NIGERIA'S ENERGY OPTIONS IN THE ERA OF CLIMATE CHANGE: AN ESSAY

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Abstract - Access to modern energy services is critical to realising a number of socioeconomic development challenges such as poverty eradication and improved health conditions. However, despite the plethora of energy resources in Nigeria, access to modern energy services in the country is still abysmal. With its per capita energy demand among the lowest in the world as well as its projected population growth rate, Nigeria's energy demand is expected to continue growing in the future. At the same time, Nigeria is faced with the severe threat of climate change which further exacerbates poverty in the country. Going forward, a transition to a low carbon development path is urgently needed. This essay discusses different options available for decarbonisation of the Nigerian economy.

Keywords: Climate change; Energy access; Energy policy; Greenhouse gas; Low carbon development; Nigeria

1. INTRODUCTION

Energy has been identified as the prime mover of socioeconomic development. Access to affordable and sustainable modern energy supplies is an essential component for economic growth and overall wellbeing of a society [1]. Access to modern energy would usher in a wider range of other benefits such as improved efficiencies in productive applications [2]. However, the current energy market direction shows that many countries in sub-Saharan Africa (SSA) are still "energy thirsty". In 2016, the total population of SSA was estimated at around 996 million and about 60% of the population live in rural areas. Only about 43% of SSA population have access to electricity while about 84% of the population do not have access to clean cooking equipment [3]. The energy systems of SSA is faced with numerous challenges alongside a suppressed demand for modern energy services. This can be attributed to the wide spread poverty in the region and the lack of adequate energy infrastructures [4]. Though the provision of modern energy access alone is not sufficient to pull SSA out of poverty, productive uses of energy for income generating activities can be an effective way of reducing poverty in the region [5].

Nigeria is the most populous country in Africa with a population of around 200 million persons. The country also has the largest economy in Africa but parades the largest number of persons living in extreme poverty globally[1]. Additionally, the country houses the second largest number of people who do not have access to electricity globally just after India [3]. Just like other SSA countries, Nigeria faces the challenges of wide spread poverty and low modern energy access levels. The immediate priority of the federal government of Nigeria (FGN) is to simultaneously provide adequate energy access, other basic amenities like good roads and healthcare centres, as well as employment opportunities for all its citizens. Modern energy access has been recognised as a policy priority of the FGN and this stems from the recognition of the links between modern energy access and other socioeconomic development goals. Without modern energy access, essential energy services like lighting and cooking can only be satisfied at the expense of economic productivity [6]. In fact, the literature also reveals that energy has greater positive linkages with the other United Nations sustainable development goals (SDGs) [7].

Over the years, it has been observed that no country has significantly reduced poverty without massive investments in its energy sector. Specifically, electricity plays a key role in improving the quality of modern life and this is further confirmed by the empirical relationship between per capita electricity consumption and the human development index (HDI) [8]. The HDI of Nigeria as of 2015 was still very low at 0.527— ranking 152 out of a global rank of 188 countries [9]. Therefore, to improve the HDI of Nigeria, its energy demand will grow at an even faster pace. However, the Nigerian energy system is dominated by biomass and fossil fuels, with natural gas accounting for over 80% of the electricity system [10], and gasoline and diesel accounting for over 95% of the transport system [11]. This further indicates that greenhouse gas (GHG) emissions from the Nigerian energy sector will continue to grow if the conventional development pathway is not changed [12]. The fear is that many developing countries like Nigeria currently have no practical plans to deviate from the "dirty" development pathway. Nigeria continues

[1] More information available here: https://qz.com/africa/1313380/nigerias-has-the-highest-rate-of-extreme-poverty-globally/

to follow the industrial development pathway of the developed countries by investing heavily in fossil fuel production which is the main cause of climate change. This conventional development model leads to unsustainable consumption of energy resources. In fact, the model exacerbates the dependence on fossil fuel as an economy grows. This unsustainable energy-economy-environment (E3) interaction especially for developing economies like Nigeria is shown in Figure 1 [13].

The current climate crisis has been attributed to the rising levels of anthropogenic GHG emissions in the atmosphere. Today, global climate change has become the most serious environmental challenge facing the world due to its adverse impacts on humankind and other biodiversity. While there remain significant uncertainties, there is now increased scientific evidence on the drivers of climate change. The fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC) confirmed that historical anthropogenic GHG emissions are responsible for the current unprecedented increase in global mean temperature which has resulted to climate change [14]. In fact, the recent IPCC report on 1.5 ^{0}C further argues that the catastrophe created by historical emissions will continue over the century [15]. The IPCC has concluded that climate change is not only speeding up but has been instigated by anthropogenic activities, especially by the combustion of fossil fuels for energy generation. This is not surprising as around 80% of the world primary energy supply is from fossil fuels [16], while CO_2 emissions from fossil fuel combustion since the pre-industrial era accounts for about 60% of climate forcing [17].

