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Modelling Pathways to Energy Transition in Nigeria Using OSeMOSYS (Open-Source Energy Modelling System)

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ABSTRACT: *During the COP26, world leaders reaffirmed their commitments to reduce CO2 emissions and discussed financial support for developing countries. Three important topics were highlighted: international carbon markets, common time frames, and transparency (WRI, 2021). This pledge is crucial for countries such as NIGERIA, who contributes less than 1% to global carbon emissions, yet it is one of the most affected by climate change (Germanwatch, 2021). NIGERIA being the world's sixth-most populous nation (218.5 on 2022), has ambitious energy plans.*

KEYWORDS: Modelling Pathways, Energy Transition, Nigeria, OSeMOSYS

INTRODUCTION

During the COP26, world leaders reaffirmed their commitments to reduce CO_2 emissions and discussed financial support for developing countries. Three important topics were highlighted: international carbon markets, common time frames, and transparency (WRI, 2021). This pledge is crucial for countries such as NIGERIA, who contributes less than 1% to global carbon emissions, yet it is one of the most affected by climate change (Germanwatch, 2021). NIGERIA being the world's sixth-most populous nation (218.5 on 2022), has ambitious energy plans.

The current world energy consumption is estimated to be 418 EJ and is mainly based on oil, natural gas, coal, and electricity supplies (IEA). In August 2020, the government of Nigeria approved the *Alternative and Renewable Energy Policy*, aiming to boost the share of electricity generated from renewables from up to 60% by 2030. However, this action plan requires further examination and tailoring to meet the country's needs. As population grows at 2.41% rate so does its energy demand by 15% yearly. This translates as a large gap between energy demand and supply. More than 40 million people don't have access to electricity and it is estimated that half of the population lacks access to clean cooking facilities. According to the International Energy Agency (IEA), demand is expected to be three times higher by 2050 (Cozzi *et al.*, 2022). To address the demand- supply gap, most countries aim to transition towards renewable energy. Despite having sizeable renewable resources, Nigeria's current energy system relies heavily on Oil and Gas (87%). The main sectors impacting the energy demand are industry, transport, and domestic. The country's overloaded infrastructure and the deterioration of old power plants together with rising awareness on environmental impacts has rushed Government of Nigeria to reconsider its energy mix and include new, clean, and renewable resources such as wind and solar. These represent an opportunity to both reduce dependence on fossil fuels and limit CO_2 emissions, but also to deal with current socio-economic pressures. Nigeria aims to reduce its imports of refined Oil, diversify its fuel sources, improve its supply, and increase renewable energy in power generation.

Nigeria is in a unique position to secure a sustainable energy transition. Literature available mostly focuses on single technologies and consumption trends, bringing valuable information to assess the potential implementation of different resources and their contribution on energy sectors. Nevertheless, there is limited literature examining the potential of high shares of renewable technologies in Nigeria's energy transition, especially as the most cost-effective and efficient option. In response to this, this study analyses Nigeria's opportunities for building energy security throughout an accelerated energy transition.

BACKGROUND & LITERATURE REVIEW

Energy Panorama in Nigeria

Economic burdens are heavily met with a growing population and electricity demand. In response, Government of Nigeria has increased Refined Fuel imports. Existing plans favour low-cost fuels despite the country's large potential for renewable energy sources and increasingly cheaper renewable technologies. Installed generation capacity has increased from 19,429 MW in 2008 to 41,240 MW in 2022 addressing immediate shortfalls, yet it is not sufficient to overcome future demand and an energy consumption growing at 7.7% annual. Similarly, current policies fail to adequately assess the degraded energy infrastructure and transmission-distribution efficiency. Instead, large investment is granted to foreign infrastructure projects like some of IPP (Independent Power Projects in various states of Nigeria). Installed capacity has increased at the expense of a chronic pattern of economic stagnation and environmental degradation mostly felt by vulnerable communities . Government of Nigeria must re-examine and tailor its action plans according to the population's needs to adequately address

Energy crises.

