential services. Many oil-exporting countries have excellent renewable energy resources, which when combined can provide very low-cost electricity together with high capacity factors (IRENA, 2019).

Despite the comparatively low access rate, sub-Saharan Africa has made progress with the pace of electrification over the past five years. The number of people gaining access to electricity for the first time more than doubled from 9 million a year between 2000 and 2013 to more than 20 million a year between 2014 and 2018, outpacing population growth for the first time. As a result, the number of people without access to electricity in sub-Saharan Africa peaked at 610 million in 2013, before slowly declining to around 595 million in 2018. The region now faces a dual challenge: how to provide access to the 600 million currently deprived while at the same time reaching the millions born every year in areas without access to electricity (IEA, 2019).

Investment in power infrastructure in sub-Saharan Africa has mainly been financed by state budgets with substantial contributions from international donors. Public and international development finance collectively accounted for more than 90 % of the capital committed to power infrastructure in 2017 (ICA, 2017). While public sources of finance have an important role to play, they are unlikely to be sufficient to address the significant investment gaps that exist, and need to be supplemented by private sector financing. Africa has so far had limited success in mobilizing private finance. Between 2013 and the first-half of 2018, power sector investment based on private sector participation in infrastructure (PPI) models in sub-Saharan Africa amounted to around $4.5 billion per year on average, less than 10 % of the annual needs between today and 2040 (IEA, 2019).

For many developing nations in sub-Saharan Africa, and Nigeria in particular, are faced with substantial electricity supply gap (Rapu et al., 2015). For instance, the electricity demand in Nigeria far outstrips the supply, and the supply is epileptic in nature (Sambo, 2008). With the grossly inadequate national grid electricity supply in the country, total installed national grid capacity is far less than the demand and out of this installed capacity the available capacity is barely above half of the installed capacity. As at 2016, percentage of the population with access to electricity in Nigeria was 61 %, leaving behind barely 39 % without electricity (Pappis et al., 2019). Particularly, the per capita energy consumption is too low for meaningful economic and social development. In spite of this, Nigeria still has a constraint of supplying 70 MW of energy to Niger Republic (Ezennaya et al., 2014).

Studies exploring pathways to enhance energy supply, reduce energy demand and GHG emissions in Nigeria are limited and have not really focused on what is economically and technically feasible in the country. In this research, we use the Nigerian Energy Calculator 2060 to examine and compare the energy balances and GHG mitigation potentials for four alternative low carbon scenarios which are possible by 2050 (Dioha et al., 2019). The NEECAL2060 simulates final energy demand and supply, sectoral GHG emissions, per capita GHG emissions, air pollutants as well as policy implications of different scenarios. Finally, a sensitivity analysis was conducted of the final energy demand with the household sector of Nigeria as it is the largest energy-consuming sector in the nation.

2060 Net Zero Emission Agenda and Nigeria's Commitment

There is universal acceptance that climate change, caused by the increased concentration of greenhouse gases (GHGs) emitted by human activities, is a major threat to economic systems and livelihoods globally. In December 2015, the 21st edition of the United Nations Framework Convention on Climate Change (UNFCCC) Conference of Parties (COP-21) was held in Paris. During COP-21, governments across the world reached an agreement to reduce the global average temperature below 2^0 C above the level during the pre-industrial era. The Paris Accord was binding for both developed and developing countries. Achieving these ambitious targets requires serious transformation in all sectors of the economy, especially the energy sector, which is the dominant source of GHG emissions globally (Dioha et al., 2019).

In the light of the current and projected climate disruptions, governments across the world including Nigeria, signed up to the Paris Agreement. The Agreement provides an international framework for climate action with its core objective to minimize the global temperature increase to well below 2° C/1.5° C (Pathak, 2017). This was a follow up from being a signatory to the Paris Agreement in 2016 and ratifying the document under Nigerian law in March 2017. In furtherance to this, Nigeria established its Nationally Determined Contributions (NDCs) towards reducing emissions of Green House Gases (GHG) and limiting global warming to well below 2° C (Pappis et al., 2019).

On 31 March 2021, the International Energy Agency (IEA) hosted a Net Zero Summit to take stock of the growing list of commitments from countries and companies to reach the goals of the Paris Agreement, and to

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focus on the actions necessary to start turning those net zero goals into reality. Subsequently, November 2021 saw the most important UN Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP 26) since the Paris Agreement was signed in 2015. At COP 26, an increasing number of countries announced their long-term goals to achieve net-zero greenhouse gas (GHG) emissions over the coming decades.