Today, climate change has become a reality and its negative impacts can be felt globally at different magnitudes by various sections of people. Common climate change phenomena include the rising of sea levels, melting of polar ice caps, increased desertification, intense rainfall, increased drought, wild forest fires among others. Nigeria is not an exception to these tragedies. The country is currently battling with the adverse effects of climate change and this can be observed in the drying up of Lake Chad and the intense flooding in different parts of the country [18]. At the same time, classification of countries based on their levels of vulnerability to climate change (Figure 2) indicates that developing economies like Nigeria are more susceptible to the adverse impacts of climate change. Literatures such as Althor et al. [19] made it clear that there are clear inequities between the historical GHG emitters and those mostly impacted by the adverse effects of climate change. It is also well-established that the poor countries like Nigeria in which over 70% of its rural dwellers depend on agriculture for their livelihoods are more vulnerable to any changes in the natural environment. Accordingly, this scenario makes it important for countries like Nigeria to be cognizant of the negative impacts of climate change as well as take bolder steps to reduce its GHG emissions. Despite contributing less than 1% to the global GHG emissions, Nigeria also need to curtail its emissions in support of the global climate action in order to provide a safe environment for future generation. Consequently, for Nigeria to provide modern energy access for its citizens while limiting the resultant GHG emissions, a transition to a low carbon development (LCD) path is urgently needed.

The concept of LCD originated from the United Nations Framework Convention on Climate Change (UNFCCC) which was adopted in Rio in 1992[2]. Over the years, there have been different schools of thought on the term "low carbon development". Among these definitions include Wlokas et al. [21] who defined LCD as the process of human and socioeconomic advancement which reduces GHG output. They further suggested that such a process will require the full cooperation of capable individuals in the society. Krewitt et al. [22] considers LCD as the replacement of fossil fuels with low carbon energy sources which is based upon the belief of greater economic prosperity and overall welfare of the residents. Mulugetta & Urban [23] has opined that the common characteristics of LCD in different countries is pursuing economic growth while utilizing less carbon. They further argued that the version of LCD in which a country follows need to stem from its own local circumstances. In a different study, LCD in Asia and Europe is examined as minimising CO_2 emissions as much as possible while simultaneously pursuing economic growth [24]. In the "China's Low-carbon Development Path to 2050" [25], the authors suggested that the purpose of LCD is the development of socioeconomic system which brings about low carbon emissions.

From a different view, the "low carbon Singapore community" suggested that the three key features of their future low carbon Singapore encompasses (i) the use of cleaner energy sources and energy efficiency improvement (ii) using technological and policy innovations to minimise its carbon footprint and (iii) becoming a global champion of LCD while supporting developing countries to adapt to climate change. However, for developing countries like Guyana, LCD refers to massive investments in low carbon infrastructures, improvement in human capital and promotion of sustainable forest development [26]. Despite the differences among the different meanings, there is a common consensus on low carbon development which is centred on limiting GHG emissions. The focus of this essay is on the energy sector, and low carbon development of the sector in Nigeria. With the aforementioned definitions in mind, low carbon energy development (LCED) can be defined as a development pathway which revolves around the use of low carbon energy resources and technologies, which in turn limits GHG emissions from the entire chain of energy production and utilization.

Pursuing a low carbon development path is indeed a defining challenge as it will involve structural transformation in all sectors of the Nigerian economy [12]. Moving forward, there are set of policy options the government could adopt to enhance access to modern energy in the country, improve economic growth, while maintaining environmental sustainability. This essay discusses the options available for Nigeria to decarbonise

[2] More details available here: https://sustainabledevelopment.un.org/index.php?menu=1448