In 2012, the Department of Climate Change of Nigeria approved the *National Climate Change Policy* (NCCP). This is the first national policy recognizing the risk climate change poses to energy security and economic stability. Aiming to raise awareness and financial support, it steers towards national climate resilience and sustainable economic growth by recommending a series of adaptation actions. As a response, the Alternative Department of Climate Change presented the *Alternative and Renewable Energy Policy,* emphasises on energy conservation and greenhouse gas (GHG) emissions reduction. In this document, Government of Nigeria commits to a series of actions relevant to the energy and industrial sectors. For instance, it promotes energy efficiency technologies, enforces energy conservation legislation and audit standards, and encourages the adoption of low-emission technologies. The *Alternative and Renewable Energy Policy* (ARE) aims to increase the share of new variable renewable energies (VRE) up to thirty percent of the energy mix by 2030. This include solar, wind, biomass, geothermal, and storage technologies. It also aims to boost hydro energy to thirty percent by 2030, meaning that renewable technologies would represent sixty percent of the total energy mix (ARE, 2019). Behind this policy are Government's motivations to lower the average basket cost of power generation by displacing from expensive fossil imports to cheaper and cleaner resources. The policy promotes indigenization of energy resources and the development of local manufacturing. Some of the actions include federal and State sale arrangements and business projects. It introduces new tariffs through an open bidding process by proposing the lowest evaluated tariff as main determinant. ARE represents a turning point in energy policy in Nigeria. Notwithstanding, it faces technical challenges, the main one being the inherently intermittent nature of renewable energy. In order to address this, ARE projects must also introduce supportive technology to ensure grid stability. Similarly, this power-specific policy fails to adequately include other energy intensive sectors such as transport. Once again, the projects are dedicated mostly to increase installed capacity and sale of power, rather than assessing energy efficiency.

Climate Change actions are driving towards de-carbonization. The *Indicative Generation Capacity Expansion Plan* (IGCEP) aims to make the energy mix more sustainable and reliant on local production by 2040, rather than continuing national dependency on energy imports. Following the COP26, Nigeria has revisited and adjusted its NDC to targets to shift hydro-generation to 30%, VRE to 16%, and Solar power to 25%. These ambitious numbers should balance the reduction of imported Refined Fuel to 5% and 6% respectively. In comparison with previous governmental policies, it acknowledges the impact of distribution (18.3%) and transmission (2.4%) losses in optimal energy mix and national debt. Consequently, it aims to limit these through collaboration between key governmental and energy stakeholders. As previously mentioned, Nigeria is among the 189 countries to have signed the Paris Agreement and is committed to substantially reduce its greenhouse (GHG) emissions. The UN General Assembly is working on plans for eliminating poverty, improving equity, peace, and the protection of the human and natural environment (UNFCCC, 2015). In accordance with these efforts, accelerating deployment of clean renewable energy technologies on a large scale and climate action could translate a sustained economic growth for Nigeria. Furthermore, contributing to the alleviation of social grievances such as poverty and inequalities.

Energy Security

The abundance of energy security definitions reflects the evolving concept of such. In order to determine a definition appropriate to the Nigerian scenario, this paper briefly revisits some important literature on energy security.Initially under an economic approach, Manson Willrich marks the difference between energy supply and demand. Similarly, under an international scheme, he points that there are producer and consumer nations. The first one aiming to secure energy demand, and the later energy supply. In this sense access to primary and non-primary energy sources is fundamental. Access to primary energy, such as crude oil and hydro, can be renewable or non-renewable giving a nation more flexibility to switch resources in its generation mix. In contrast, non-primary energy such as heat and biofuels limits the autonomy of a government on its national energy mix and is likely to rely on producer nation Thus, energy security here means constant access to primary resources (Willrich, 1978). In this sense, Vlado Vivoda argues that the diversification of generation mix, whether is comes from primary resources or not, can reduce both the risk of supply interruptions and reliance on imports.Pasqualetti and Sovacool argue energy security depends on the "provision of available, affordable, reliable, efficient, environmentally benign, properly governed and socially acceptable energy services" (Pasqualetti and Sovacool, 2012). In response to this, Ang and Choong examine the integral aspect of a global energy system and present different dimensions of energy security.

Besides the dimensions of energy availability, infrastructure, and cost, they also discuss societal effects, governance, efficiency, and the environment. The latest recognizes the close relationship between environmental burdens and energy actions (Ang and Choong, 2015). The IEA defines energy security as "reliable, affordable access to all fuels and energy sources." It also determines short- and long-term aspects of energy security. The first one is the ability to adapt to unexpected changes in the supply-demand balance. While the second aspect is the coordination of national plans with socioeconomic and environmental needs. In other words, energy security means uninterrupted availability of affordable energy sources (IEA).

In response to governmental policies, most studies on energy security in Nigeria focus on policy reviews, energy demand-supply gap, and diversification of installed capacity. This qualitative study is in line with Vivoda's definition of energy security. Other studies follow a similar framework but intend to provide a more quantitative analysis (Mirjat et al., 2017). For instance, Mark (2016) examines the potential reduction of energy imports by 5%, 10%, and 15% up to 2050 and provides insights on the large potential of renewable energy. However, it doesn't consider the economic impact that reducing refined petroleum imports could have during transition, especially on consumers. Both qualitative and quantitative studies provide great inside of Nigeria's main challenges to achieve energy transition and consequently energy security. Nevertheless, these remain limited and fail to capture the burden energy transition represents under the current national debt. This makes one question the feasibility and completion of energy projects, whether they are renewable or not, in accordance with national policies and population's needs.