Achieving the demanding GHG emission reduction targets of some 80 % or more that prevail for 2050 will require a fundamentally different energy system, with intermittent renewables such as onshore and offshore wind and photovoltaic energy, playing a crucial role in the electricity generation mix (Ball et al., 2015). Renewable Energy (RE) resources will play a key role in the transition towards a clean and sustainable energy system. The main challenge in transitioning towards 100 % RE is the variable and intermittent nature of these resources (Dawood et al., 2020). On the other hand, the Covid-19 pandemic delivered a major shock to the world economy, resulting in an unprecedented 5.8 % decline in CO_2 emissions in 2020. However, monthly data showed that global energy-related CO_2 emissions started to climb again in December 2020, and were estimated to rebound to around 33 gigatonnes of carbon dioxide (Gt CO_2) in 2021, only 1.2 % below the level in 2019 (International Energy Agency, 2021).

In Nigeria, the adverse impacts of climate change are also evident. Examples include the shrinking of Lake Chad from about 45,000 to about 3,000 km^2 between 1960 and 2007, and the 2012 flood whose damage amounted to about 1.4 % loss of the GDP (US$ 17 billion) that year. Owing to the importance of energy in development and the devastating effects of climate change, countries across the world are now charged with developing effective strategies that provide long-term energy security and also protect the climate. To achieve net- zero emissions, the IPCC indicates that a systemic transformation is needed in the sectors of energy, cities and transport systems, and land-use and also in agriculture (Inter-American Development Bank & DDPLAC, 2019).

The Nigerian government aims to pursue its developmental goals in a sustainable manner and, thus, has the responsibility to limit its national GHG emissions. Hence, decisions need to be made based on a sound understanding of the future challenges in terms of energy demand, supply, and GHG emissions. The year 2050 has globally been identified as a milestone in the low carbon transition agenda by the Intergovernmental Panel on Climate Change (IPCC), and between 2050–2100, negative GHG emissions will be needed to ensure that the global temperature is kept below 2^0 C. Thus, exploring energy pathways to 2050 for Nigeria will help us understand the challenges and opportunities facing the nation in the context of energy security and climate mitigation (Dioha et al., 2019).

The direct use of low-emissions electricity in place of fossil fuels is one of the most important drivers of emissions reductions in the NZE, accounting for around 20 % of the total reduction achievable by 2050. Global electricity demand more than doubles between 2020 and 2050, with the largest absolute rise in electricity use in end-use sectors taking place in industry, which registers an increase of more than 11000 TWh between 2020 and 2050. Much of this is due to the increasing use of electricity for low- and medium-temperature heat and in secondary scrap-based steel production (Figure 2.16) (International Energy Agency, 2021).

Global Electricity Access

The share of the world's population with access to electricity grew from 83 % in 2010 to 90 percent in 2019. Worldwide, 1.1 billion people gained access between 2010 and 2019. However, the spread of electrification, the number of people lacking access fell from about 1.2 billion in 2010 to 759 million in 2019. Continuous progress was made from 2017 to 2019, with 130 million people gaining access to electricity each year, slightly more than the average of 127 million people who gained access each year between 2010 and 2017.

Electrification through decentralized renewables-based solutions has advanced significantly since 2010, accelerating in recent years. The number of people connected to mini-grids (all technologies) more than doubled between 2010 and 2019, growing from 5 to 11 million people (IRENA 2020b). In 2019, 105 million Central Asia and 71.8 % people had access to off-grid solar solutions, rising from 85 million in 2016 (GOGLA

2020). Forty-nine Southern Asia, 23.6 percent of them reside in Sub-Saharan Africa, while 29 percent inhabit South Asia. According to analysis from RISE (ESMAP 2020), policy frameworks to support mini-grid and off-grid systems developed more in Eastern Asia after 2010 than did those for on-grid electrification (World Bank, 2021).thus, ensuring access to affordable, reliable, sustainable, and modern energy for all implies a substantial increase in the share of renewable energy in these end-use sectors.

Access to modern energy is a central pillar of efforts to reduce poverty and support economic growth in sub-Saharan Africa. Modern household energy services have two components: first, access to clean cooking facilities, where progress remains slow, with around 900 million people without access today; second, access to electricity, where there has been strong progress in several countries over the past decade but almost 600 million people in sub-Saharan Africa remain without access today (Box 1.2)(IEA, 2019).

Even as the share of electricity has increased from 31.1 % to 41.2 % since 1990, fossil fuels have remained a staple of total energy use. Moreover, global energy use today only serves about 6.5 billion of the 7.7 billion people on the planet, and a good portion of the 6.5 billion who are served are not served reliably. So, the scale of the energy problem demands a portfolio of innovative solutions. Hydrogen can play a major role in that portfolio (Lambert, 2021).

Electricity Demand and Supply

The rise in electricity demand calls for extensive efforts to ensure the stability and flexibility of electricity supply through demand-side management, the operation of flexible low-emissions sources of generation including hydropower and bioenergy, and battery storage (International Energy Agency, 2021).