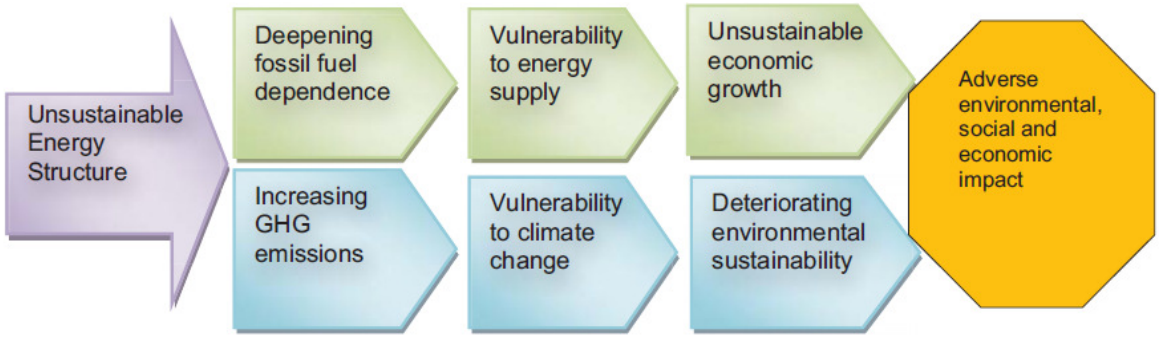

Fig. 1. Unsustainable energy-economy–environment interaction of fossil fuels

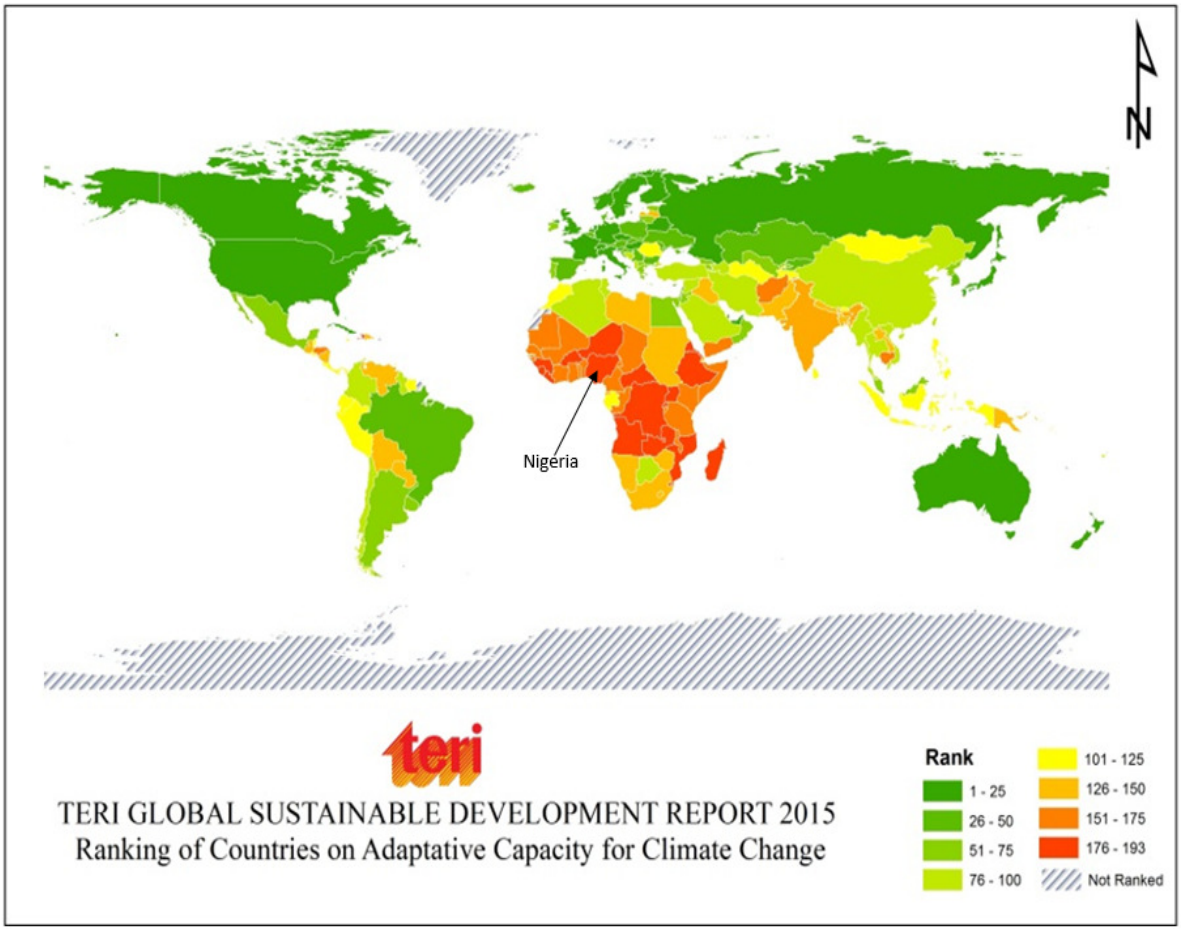

Fig. 2. Classification of countries based on adaptive capacity for climate change
Source: [20]

its energy system. While the essay is written with a national lens, the low energy carbon options offered here will be of wider importance to the international community especially for countries in the global south.