A more precise assessing on the relationship between economic alleviation and energy security is found in a study conducted by the Asian Development Bank Institute (ADBI) (2019). Following Yao and Chang's 4As framework (2014), it maps energy security for the period of 2011-2017 under four dimensions:

1. Availability: sustainable supply of primary renewable and non-renewable sources
2. Applicability: feasibility to adopt technologies and infrastructure maximizing usage of sources
3. Acceptability: sources' environmental and social impacts
4. Affordability: economic liability for government and end-users

The study identifies an improvement of energy security in various countries between 2011-2013 to later deteriorate during 2014-2017. It recommends the immediate adoption of "green energy solutions" such as solar PV and smart metering, accompanied by conservation efforts.

In light of recent national and international policies, ongoing political-energy crisis, and national debt, the definition of energy security in Nigeria takes into account: demand-supply gap, meeting NDC and ARE targets, non-reliance on imports, energy transition, and the 4As framework. Therefore, this paper adopts the following definition: In order to meet Nigeria's NDC targets by 2030, energy security is achieved under uninterrupted supply of primary sources and an installed capacity meeting the population's demand. Similarly, energy transition is understood as the decrease of energy system costs while reducing dependence on imported fuels. Considering that the ADBI study was conducted before the ARE policy in 2019, this paper will analyse energy security under the 4As framework.

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METHODOLOGY

OSeMOSYS

The Open Source Energy Modelling System (OSeMOSYS) was used to produce long-term scenario analysis and least-cost optimisation (Howells *et al.,* 2011). This study provides policy-makers with key insights on power generation, capital investment, energy imports, costs of electricity generation, and CO2 emissions. The model presents Nigeria's energy system with a set of technologies converting primary and secondary commodities to meet total electricity demand. By applying constraints on activity and capacity power, it explores the maximization and least-cost usage of fossil reserves and renewable energies potential.
Modelling input

To effectively run the platform, Climate Compatible Growth (CCG) provides free starter data kits which can be further updated, adapted and applied by consultants and academics among others. For the purpose of this study, a starter data kit for Nigeria was developed following the methodology outlined in Cannone et al. (2022a). All data was retrieved from open-sources and inserted into the data collection and manipulation tool (DaCoMaTool), an excel workbook designed to facilitate the creation of such kit. Access to data is often a barrier for energy modelling in developing countries such as Nigeria, therefore, this study used assumptions when needed.

First, technoeconomic data to determine fuel and renewable technologies capital price projections was retrieved from various online sources. The country's installed generation capacity in 2021 was then estimated to reach 41,240 MW with power plants under construction aiming to add 17,832 MW. Power transmission and distribution output activity ratios were retrieved from IEA (2018) data. Assuming combined losses reach 5% in 2050, data between 2015 to 2070 was calculated using the compound annual growth rate (CAGR) from historic data between 1975-2015. Abundance of natural resources has been proven in Nigeria. Data for domestic coal, crude oil, and natural gas reserves was respectively retrieved from EIA (2022a; 2022b). Similarly, solar PV potential is estimated to reach 2900 GW by Independent Research Studies. Studies show that Nigeria has over 9% of land suitable for utility- scale wind turbines, thus estimating a total wind power generation capacity potential of 346,000 MW. Additionally, no offshore wind is produced in Nigeria, but it's estimated potential reaches 21,000 MW (World Bank, 2020a). Surely Hydropower represents the largest renewable technology in Nigeria which is approximately untapped for now. Studies argue that hydro generation capacity full potential can reach 60,000 MW. Small hydro is seen as a more environmental and economic-friendly alternative under Nigeria's current economic crisis. Water resources elevate its generation capacity potential to 9,507 MW. Although recent research advice the implementation of geothermal power plants in Nigeria, no projects are yet installed nor in construction. The estimated generation capacity potential for this source is 240 GW. Finally, electricity demand projection was based on final consumption and energy balance data retrieved from the IEA

Scenarios

Following a consultation with the Energy Transition Council for the COP27, political and academic preferences determined the development of three BASE scenarios to explore Nigeria's most cost-effective ways to meet its NDC targets (table 1).

Scenario	Description and Constraints
Least-Cost (LC)	• Least cost pathway for commodities to meet energy demand assuming no new policies are implemented. • No additional constraints as the model determines by default the most cost-effective system.
Fossil Future (FF)	• Total annual maximum capacity investment for all renewable and efficiency technologies constrained to zero between 2021-2070.
Net Zero (NZ)	• Least cost pathway to reach net zero by 2050. Emissions are set to peak in 2030 based on annual growth rates followed by a steady decline. • Constrains set to limit CO_2 emissions to 0 from 2050 onwards.

RESULTS & ANALYSIS

Installed Capacity & Production by Scenario

Under no constrains, the first scenario shows the most cost-effective way to overcome the supply-demand gap. With a continued investment in gas and coal, large hydro dominates the energy production. From 2040 onwards, both solar PV and Geothermal power generation increase significantly to support growing demand, thus ensuring energy security.