In recent decades, African energy demand has been driven by the growing needs of North Africa, Nigeria and South Africa. In 2018, primary energy demand in Africa was more than 830 million tonnes of oil equivalent (Mtoe): North Africa (24%), Nigeria (19%), and South Africa (16%) together accounted for 59% of this despite making up only 35% of the population. Average energy consumption per person in most African countries is well below the world average of around 2 tonnes of oil equivalent (toe) per capita. In 2018, per capita consumption in sub-Saharan Africa was highest in South Africa at 2.3 toe/capita and in Nigeria at 0.8 toe/capita. Most other sub-Saharan African countries have per capita consumption of around 0.4 toe/capita and in most a large part of it consists of the relatively inefficient use of solid biomass (IEA, 2019).

In the electricity sector in particular, it would be necessary to produce an additional 11,300 TWh of electricity for industry and fuel transformation and to replace virtually all of the electricity generated from fossil fuel powered plants equipped with CCUS in 2050 in the NZE. Using renewables, this would require an additional 7,000 GW of wind and solar PV capacity in 2050. This is around 30% more than in the NZE, and would mean that annual capacity additions of solar PV and wind during the 2030s would need to reach 1,300 GW (300 GW more than in the NZE). To accommodate this additional level of variable renewables and to provide the flexibility that is available from fossil fuel CCUS equipped plants in the NZE, around 660 GW more battery capacity would be needed in 2050 (20% more than in the NZE in in 2050), together with additional 110 GW of other dispatchable capacity(International Energy Agency, 2021).

Despite being home to almost a fifth of the world’s population, Africa accounts for little more than 3% of global electricity demand and North African countries (42%) and South Africa (30%) represent nearly three-quarters of this (IEA, 2019). Africa’s electricity demand is growing, but only at half the rate of developing Asian countries: it rose to 3% a year on average between 2010 and 2018, increasing from 560 terawatt-hours (TWh) in 2010 to around 705 TWh. The latter figure is equivalent to a fifth of electricity demand in Europe in 2018.

Electricity accounts for around 10% of Africa’s total final energy consumption, but per capita electricity demand in Africa remains very low at around 550 kWh (370 kWh in sub-Saharan Africa) compared with 920 kWh in India and 2,300 kWh in Developing Asia (IEA, 2019).With rising income levels and access to basic energy services, means that demand for electricity grows more than for any other energy source. Although

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energy conservation and efficiency is not a resource per se, it is acknowledged that its adoption in a country can significantly mitigate the supply challenge (Sambo, 2008).

Demand for lighting and other appliances grows six-fold to 2040, while demand for cooling increases by more than 13% per year to 2040 in the Africa Case, making the issue of cooling one of the most consequential in determining the extent of future residential energy demand. The consequences for energy demand of meeting this challenge can be mitigated by ensuring that sustainability is central to the choices made when designing Africa's future built environment (IEA, 2019).

In Nigeria, energy is the mainstay of the country's economic growth and development. It plays an important role in the nation's international diplomacy and it serves as a tradable commodity for earning the national income, which is used to support government developmental programs (Sambo, 2009). Adequate power supply is an unavoidable prerequisite to any nation's development, and electricity generation, transmission and distribution are capital-intensive activities requiring huge resources of both funds and capacity. In the prevailing circumstances in Nigeria where funds availability is progressively dwindling, creative and innovative solutions are necessary to address the power supply problem (Sambo et al., 2010).

METHODOLOGY

Nigeria is one of the 10 counties supported by the UK Government to develop an Energy and Emissions Calculator, one of the tools used to inform the country's Nationally Determined Contributions (NDCs), called Nigeria Energy and Emissions Calculator 2060 (NEECAL2060)(ECN., 2015). The main reason for selecting the NEECAL2060 model for this study was because it was developed locally with Nigeria-specific data. The country's situation on economic and technological options was used in developing the model's trajectories. The model was developed based on a rigorous literature review and consultations with over one hundred local experts, to ensure that the most accurate assumptions are made and the data used are of high quality. Hence, these features give the model a comparative advantage over other models as the results produced by its scenarios actually reflect what is technically and practically attainable in the country within the given timeframe (Dioha et al., 2019). Furthermore, the NEECAL2060 platform does not 'recommend' or 'prefer' any one scenario or pathway over the others. It merely provides the user a way to understand the realm of possible scenarios and their implications and post their preferences and choices as a contribution to the debate on sustainable energy development for Nigeria.

Long-term horizon modelling of energy infrastructure and their interactions with other domains such as socio-economic and technical aspects of a country is complex and challenging. It is difficult to forecast the evolution of a particular country and its constituent sectors (e.g. economy), 25 or 50 years into the future. The difficulty in modelling arises from the uncertainty inherent in the interactions between in-country and external factors that affect model choices and underpinning assumptions. Scenario-based models based on plausible and acceptable descriptions of the future are often recommended in such cases to study the effect of an evolving system. Outputs from scenario-based models give a probable range, rather than a deterministic one (ECN, 2015).