2. LOW CARBON ENERGY OPTIONS FOR NIGERIA

Across the different energy producing and consuming sectors in Nigeria, there are different strategies that could be adopted to limit GHG emissions as outlined below:

2.1. Power sector

Increased deployment of renewable energy technologies

Despite the current efforts by the Rural Electrification Agency (REA) to deploy off-grid solar PV in different parts of the country, there is still significant scope to improve renewable energy technology diffusion in the country. Currently, renewable energy accounts for less than 1% of the Nigerian electricity mix. In order to achieve the Nigerian Vision 30:30:30—to achieve 30% share of renewable energy in the available electricity mix by 2030 [27], it will be imperative for the FGN to tap

into the full menu of renewable energies in the country. Nigeria is blessed abundantly with many forms of renewables including solar, wind, biomass, and small hydro. However, till date, there is still no real commercial large-scale renewable energy power plant connected to the grid [27]. Therefore, it will be pertinent for the FGN to keep exploiting the potential of these resources.

With respect to solar, Nigeria has an estimated solar potential in the ranges between 4.0 kWh/m^2/day to around 6.5 kWh/m^2/day based on 5 hours average sunshine per day [28]. Nigeria can harvest solar power via solar PV and concentrated solar power (CSP) technologies. Most of the solar PV projects found in the country are off-grid systems in the form of residential rooftop solar PV, street lights, solar lanterns, and solar powered bore-holes [29]. In 2010, the total estimated capacity of standalone solar PV in the country was around 0.015 GW [28]. The northern parts of Nigeria have been identified to have good potentials for CSP implementation. However, till date, there is no CSP plant in the country. In fact, it has been argued that using 1% of Nigeria landmass has a potential to generate 500 GW electricity capacity based on CSP [28]. Talking about wind, at 10 m hub height, Nigeria has wind speeds in the range of 1 to 5.1 m/s and can be classified as falling between the poor to moderate wind regime [30]. In view of this limitation, it is recommended that micro turbines are used to exploit the wind potentials in the parts of the country that have good wind regime. In terms of technology diffusion, there are few wind plants in the country which are mainly used as pilot projects and water pumping in rural communities.

Biomass power generation is still at an infant stage in the country despite the huge potential of biomass resources in the country. Potential for agricultural residues in the country is estimated at around 145.62 Mt/year [31]. However, to date, there is no biomass power plant in operation in the country. Notwithstanding, it is worthwhile to note that a 0.005 GW biomass power plant is under construction in the country [28]. Small hydro still remains untapped in the country despite its potential to improve rural electricity access without increasing GHG emissions. Currently, only about 0.064 GW has been exploited out of the 3.5 GW potential of small hydro power in the country. The foregoing indicates that Nigeria still have a large scope to deploy renewable energy in its electricity mix. This will go a long way to decarbonise the Nigerian electricity sector and keep the country in the path of sustainability.

Improving the efficiency of gas thermal power plants

Government need to renovate and modernize the existing combined cycle gas power plants in the country, and make efforts to retire the existing old and inefficient single cycle gas power plants. Though the initial capital cost of combined cycle gas power plant is higher compared to single cycle, its lifecycle cost is cheaper due to the cost-effective measures in fuel consumption. Therefore, there should be determined effort to retire all old single cycle gas power plants as this will lead to better utilization of resources. A policy directive should be issued to power generation companies to implement the deployment of only combined gas power plants in the coming years. Improving the efficiencies of gas-based thermal generation to the maximum extent possible should remain a key goal in the immediate short term and large-scale deployment of combined gas power plants should be pursued. This may however need efforts both on the research and development front as well as higher investment.

Deployment of Nuclear power

This is one of the cheapest options for low carbon electricity generation globally but it is currently not part of the Nigerian energy mix. Going beyond costs, it can also serve as the base load to support a grid supplied by intermittent solar and wind power. Uranium for nuclear power generation can be found in 7 states in Nigeria which encompasses Adamawa, Taraba, Bauchi, Kano, Cross River, Kogi, and Plateau states. Over the years, there have been efforts to estimate the uranium reserve in Nigeria. After several studies, the uranium reserve in Nigeria was estimated at around 200 TU (grades ranging from 0.63-0-9%) at a vertical depth of 130-200 m [32]. The key issues facing nuclear development in Nigeria include public acceptance, lack of qualified professionals, inadequate administrative and technological infrastructures, as well as inadequate funding for exploration activities [33].

Improving the Grid system

Strengthening of the country's transmission capacity for optimum utilization of available power is necessary. It is essential to encourage the use of modern project management tools followed by timely monitoring and corrective actions to avoid delays and the consequential losses. Increase in the transmission system at higher voltage levels and sub-station capacities to support transmission network to carry bulk power over longer distances and at the same time optimize right of way, minimize losses and improve grid reliability is needed. Planning for integration of renewables into the grid is a key requirement for the success of renewable power. Investments must be made to support infrastructures and renewable energy evacuation should be accorded high priority. Grid connectivity to renewable energy generation should be provided by the Transmission Company of Nigeria (TCN). Transmission system plans prepared by TCN should cover evacuation and transmission infrastructure requirements for renewables. Additionally, efforts should be made to integrate smart grids and energy storage systems into the Nigerian electricity infrastructures as earlier opined by Dioha & Kumar [29].