The Second scenario presents no further investment on renewable energy and stops producing hydropower in 2050. This rushes the model to further invest in coal which dominates generation capacity by 2062. This scenario fails to meet demand generating only 67 GW in 2050, compared to 142 GW in First Scenario.

In contrast, the NZ scenario considers renewable energies potentials and suggest that if Nigeria is to meet its NDC targets and reach net-zero by 2050, coal generated power would be replaced by a sustained investment in hydro and geo technologies. Government of Nigeria has manifested its willingness to invest in geothermal energy, but no power plants has been built to date. The model suggests that investment in this technology from 2030 onwards will support 75% of total power generation by 2060. Similarly, solar PV supports transition from 2040 onwards and ensuring energy security as defined in this study. Gas generated power is still required to meet population's demand.

The three scenarios prove dependency on coal and gas will remain as long as energy transition is not achieved. Fossil fuels play a vital role in a sustainable energy future in Nigeria. The model considers the immense potential of renewable technologies untapped so far. Hydro energy key capacity to support transition is proven by continuous investment throughout all scenarios. However, as local population keeps growing so are the need for water for consumption and food production. In this sense, hydropower alone can't be considered as the most viable source to meet demand in the long run and supportive technologies should be considered. On one hand, although Nigeria has a large wind energy potential the model doesn't suggest investing on it due to the current lack of affordable infrastructure for transmission and distribution. But on the other, the cost of geothermal and solar technologies is expected to decrease significantly in upcoming years, meaning GoP can address cost-tariff deficit without the need to increase energy prices for consumers (Nicholas and Buckley, 2018). To illustrate, Nigeria is suitable for solar PV expansion, including supporting technologies such as PV batteries. With more sectors shifting towards solar power, especially the domestic sector, Government of Nigeria is targeting to increase rooftop PV panels and net metering to avoid rising costs of electricity.

Emissions

The annual CO_2 emissions The FF scenario reaches the highest cumulative amount of CO_2 emissions in comparison to NZ meeting net-zero in 2050. The LC steady increase of emissions reflects the growing energy consumption and begins to fall in 2068 due to increase in offshore wind.

Total System Costs

While the LC scenario remains similar in both operating costs, NZ fluctuates the most from variable and fixed costs. Investment required to support sustainable transition in this scenario is the highest as there is need to build newer and larger infrastructure. However, as NZ presents little to no use of fuel, its variable cost is the lowest in comparison to high prices in FF scenario. The latest reflects the high fuel costs which tend to fluctuate depending on global markets.

DISCUSSION

Furthering Sustainable Energy Transition

As previously defined, energy transition and energy security in Nigeria are intertwined. Furthering a sustainable energy transition translates as the decrease of energy cost and dependence of imported refined product while increasing share of renewables in generation mix, thus increasing energy security.

Increase in Energy Security

Following the 4As framework, increasing the share of local renewable energy sources is proven to fill demand-supply gap while still reducing dependence of imports in Nigeria:

1. **Availability** and flexibility of untapped renewable sources have the potential to meet growing demand while reducing energy imports. Data shows that allocating only a small percentage of land in Nigeria for solar PV would help meet current demand (The World Bank, 2020b). Similarly, Nigeria's windiest areas have an

estimated 7.87 m/s speed. Despite positive results, these two only account for 5% of total generation mix (1,866 MW).

2. **Applicability** of new renewable sources to support diversification in generation mix is achieved with other supporting technologies. Flexible power technologies, such as battery storages and domestic gas, can compensate for RE lower capacity factors to meet growing demand during transition. This dimension also emphasizes on reliability of renewable solar and wind sources.
3. **Acceptability** of VRE is largely proven by several factors. Besides being environmentally friendly and improving air quality, better access to electricity is provided in off-grid rural areas by reducing supply risks and delays from plants. This dimension analyses the sustainability and efficiency of VRE and estimates their expansion could save up to $5 billion (The World Bank, 2020c). Their implementation largely depends on Government of Nigeria efforts to encourage investment.
4. **Affordability** is measured by a country's ability to access renewable sources at a reasonable price. Countries like Jordan have proven that an increased share of renewables has resulted in cheaper electricity prices in the long-run. In this sense, Government of Nigeria pledges to reduce renewable energy tariffs by 15% thus supporting the LC scenario. For a sustained improvement of electricity prices a shift towards VRE must be accompanied by increased supply and maintenance of subsidies for lower-income users.