NEECAL2060 is a transparent and open source model of energy, GHG emissions (CO_2, CH_4, N_2O, HFCs, PFCs, SF_6), and land use. As a scenario–based modeling tool, it is an accounting framework that is algorithmically equipped with a mechanism to balance the energy numbers rising out of various combination of demand and supply choices on five-yearly intervals up to 2060. The model also accounts for emissions of air pollutants such as PM10, NO_X, SO_2, and NMVOC (Non-methane volatile organic com- pounds). It uses a set of existing and future technologies to ensure that energy supply satisfies the varying energy demands. Two versions of the model were developed by the Energy Commission of Nigeria (ECN): the MS Excel-based type and the Web-based type. In this paper, the MS Excel version was employed. As an integrated model, NEECAL2060 aims to identify secured pathways for energy supply and demand at minimal or net-zero GHG emissions level from 2015 to 2060.

NEECAL2060 is split into six sectors; (i) industry, (ii) building, (iii) transport, (iv) electricity, (v) land use and waste (AFOLU) and, (vi) CO_2 removal and other gases. The demand is determined by the user's choices from

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each of the demand sectors (industry, building, transport and land-use). Then the user also determines how the energy supply would be and then NEECAL2060 compares the demand-supply figures based on the user's choices. The primary energy supply side consists of mainly liquid and gaseous fossils (petroleum gas, oils, natural gas) and fire wood. When the supply is higher than demand, it is assumed that the domestic energy resources are sufficient to match the demand (Dioha et al., 2019). In this research, two out of four scenarios were examined and compared for electricity access and low carbon development in Nigeria; the Business-as-Usual (BAU) scenario and Most Ambitious Level (MAL) scenario, targeting utmost determination of GHG removals whilst meeting-up adequate energy supplies for the demand.

RESULTS AND DISCUSSION

Nigeria's peak power demand was computed, and projected to 2060 using NEECAL2060 with the key power demand drivers, demography, socio-economy and technology. The two selected scenarios, BAU and MAL, were analyzed for the application of power into agriculture, industries, building heat and building others (specific electricity use, cooling and cooking). The year 2015 was selected the base year in this study on the basis of availability of data that represented the country's steady economic and energy situation.

The structure of the nation's economy and climate change mitigation are the major driving parameters in these selected two scenarios. Projected electricity demand has been translated into demand for grid electricity and peak demand on the bases of assumptions made for T&D losses, auxiliary consumption, load factor and declining non-grid generation.

Table 1: Peak Power Demand, BAU (GW)

Year	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
Agriculture	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233
Industry	15.7504	15.47554	18.47636	21.33678	24.1827	27.09347	30.20599	33.3616	36.409	39.50053
Transport	0.023062	0.034071	0.034318	0.048948	0.067124	0.088878	0.113441	0.141415	0.161485	0.18244
Buildings Other	17.69975	18.02948	20.81344	23.44145	25.11661	25.18767	30.8924	37.57103	41.63399	45.91275
Buildings Heat	0.001019	0.001037	0.001147	0.001262	0.00138	0.001501	0.001627	0.001757	0.001891	0.002028
Total	**33.47563**	**33.54152**	**39.32667**	**44.82985**	**49.36923**	**52.37293**	**61.21482**	**71.07712**	**78.20764**	**85.59898**

Table 1 shows the electricity peak demand projections for BAU scenario. It must be emphasized that despite suppressed demand being experienced in the country since 2015 due to inadequate generation, transmission and distribution facilities, suppressed demand is expected to be non-existent by 2030. From Table 1 above, it indicates ever growing demand from 33.5 GW in 2015 to 85.6 GW 2060 for the BAU. Building sector is most demanding with about 53 % compared to industrial sector, 46 % while agriculture and transport with insignificant energy demands.

Table 2: Peak Power Demand, MAL (GW)

Year	**2015**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
Agriculture	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233	0.001233
Industry	15.7504	15.47554	18.93627	22.7078	26.93474	31.45823	36.63384	42.30853	48.49473	55.36861
Transport	0.023062	0.034071	0.099309	0.222201	0.341953	4.496197	8.683085	12.98554	16.51847	19.65411
Buildings Other	17.69975	18.02948	18.4252	19.36006	20.5826	22.12842	26.29152	30.963	33.11525	35.27584
Buildings Heat	0.001019	0.001037	0.001016	0.000993	0.00097	0.000945	0.00092	0.000893	0.000865	0.000835

Total	**33.47563**	**33.54152**	**37.46319**	**42.29245**	**47.8615**	**58.08503**	**76.98102**	**96.97782**	**112.1274**	**126.7411**

Total energy demand from the projected MAL shows active economic activities that support consumption of clean energy, as seen in Table 2, consumption of significant electricity by Electric Vehicles (EVs) from 2040, while industry leads in the consumption of electricity from 2030.

The total energy supplies were computed using same NEECAL2060. This is one of the advantages of using the tool; assessment of energy demand whilst generation by optimization, strategic energy supply based on technology application provided which includes both available and future technologies. The tool, simultaneously, assesses the environmental impacts of the energy resources utilized for an exogenously given demand of final energy, targeting net-zero emission at the determined year, 2060 in this case. Nigeria is quite blessed with a lot of resources for electricity generation (Table 3) such as coal, natural gas, fossil oils, hydro and other renewable energy sources.