2.2. Oil & Gas sector

The main source of GHG emissions in this sector is the flaring of gas [34]. The Nigerian oil and gas sector is a key contributor to the country's national GHG inventory [35]. In order to reduce this environmental menace, there will be a need to make productive use of the flared gas. In this regard, the FGN need to start establishing gas processing facilities that can be used to collect this flared gas for export/transport as liquefied

petroleum gas (LPG) for cooking. Beyond the climate benefits, this action will also have co-benefits as the LPG can be used to improve modern energy access especially for the rural households who mainly depend on inefficient biomass cookstoves for cooking and heating purposes. Another important strategy for this sector is to replace the old on-site power plants with new and efficient ones and to make efforts to reduce fugitive emissions during oil exploration [36].

2.3. Industry sector

The Nigerian industry sector is still under-developed when compared with the industry sector of countries like USA, Germany, India, China, Japan etc. However, the Nigerian cement industry is relatively developed and Nigeria is one of the leading countries for cement production in Africa. The key GHG emissions mitigation options for the cement industry sector are as follows [37].

- Widening and deepening the use of alternative fuels and alternative raw materials (such as waste co-processing in cement kilns).
- Enhanced recycling of materials such as use of fly ash and slag in cement production etc.
- Focusing on energy efficiency improvements by phasing out wet cement production processes and inefficient long-dry kilns.
- Widening and promoting the reduction of clinker to cement ratio.
- Deployment of cogeneration/ waste heat recovery system.
- Moving to halocarbons with low global warming potentials for refrigerant/coolant in the sector.
- Supporting the development and deployment of new and emerging low carbon technologies for cement production such as kilns fitted with carbon capture and storage technologies.

2.4. Transport sector

Improved efficiency of vehicles

Though efforts such as the fuel efficiency norms and fuel efficiency labelling efforts are being introduced in Nigeria, there should be a continuous increase in the energy efficiencies of both passenger and freight vehicles in the country. A higher penetration of the newer and more efficient vehicles in the vehicle stock would lead to reduced energy intensities of the Nigerian transport sector. The FGN need to come up with stricter fuel efficiency standards for all vehicles in all modes of transport in the near future, which again would be an important element for the sector. To reduce the average fuel consumption of new cars introduced in the Nigerian market, medium- and long-term fuel consumption standards for new cars have to be announced. The Fuel Consumption Standards should provide a mandate to manufacturers and vehicle importers to continuously reduce the average fuel consumption of cars sold by them in the next 20 years. Labelling systems for cars sold in the Nigerian market could help consumers to make informed choices and promote efficient vehicles. This coupled with other incentive and disincentive mechanisms can help push efforts in improving transport sector emissions intensity.

Push towards public mode of transport

In Nigeria, public transport still remains the main mode of transport for most of the population. However, with increasing economic growth, if increase in public transport capacity and efficiency fails to keep up with growing demands, a large volume of passenger transport would increasingly need to rely on private modes of transport. In Nigeria, where a large volume of the transport infrastructure is being built or is going to be built in the near future to provide access both in urban and rural regions, it is therefore important to ensure that the modes identified for providing access are relatively more energy-efficient than other modes available. This will involve the development of urban infrastructures. There will be a need to create urban reforms to decentralise funds and functions, thus ensuring that positive measures to improve transport infrastructure is in the hands of urban local bodies. This will result in efficient transportation systems in the cities and towns.

Efforts to increase the share of rail-based movement

The share of railway transport is gradually growing in Nigeria. A typical example is the railway transport between Kaduna and Abuja which has been very active since commissioning. However, there will be a need to focus efforts and make aggressive actions in this regard so that the share of railways will continue to increase in the future. Efforts to promote the share of railways would necessitate large infrastructure and upfront investment costs, but at the same time would have important implications on the long run, on both energy and emissions. The development of Dedicated Freight Corridors (DFCs) along with High Speed Railways (HSRs) would lead to a major shift of both passenger and freight movement from road to rail. Being the most energy-efficient mode of transportation, its preference would increase once it is technologically and operationally efficient too, providing better services as compared to road.

Fuel switching towards cleaner fuels

Cleaner fuels can play an important role in reducing the amount of GHG and particulate matter coming from the Nigerian transport sector. Given the abundance of natural gas in the country (182 trillion cubic feet [38]), and its relatively lower price and carbon content compared to diesel and gasoline, a shift to compressed natural gas (CNG) vehicles becomes an option for the Nigerian transport. Additionally, owing to the abundance biomass feedstock in the country (41 Mt/year of cassava [28]), bioethanol and biodiesel also become options for the Nigerian transport. However, the major setback to the implementation of alternative fuels in Nigeria is the lack of availability of the ready fuels which thereby reduces the choices available to Nigerian consumers. For example, in the case of motorised land transport, where CNG and biodiesel can be a fuel choice, however, due to the lack of large-scale CNG and biofuels

stations, the fuel choices available to Nigerian motorists reduces.