Most Cost-Effective Option

Global cost trends and advantageous insolation and wind conditions in Nigeria create the potential for large installed capacity of cheap VRE. For instance, India and Israel among other Sun Belt countries, have based their most cost-effective scenarios on affordable solar technology and battery storages (Gulagi, Bogdanov, and Breyer, 2018). Today, the latest decreased mainly due to ARE policy's efforts to cut taxes for manufacturing of PV panels, wind turbines, and batteries. For solar projects generating up to 100 MW, the average levelled cost of electricity is 50 $/MHw. As VRE is estimated to supply growing demand and dominate installed capacity by 2050, increasing usage of solar panels in rural households, particularly those off-grid, is the cheapest form to support demand and improve quality of life.

Co-Benefits

A renewable energy future includes important co-benefits besides energy security. Improved public health resulting from better air quality is one. Reduced pressure on water demand and desalination sector without increasing cost of electricity is another (Caldera, et al., 2017). In the case of Nigeria, economic stability is the largest co-benefit RE can bring for two main reasons. On one hand, their flexibility and distribution particularly in marginalized areas can help reduce impacts of energy price shocks caused by international markets and inflation. On the other, as renewable energy power plants are more labor-intensive than fossil ones (Table 2) these can generate new employment and economic incentives, thus improving political stability.

Renewable energy source	Generation (MW)	Employment (x1000)
Solar PV	175,305	2495
Liquid Biofuels	1633	1788
Wind Power	369,608	1027
Biogas	12,666	381
Small Hydro	134,368	209
Geothermal	12,414	154
Concentrated Solar Power	4334	22

Table 2. Employment generated by renewable resources globally Source: IRENA 2015a; 2015b

Challenges

Despite policies advocating for clean energies, Nigeria generates only a fraction of electricity from solar and wind (1000 MW). Slow penetration of these is due to lack of a regulatory framework which derives into two main challenges. First, financial incentives for VRE are insufficient as most economic efforts are designated to support fossil fuels imports and subsidy electricity prices for low-income households. These actions continue to aggravate fiscal deficits and are not sustainable in the long run (Asian Development Bank Institute, 2019). Second, poor infrastructure and understanding of VRE represent a limitation for their deployment. Regardless of financial and technical difficulties, the main challenge remains the lack of political will to enable penetration of VRE in national grid. Although the ARE policy marks a great initiative towards a sustainable energy future, an integrated policy promoting higher shares of solar and wind is required.

Recommendations: Planning for a Renewable Future

The complexity remains balancing phaseout with socioeconomic demands without aggravating the political crisis. In this sense the overall goal is not to electrify Nigeria in the short-term, but to transition to a cleaner energy system. Drawing from the updated National Climate Change Policy (2021), policymakers should further detail strategies for emissions reduction and energy transition. This study highlights main areas of action:

- Monitoring, Evaluation & Reporting: Collaborative efforts are needed to consolidate databases Stakeholder collaboration is imperative to consolidate databases needed to model pathways and build concrete action plans.
- Assessing Demand & Economic Growth: Align governmental policies and demand trajectories with socioeconomic priorities for an integrated action plan. This can unlock the re-allocation of funds for clean energy projects, exploration of domestic indigenous resources, and incentivize energy conservation. For instance, the integration of the Climate Change Policy in demand analysis can prove beneficial when defining future energy demand scenarios. Particularly when assessing impacts on the desalination sector and local environment.
- Improving Energy Efficiency & Renewable Energy Initiatives: Nigeria has the capacity to meet energy demand while reducing negative environmental impacts as long as energy efficiency is improved. From energy auditing to economic incentives for conservation, increasing the share of renewable technologies during transition period is key to compensating variable supply. As the domestic sector demand is mainly met with Fossil fuels, shifting consumption to decentralized solar PV can provide access to distant households and rural areas.
- Investing in Energy Transition: Although Nigeria is the 28th most attractive country for renewable technologies investment (Farzaneh, Zusman, and Chae, 2021), an estimated $100 billion is required to support transition and phaseout (IEP report, 2022). The Government of Nigeria is intending to shift to an auction system where the Central Power Purchasing Agency is replaced by energy companies. Nevertheless, recent decades have been characterized by a precipitated capacity boost development under an inconsistent financial and regulatory framework. Policymakers should consider the creation of an open energy market platform for sustainable and transparent electricity businesses. Similarly, greater technical capacity is needed to unlock international fundings and green bonds, finance decarbonization projects and create green jobs.

Study Limitations & Future Research

While most of the data was found through the EIA and governmental reports, a few key numbers for this modelling had to be estimated and retrieved from previous studies. Although numerous efforts to determine the potential of renewable energies, no consolidated work available provides concrete numbers of energy potential for sources such as offshore wind and geothermal in Nigeria. The underutilization of VRE is mostly due to the lack of awareness of long-term economic, social, and environmental benefits. More advanced and updated research is required for further understanding. This study doesn't consider possible development of domestic indigenous resources. If the expansion of domestic coal stations continues, results are likely to differ under OSeMOSYS cost-effective approach. In light of obtained results, further studies could expand on the implementation of geothermal energy. Especially on its potential to meet ARE's target of shifting VRE generated capacity to 30% by 2030. Further studies could also focus on detailed modelling on different sectors and application of individual technologies across Nigeria's provinces. Lastly, as this study doesn't assess energy efficiency, future research can assess the most cost-effective ways to reduce transmission and distribution losses.