Similar analytical modeling tools, Model for the Analysis of Energy Demand (MAED) and Model for Energy Supply Strategies and their General Environmental Assessment (MESSAGE), both developed by the Internal Atomic Energy Agency (IAEA) were used, also, for the purpose of energy demand assessment and projections as well as supply strategies, whose results were used for the development of the Nigerian National Energy Policy (NEP), 2014. These tools were operated individually but they do not estimate emissions. Thus, the application of NEECAL2060 in this study.

Table 3: Available Non-renewable sources of electricity and status of use

	Resource Type	**Reserves: 2019 (Natural Units)**	**Production Level: 2019(natural units)**	**Utilization: 2019 (natural units)**
1	Crude Oil	37.062 billion barrels	0.723 billion barrels	Domestic: 0.162 bbd (22%) Export: 0.561 bbd (78%)
2	Natural Gas	203 trillion scf	2.94 trillion scf	90%: Utilized – 41% Export -- 16% (Domestic use, power/ Industry/commercial --33% Field use (fuels/gas lift/re-injection) 10%: flared
3	Coal and lignite	2.7 billion tonnes	810,171 tonne	Not applicable (as at 2015)
4	Tar Sands	31 billion barrels of oil equivalent	0	Not applicable (as at 2015)
5	Nuclear Element	Yet to be quantified	0	30kW experimental nuclear reactor

Table 4: Available renewable sorces of electricity and status of use

	Resource Type	**Reserves: 2019 (Natural Units)**	**Production Level: 2019 (natural units)**
1	Large hydro power	24,000MW	2,630MW

2	Small Hydro power		3,500MW		64.2MW
3	Solar Energy		4.0 kWh/m^2/day - 6.5kWh/m2/day (a) *210,000 MW solar PV @ 1% of suitable land (b) *88,700 MW CSP @ 1% suitable land		About 1000MW solar PV off-grid; 1 MW grid connected PV; No solar thermal electricity
4	Wind		3,200 MW at 10m height with wind speeds of 2-4m/s		Still under search (as at 2015)
5	Biomass	Fuel wood	11 million hectares of forest and woodlands	29,800 PJ*	Not applicable (as at 2015)
		Municipal waste	- 18.3 million tonnes in 2005*		Not applicable (as at 2015)
		Animal waste	243 million assorted animals in 2001		Not applicable (as at 2015)
		Energy Crops and Agric. waste	72 million hectares of Agricultural land		Not applicable (as at 2015)

The Nigeria's electricity supply, both national grid and off-grid, are presently entirely dependent on fossil based (natural gas, PMS, AGO) fuels about 99 % as shown in Table 5 also in Figure 1, which are highly polluting and the resources are fast depleting. The current nation's electricity provision is short of the electricity demand in the country. The present average national grid power generation is about 21 % (7 GW) of the entire electricity consumption as at 2015 to 2020 (Table 1).

Growing or sustaining the available national grid capacity has been very difficult due to inadequate supply of natural gas, for instance, for the thermal plants due to either shortage of gas or gas pipelines vandalization, has not allowed full utilization of total installed capacity of 18 GW. Low gas pressure and poor gas quality with condensate sometimes results in plant shutdown. The insufficient generation capacity creates the difficulty of leaving enough spinning reserves to cushion the effect of loss of generation in the grid

Table 5: Electricity supply, BAU

Year	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
Biomass & Waste CCS	0	0	0	3.87E-08	0.007363	0.007363	0.007363	0.007363	0.007363	0.007363
Nuclear	0	0	0	0	19.50435	31.20696	46.81044	62.41392	62.41392	78.0174
Wind	0.000111	0.00036	1.014136	1.390682	2.398041	2.516061	3.237975	4.121431	4.945717	5.770004
Solar	0.009529	0.963105	12.03857	21.66943	25.41218	25.253	31.17655	37.41186	43.64717	49.88248
Hydro	1.562774	6.122405	8.984029	12.80564	17.19775	23.69449	23.46668	22.74129	24.75353	22.28738
Biomass & Waste	0	0	0	7.550094	7.360938	8.19022	7.300199	7.23945	7.876351	9.125747
Hydrogen	0	0	0	0	0	0	0	0	0	0
Gas CCS	0	0	0	0	0.003849	0.003849	0.003849	0.003849	0.003849	0.003849

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Liguid & Gaseous Fossils	173.2963	167.4825	158.0391	172.6561	190.2106	207.7372	237.9202	270.5437	295.576	309.5511
Net Imports	0	0	0	0	23.54232	15.69488	7.84744	0	0	0
Total	**174.891**	**174.5683**	**180.0758**	**216.0719**	**285.6374**	**314.304**	**357.7707**	**404.4829**	**439.2239**	**474.6453**