Although there has been a successful rollout of CNG vehicles in Benin City, there is still limited access to vehicles operating on highways due to lack of adequate CNG infrastructure [39]. Furthermore, there is a need to promote this program to other cities in the country. In terms of biofuels, despite the Nigerian biofuel policy of 2007 [40], currently, only little progress has been made regarding the biofuel mandate. Some of the progress made so far involves the commencement of the construction of 20 bioethanol production plants, establishment of biofuel handling facilities at 2 depots (Atlas Cove and Mosimi), as well as the adoption of biofuel/conventional fuel mix retail outlets [41]. Consequently, improving availability of CNG and biofuels and the associated infrastructures could help enhance the use of this alternative fuel in the Nigerian transport sector.

Considering the adoption of electric vehicles

To completely decarbonise the Nigerian transport, there will be a need to electrify the sector. While access to electricity for basic services such as lighting presently remains a challenge in the country [42], Nigeria should consider electrifying its transport sector in the future. Though CNG will help to reduce emissions from the sector, it is also worthwhile to note that CNG is a fossil fuel which releases GHG emissions during combustion and its finite nature also raises the issue of energy security in the country. With respect to biofuels, sustainability of biomass feedstock remains an issue to be addressed. Therefore, going forward, electrification of the transport sector may well become a more sustainable solution for the Nigerian transport system. The FGN has also mentioned policies regarding the electrification of transport in the National Energy Masterplan [43]. However, this scheme needs to focus on building charging infrastructures and providing incentives for the manufacturing as well as sale of electric vehicles in Nigeria. Other initiatives may also be explored in this regard to step up electric vehicles in the country.

2.5. Residential and Commercial sector

Efficiency improvement in lighting

The FGN through the Energy Commission of Nigeria (ECN) need to launch a nationwide LED based home and street lighting programme. The programme should cover all households who already have access or will have access to electricity in the future. Currently, many rural households in Nigeria still depend on incandescent bulbs for lighting. Therefore, plans should be made to address the issues of standardisation in lighting technologies in the country. Along with this, there will be a need to raise awareness, and bring down the costs of LED through subsidies as this can further help to ramp up the switch to LEDs even faster.

Efficiency improvement in appliances

Standards and Labelling Programme launched by the ECN need to be sustained for all appliances in Nigeria in order to enable consumers to make informed decisions by providing information about the energy consumption of an appliance. Efforts on this front need to be continued and stepped up.

Penetration of energy efficient buildings

The FGN need to establish a robust scheme for energy efficiency in the buildings sector. It needs to develop Energy Performance Index (EPI) in kWh/sqm/year for rating both residential and commercial buildings in the country. There will also be a need to enhance the spread of star rating programme for residential and commercial buildings to other types of buildings such as educational and religious.

2.6. Agriculture Sector

Promotion of energy-efficient pump sets

Due to the poor electricity access levels and the erratic power supply in the rural areas, many Nigerian farmers depend on gasoline and diesel generator sets for irrigation water pumping. Moreover, many of the generator sets are old and inefficient and thus, consumes significant amount of energy. The emissions coming from the generator sets also pollutes the ambient air and contributes to climate change. Consequently, in this sector, access to grid electricity need to be provided for Nigerian farmers to discourage the use of diesel and gasoline generator sets for irrigation water pumping. Additionally, there is a need for massive dissemination of energy-efficient pumps to rural farmers via agricultural extension workers. In this regard, regulatory mechanism needs to be established to mandate the use of energy-efficient star rated pump sets. Efforts should also be scaled-up to deploy solar water pumps for off-grid communities as this will also reduce the carbon footprint of Nigerian electricity grid. Along with this, it will be necessary to improve the technical capacity of all stakeholders involved in the entire chain of providing irrigation water as well as placing a rational price on electricity and water.