CONCLUSION

Nigeria is facing energy deficiency but due to its favorable geographical location, huge potential for VRE penetration has been proven. This study argues that VRE represents a solution to reducing dependence on imported Refined fuels, thus supporting energy transition and increasing security under the 4As framework. The ARE policy along with other national plans prove that Nigeria is on the right path towards energy transition.

Under an uncertain panorama, Nigeria faces lack of coordination, inconsistent policies, and limited investment to support energy transition efforts. Pressures of a fast-growing demand from the domestic, industrial, and transport sectors, accompanied with recent devastating floods, have forced Nigerian Government to maintain investment on imported refined fuels. The rising bill has prompted a periodic balance-of-payment crisis, leading to months of protest and political instability. Heavy dependence on imported refined fuels also explains Nigeria's constrained growth and fiscal deficit as governmental subsidies are required to support population's needs. Despite recent investment in energy infrastructure, most economic efforts continue to go towards imported refined fuels meaning Nigeria continues to be energy insecure.

Results show that in order to increase energy security in the most cost-effective way, Nigeria needs to increase its share of VRE. Besides continued investment in hydropower, further development of solar PV and geothermal energy is key to support transition while meeting demand. While supporting mitigation actions,

these can potentially enhance economic alleviation by reducing reliance on expensive imported fossils as early as 2030 under the NZ scenario, and 2040 in the LC. Contrary to the FF scenario, where energy production exclusive on refined fossil fuels doesn't meet population's needs.

Growing electricity demands urges Government of Nigeria to assure equilibrium in the generation mix for a sustainable transition, with the right balance of security, conservation, and economic growth. Policy-makers should focus on: attracting more investment for both on- and off-grid technologies, strengthen regulatory frameworks encouraging participation of stakeholders, and promote large deployment of VRE. The latest must be supported by other green initiatives. These actions combined should translate into integrated national plans considering most electricity intensive sectors, and support the development of a strong economy well insulated from international energy prices fluctuations.

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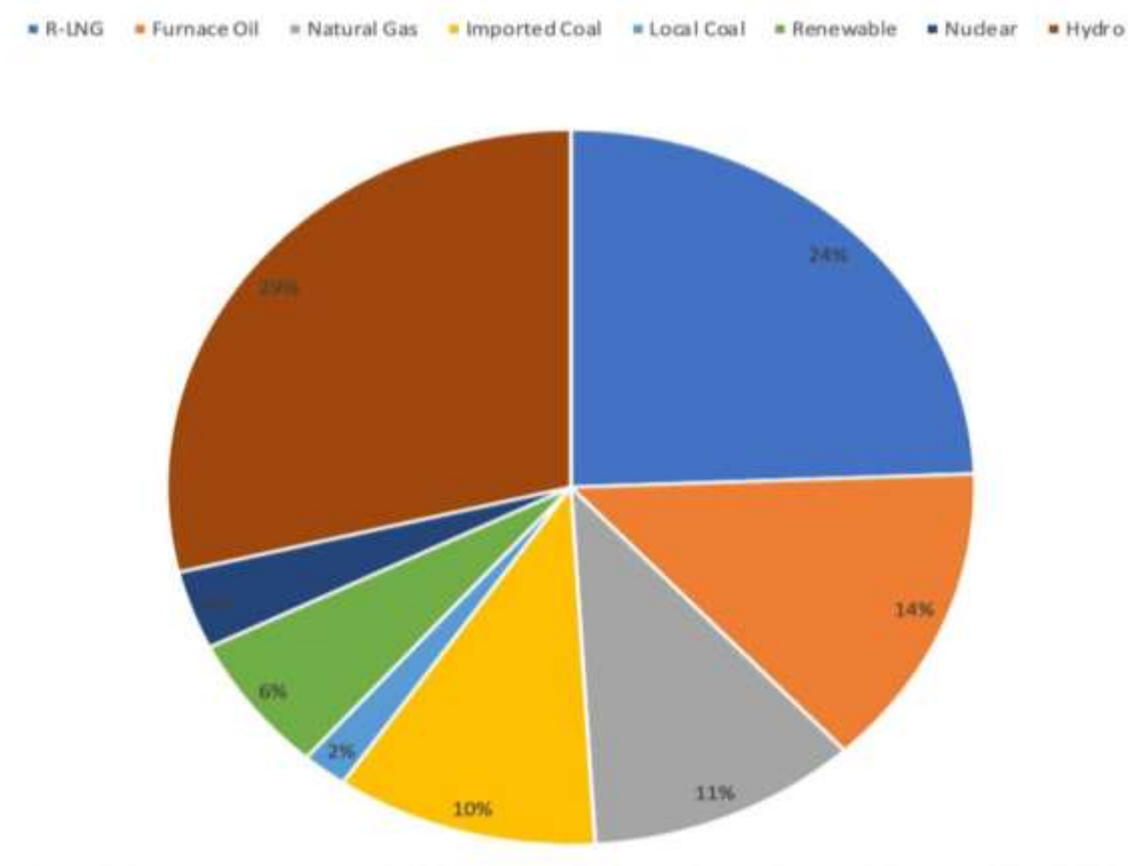