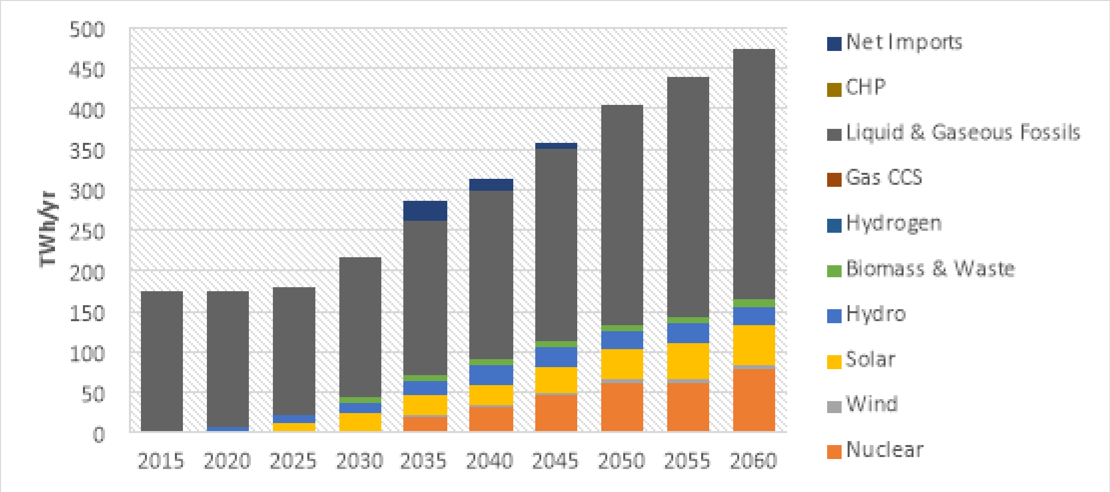

Fig. 1: Electricity Supply, BAU

Table 5 is a summary of the Electricity supply strategies based on economic activities at business as usual 7 % growth rate, demand for electricity is expected to vary from 174.8 TWh in the base year to 474.6 TWh by 2060. Electricity generation in this scenario will be of highly CO_2generation, creating continues global warming at base year, there was a generation of 69 $MtCO_2$ to the atmosphere and it will continue to rise to 130.8 $MtCO_2$ (Fig. 2).

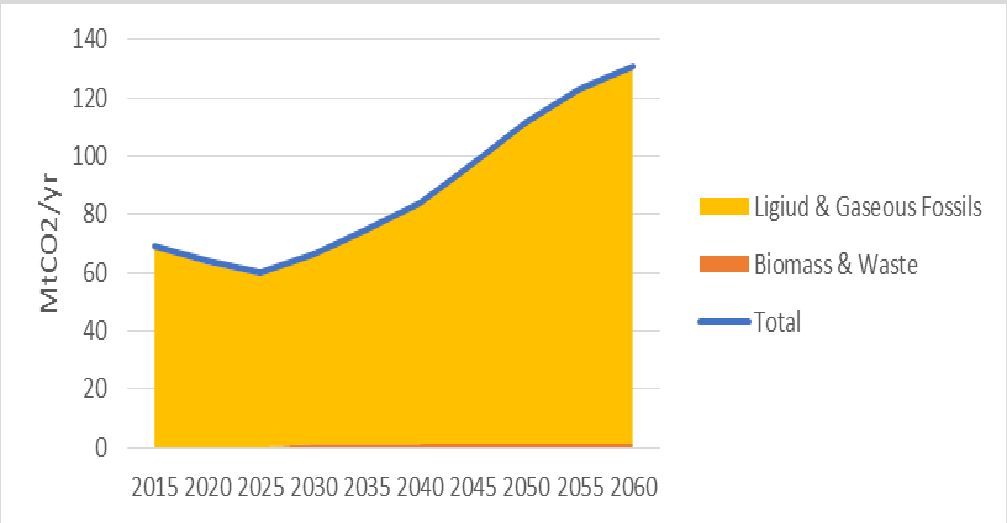

Fig. 2: Emissions from Electricity Generation ($MtCO_2$/yr) BAU

It was also observed that emission of CO_2 between 2020 and 2025 would be reduced to 63 $MtCO_2$ and 59.9 $MtCO_2$, respectively. This is based on shot-down of activities during COVID-19, buy it would continue to rise after 2025 due to high involvement of fossils for business activities (Fig. 2). It was also observed that fossil-based fuels at base year formed 99 % of the supply while hydro made up the 1 %. By 2030, it is expected that Fossil based electricity generation would be decreased to 67 %, hydro would improve to 6 % and other cleaner fuels would come up such as Solar, 10 %; wind, 1 %; biomass and wastes, 3 %, and by 2060, fossils based generation would be 65 %; hydro, 5 %; wind, 1%, solar, 11 %; biomass and wastes, 2%, this is demonstrated in Fig. 2. But because of volume of resources utilized, emission would continue to rise (Fig. 2).