3. CONCLUSIONS

In conclusion, there will be some social, economic and political challenges that Nigeria will face in its journey to a low carbon economy. From the social dimension, a vast majority of Nigerians are ignorant of the adverse effects of climate change and the need to transform the energy system to a more sustainable mix. Additionally, even some of the climate change literates in the country have the notion that efforts to limit GHG emissions could become a barrier to rapid economic growth of the country. From the economic front, significant investments will be needed to transform the energy infrastructures in the country and this will require effective mobilisation of funds from the private sector. However, many private investors are reluctant to invest in renewable energy technologies owing to the political and economic uncertainties of the country. In the light of political challenges, corruption and lobbying of the multi-national oil companies still persists and this impedes the government ability to introduce stringent

climate policies. Additionally, as a middle-income developing country, the Nigerian government is highly unlikely to prioritise climate action as it is already pre-occupied with other development challenges such as enhancing modern energy access and upgrading of health facilities in the country. Therefore, for Nigeria to move towards a low carbon future, it will be necessary for the government to integrate climate change mitigation priorities into all aspects of domestic and international policymaking. There will be a need to promote energy efficiency, and a serious need to tap into the full menu of sustainable energies in the country. It will be pertinent for the government to mobilise financial resources, promote research & development of low carbon technologies as well as build appropriate institutional frameworks to support low carbon transitions. Furthermore, the government need to leverage on public-private partnerships and increase public awareness to support the transitions to a low carbon economy.

REFERENCES

[1] Dioha MO. Energy System Models for Sub-Saharan African Countries-A Systematic Review. J Sustain Energy 2017;8:159–68.

[2] Brew-Hammond A. Energy access in Africa: Challenges ahead. Energy Policy 2010;38:2291–301. doi:10.1016/J.ENPOL.2009.12.016.

[3] IEA. World Energy Outlook 2017. Special Report: Energy Access Outlook. Paris: International Energy Agency (IEA) and the Organisation of Economic Co-Operation and Development (OECD); 2017.

[4] George A, Boxiong S, Arowo M, Ndolo P, Chepsaigutt-Chebet, Shimmon J. Review of solar energy development in Kenya: Opportunities and challenges. Renew Energy Focus 2019;29:123–40. doi:10.1016/J.REF.2019.03.007.

[5] Dioha MO, Emodi NV. Investigating the Impacts of Energy Access Scenarios in the Nigerian Household Sector by 2030. Resources 2019;8:127. doi:10.3390/resources8030127.

[6] Kumar A. Growth, Sustainable Development and Climate Change: Friends or Foes? Utrecht University; 2011.

[7] McCollum DL, Echeverri LG, Busch S, Pachauri S, Parkinson S, Rogelj J, et al. Connecting the sustainable development goals by their energy inter-linkages. Environ Res Lett 2018;13:033006. doi:10.1088/1748-9326/aaafe3.

[8] UNDP. Energy for Development: HUMAN DEVELOPMENT REPORT 2007 2007:73. http://hdr.undp.org/sites/default/files/khdr2007_en1.pdf (accessed August 6, 2019).

[9] UNDP. Human Development for Everyone: Briefing note for countries on the 2016 Human Development Report - Nigeria. Hum Dev Rep 2016 2016. http://hdr.undp.org/sites/all/themes/hdr_theme/country-notes/NGA.pdf (accessed May 4, 2018).

[10] NPBR. Nigeria Power Baseline Report 2015. http://www.nesistats.org/uploads/3/6/3/6/3636925/20150916_nigeria_energy_power_report_final.pdf (accessed October 12, 2017).

[11] Gujba H, Mulugetta Y, Azapagic A. Passenger transport in Nigeria: Environmental and economic analysis with policy recommendations. Energy Policy 2013;55:353–61. doi:10.1016/J.ENPOL.2012.12.017.

[12] Dioha MO, Emodi N V., Dioha EC. Pathways for low carbon Nigeria in 2050 by using NECAL2050. Renew Energy Focus 2019;29:63–77. doi:10.1016/j.ref.2019.02.004.

[13] ESCAP. Low-carbon Development Path for Asia and the Pacific: Challenges and Opportunities to the Energy Sector. UN Environment and Development Division (ESCAP), Bangkok, Thailand; 2010.

[14] IPCC. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.; 2013.

[15] IPCC. Global warming of 1.5°C: An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change,. 2018.

[16] Abas N, Kalair A, Khan N. Review of fossil fuels and future energy technologies. Futures 2015;69:31–49. doi:10.1016/J.FUTURES.2015.03.003.

[17] Dioha MO. Modelling the Impact of Nigeria Household Energy Policies on Energy Consumption and CO2 Emissions. Eng J 2018;22:1–19. doi:10.4186/ej.2018.22.6.1.

[18] FGN. Nigeria Intended Nationally Determined Contribution 2015:1–23. http://www4.unfccc.int/ndcregistry/PublishedDocuments/Nigeria First/Approved Nigeria%27s INDC_271115.pdf (accessed June 6, 2017).

[19] Althor G, Watson JEM, Fuller RA. Global mismatch between greenhouse gas emissions and the burden of climate change. Sci Rep 2016;6:20281. doi:10.1038/srep20281.

[20] TERI. Global Sustainable Development Report. New Delhi: 2015.