Figure 1: Current Energy Mix in Nigeria

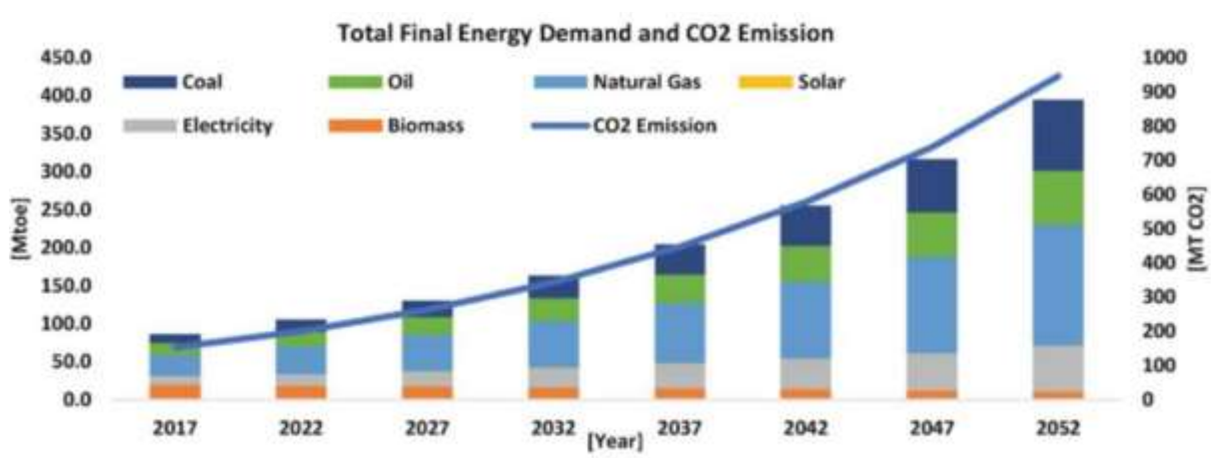


Figure 3. Source: Farzaneh, H., Eric, Z. & Chae, Y. (2021).