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Table 6: Electricity supply (TWh/yr), Most Ambitious Level

Year	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
Biomass & Waste CCS	0	0	4.54E-08	4.39E-08	0.007363	15.18835	30.29511	45.3302	60.29924	75.35835
Nuclear	0	0	0	0	19.50435	93.62088	179.7311	266.1112	339.2905	407.978
Wind	0.000111	0.00036	1.014136	6.621789	11.9902	11.92051	16.18987	20.60715	24.72858	28.85001
Solar	0.009529	0.963105	48.29371	80.1029	103.9075	137.1768	171.471	205.7652	240.0594	274.3536
Hydro	1.562774	6.122403	11.27424	20.25504	29.23583	15.24353	17.90622	21.48742	25.06862	28.64981
Biomass & Waste	0	0	0	6.229643	16.52636	26.34029	38.00362	49.75517	61.58393	36.46341
Hydrogen	0	0	0	0	0	30.79296	61.58592	92.37888	123.1718	153.9648
Gas CCS	0	0	0	0	0.003849	38.4912	76.95501	56.72141	10.10256	0
Liguid & Gaseous Fossils	173.2963	167.4825	129.0405	131.0503	137.0718	67.24788	0	0	0	0
Net Imports	0	0	0	0	23.54232	0	0	0	0	0
Total	174.891	174.5683	189.6226	244.2596	341.7895	436.0224	592.1379	758.1567	884.3047	1005.618

On electricity supply strategies based on economic activities at MAL growth rate, the electricity demand would be faced by the influence of technology advancements, efficiency gains and climate change mitigation, which will impact the drivers of electricity demand such as electricity access, security and climate change mitigation. From Table 6, the demand would rise from 174.8 TWh in 2015 to 1005.6 TWh by 2060.

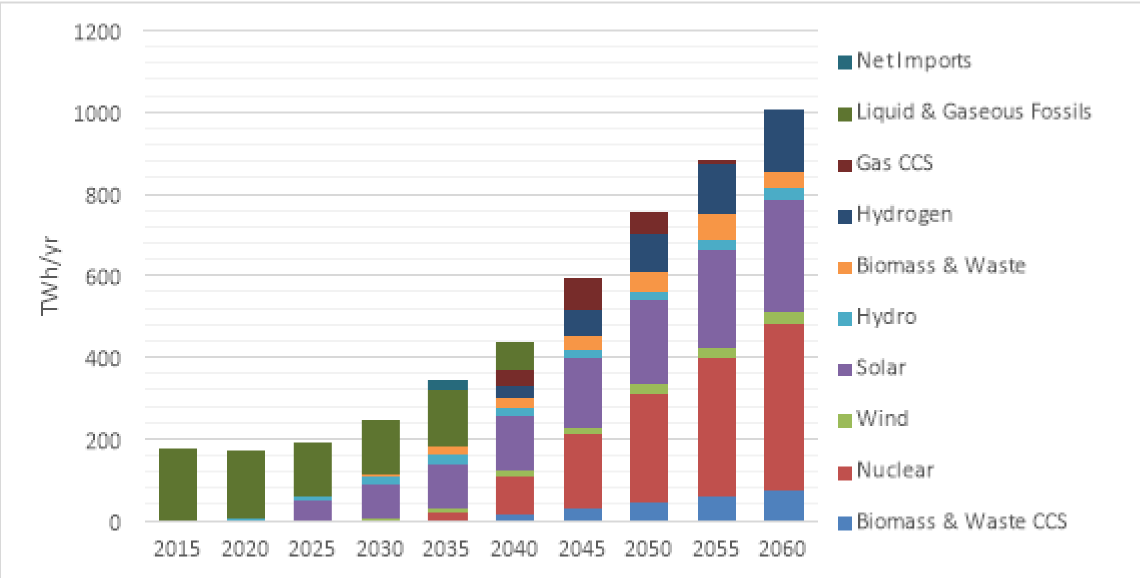

Fig. 3: Electricity supply, Most Ambitious Level

This scenario is based on providing adequate electricity access based on reduced emissions, targeting net-zero emission by 2060. From Table 6, 2015 being base year energy resources will be the same as BAU in Table 5, but from 2030, fossils would be 4educed to 54 % in electricity generation, hydro would increase to 8 % and solar, 33 %; wind, 3 %. By 2040, new technologies would be introduced in the electricity generation, so Fossils would be fueling just 15 %; hydro, 3 %; wind, 3 %; solar, 31 % and Biomass and wastes, 6 %. New technologies like nuclear would generate 21 % of electricity; biomass and wastes with carbon capture and storage (CCS) facility, 3 % and hydrogen technology, 7 %.