[21] Wlokas H, Rennkamp B, Torres M, Winkler H, Boyd A, Tyler E, et al. Low Carbon Development and Poverty Exploring poverty alleviating mitigation action in developing countries. Energy Research Centre, University of Cape Town; 2012.

[22] Krewitt W, Teske S, Simon S, Pregger T, Graus W, Blomen E, et al. Energy [R]evolution 2008—a sustainable world energy perspective. Energy Policy 2009;37:5764–75. doi:10.1016/J.ENPOL.2009.08.042.

[23] Mulugetta Y, Urban F. Deliberating on low carbon development. Energy Policy 2010;38:7546–9. doi:10.1016/J.ENPOL.2010.05.049.

[24] Islam S. Low-carbon development: a shared challenge for Asia and Europe | New Europe 2010. https://www.neweurope.eu/article/low-carbon-development-shared-challenge-asia-and-europe/ (accessed September 7, 2019).

[25] Energy Institute Team of P. R. China. The Low-Carbon Development Path to 2050 of P. R. China: scenarios analysis of energy demand and carbon emissions. National Development and Reform Commission, Beijing: Science Press; 2009.

[26] Yuan H, Zhou P, Zhou D. What is Low-Carbon Development? A Conceptual Analysis. Energy Procedia 2011;5:1706–12. doi:10.1016/J.EGYPRO.2011.03.290.

[27] FGN. Sustainable Energy for All Action Agenda (SE4ALL-AA) 2016:103. https://www.seforall.org/sites/default/files/NIGERIA_SE4ALL_ACTION_AGENDA_FINAL.pdf (accessed May 6, 2018).

[28] ECN. Nigeria Energy Calculator 2050 (NECAL 2050) report 2015:105. http://www.energy.gov.ng/index.php?option=com_docman&task=doc_view&gid=123&Itemid=49 (accessed October 14, 2017).

[29] Dioha MO, Kumar A. Rooftop solar PV for urban residential buildings of Nigeria: A preliminary attempt towards potential estimation. AIMS Energy 2018;6:710–

34. doi:10.3934/energy.2018.5.710.
[30] Dioha MO, Dioha JI, Olugboji OA. An assessment of Nigeria wind energy potential based on technical and financial analyses. J Sustain Energy 2016;7:53–7.
[31] Simonyan KJ, Fasina O. Biomass resources and bioenergy potentials in Nigeria. African J Agric Res 2013;8:4975–89.
[32] Karniliyus J, Egieya J. Uranium development in Nigeria. Int. Symp. Uranium Raw Mater. Nucl. Fuel. Cycle Explor. Mining, Prod. Supply Demand, Econ. andEnvironmental Issues - IAEA CN-216, 2014.
[33] Bute SI. Uranium ore deposits in northeastern Nigeria: geology and prospect. Cont J Earth Sci 2013;8:21–8.
[34] Ibitoye FI. Ending Natural Gas Flaring in Nigeria's Oil Fields. J Sustain Dev 2014;7:p13. doi:10.5539/jsd.v7n3p13.
[35] FGN. Nigeria's Second National Communication under the United Nations Framework Convention on Climate Change 2014. http://unfccc.int/resource/docs/natc/nganc2.pdf (accessed November 17, 2017).
[36] Cervigni R, Rogers JA, Dvorak I. Assessing low-carbon development in Nigeria: An analysis of four Sectors. The World Bank; 2013. doi:10.1596/978-0-8213-9973-6.
[37] IEA. Technology Roadmap: Low-Carbon Transition in the Cement Industry. Paris, France: International Energy Agency (IEA); 2018.
[38] ECN. Energy Implications of Vision 20: 2020 And Beyond 2014. www.energy.gov.ng/index.php?option=com_docman&task=doc_download&gid=112&Itemid=49 (accessed October 15, 2017).
[39] Ogunlowo OO, Bristow AL, Sohail M. Developing compressed natural gas as an automotive fuel in Nigeria: Lessons from international markets. Energy Policy 2015;76:7–17. doi:10.1016/j.enpol.2014.10.025.
[40] NNPC. Draft Nigerian Bio-fuel Policy and Incentives. Nigerian National Petroleum Corporation (NNPC), Abuja, Nigeria. 2007.
[41] Ohimain EI. Can the Nigerian biofuel policy and incentives (2007) transform Nigeria into a biofuel economy? Energy Policy 2013;54:352–9. doi:10.1016/J.ENPOL.2012.11.051.
[42] Dioha MO, Kumar A. Exploring sustainable energy transitions in sub-Saharan Africa residential sector: The case of Nigeria. Renew Sustain Energy Rev 2020;117:109510. doi:10.1016/J.RSER.2019.109510.
[43] ECN. National Energy Masterplan (Draft Revised Edition). ECN: Energy Commission of Nigeria, Abuja; 2014.