Electricity demand projection

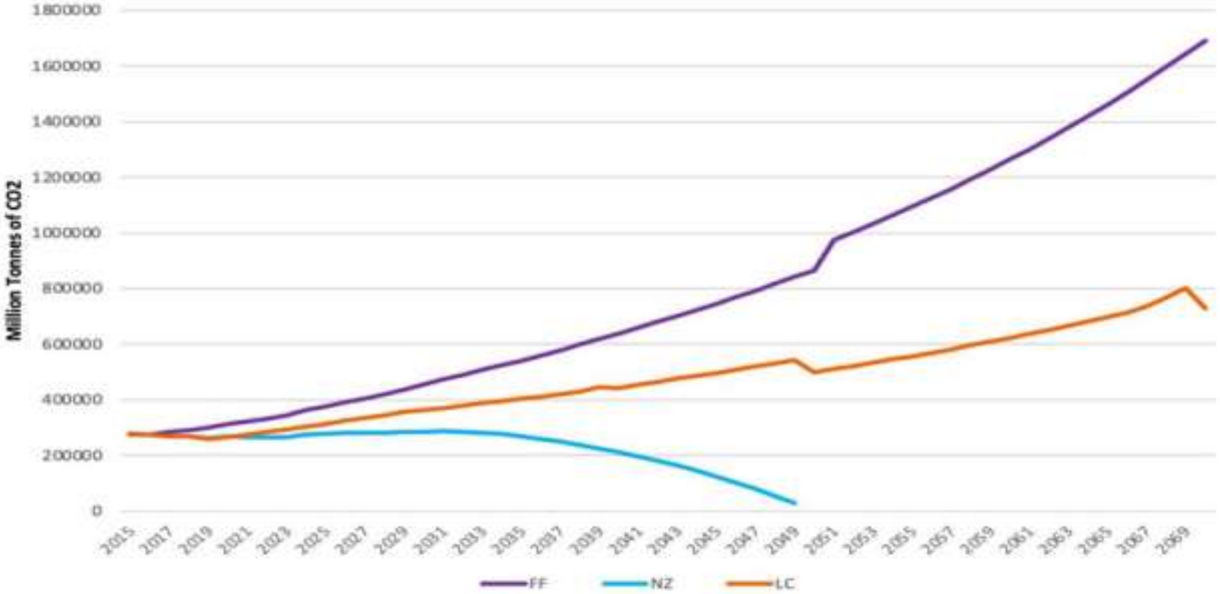
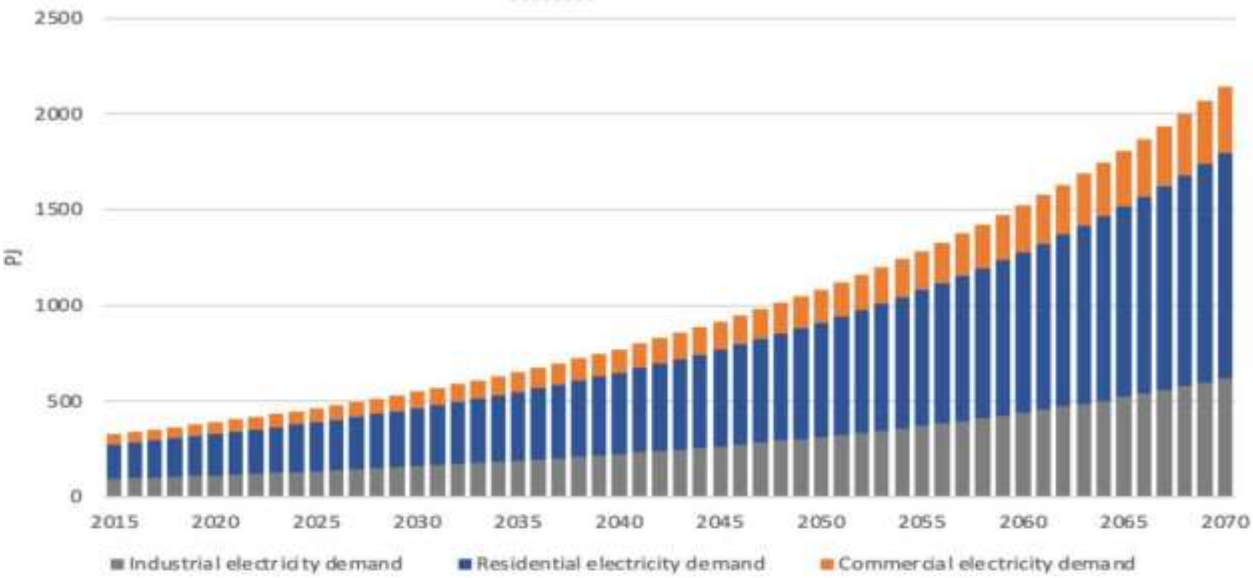


Figure 10. Annual CO2 emissions from 2015-2070 by scenario

Annual



CO2 emissions from 2015-2070 by scenario

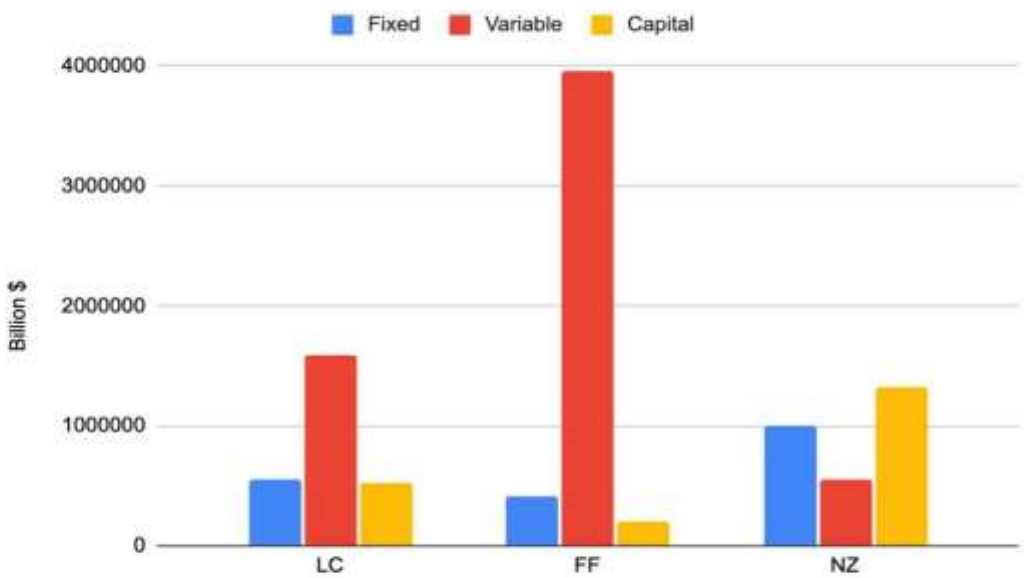


Figure 11. Total, fixed and variable discounted costs in each scenario over the modelling period