By 2045, fossil would stop to be used as fuel for electricity except natural gas with CCS facility at about 13 % generation while nuclear would take the lead in fueling electricity generation with about 30 %, hydro, 3 %; wind, 3 %; solar would power substantially with 29 %; biomass and wastes with CCS technology, 5 %; biomass and wastes 6 %; hydrogen technology would also be substantial with about 10 %. By 2050, natural gas with CCS would generate less electricity with just 7 %; nuclear would improve to generate about 35 %; hydro, 3; wind, 3 %; solar 27 %; biomass and wastes with CCS, 6 %; biomass and wastes, 7 %; hydrogen, 12 %.

Finally, by 2060, fossils would be completely eliminated from the list of resources for electricity generation in the country leaving nuclear to be the major fuel for electricity generation with about 41 %; hydro, 3 %; wind, 3 %; solar, 27 %; biomass with CCS, 7 %; biomass and wastes, 4 %; and hydrogen, 15 %. This scenario would cost less environmental impact by generating least emission. Fig. 4 shows that right after 2025, rate of emission from electricity generation in the country would start reducing and by 2035 and 2040, the value of emission generation rate would be negative, indicating carbon sink.

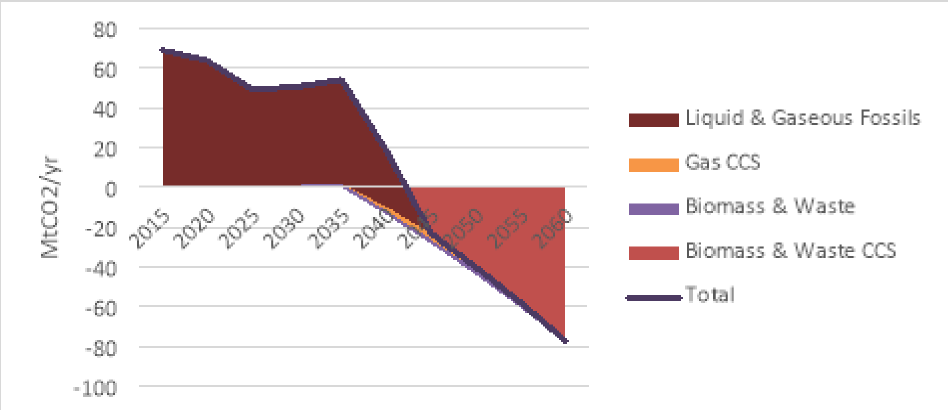

Fig. 4: Emissions from Electricity Generation (MtCO2/yr), Most Ambitious Level

In general, the need for electricity generation is driven by the extent to which the electricity system is subject to mismatches between supply and demand. In those cases, storage can serve as a buffer, which absorbs surplus electricity generated from renewable energy sources at times when supply exceeds demand, and can provide additional capacity in deficit situations, when the intermittent generation from wind and solar energy is not sufficient to cover the electricity demand. Key parameters which determine supply-demand mismatches and thus create opportunities for electricity time shift (and price arbitrage) include, on the one hand, the amount of installed intermittent renewable generation capacity (and the voltage level at which renewable electricity is fed into the grid) and their specific generation characteristics and profiles (that is the wind speed and solar irradiance profiles); and on the other hand the electricity demand profile (Ball et al., 2015).

As such, governments in sub-Saharan Africa are increasingly allowing for flexibility in their policy design. In Nigeria, the ECN has developed a set of policies that cover a wide range of renewable systems as part of their efforts to reach remote populations across the country. The Rural Electrification Agency is currently implementing a large-scale strategy including energy service company-led and utility-led models to accelerate the rate of electrification through grid extension and green mini-grids, and is targeting market clusters, manufacturing centres, schools, universities and hospitals, for electrification using solar PV and hybrid solar PV-diesel systems (IEA, 2019).

CONCLUSION

Nigeria is endowed with abundant energy resources, the significant ones include fossil, and numerous renewables such as; solar energy, biomass, wind, small and large hydropower with potential for hydrogen fuel, geothermal and ocean energies. However, the main constraints in the rapid development and diffusion of the technologies for the exploitation and utilization of these different energy resources in the country are the absence of appropriate policy, regulatory and institutional framework to balance demand with supply that would attract investors.

Technical, economic, environmental, and societal energy parameters that affect energy demand and supply and how they interact to determine the quantities of energy demand and supply are of paramount importance for policy development. Therefore, for Nigeria to unleash the enormous potential of its energy resources in its drive to match electricity supply with demand there is need for significant investment in critical areas of research and development, building of indigenous human capacities and bridging the infrastructural gap and the intensification of the on-going economic reform to create an investor friendly environment.

Long term planning also gives cues on policy interventions needed for the transition towards 2050 net zero agenda. It helps in identifying technology trends as well as highlighting the regulatory gaps where interventions could be made. This is particularly important in the case of ambitious plans for the expansion in electricity markets that could be designed to match the cost profiles of conventional electricity plants. Policy makers can rely on long-term pathways to stage regulatory reforms needed to remove barriers to investment in the energy sector and integrate the need for flexible supply and demand response.

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