Long-range electricity demand forecast and sector evolution using the NESTAS System Dynamics Model: A case study of Nigeria.

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1.0. Introduction

Electricity is an important catalyst for the growth and development of both developed and developing economies. Sub-Saharan Africa is one of the regions significantly affected by energy poverty because of its low-income levels and the relatively high average cost of energy. This generally portends economic and social implications for the citizens. The most significant of these are low electricity access, unreliable electricity supply, energy imbalance, and inadequate infrastructure resulting in the adoption of unhealthy alternatives such as diesel/gasoline generators. Hence, a need for specific policies to address the unique energy issues in each region, country, or state (Adewuyi, 2020).

In Nigeria, only about 60% of the population has access to electricity due to the poor state of the electricity sector (Adewuyi, 2020; Olaniyan et al., 2018). Improving electricity access and transitioning the generation mix requires policies and strategies that address the sector's complexities. This article evaluates Nigeria's electricity sector transition, forecasting demand, and supply mix. It considers various pathways and policies to enhance electricity access and meet future demand using system dynamics. The model highlights issues related to diversifying Nigeria's energy mix, expanding renewable energy technologies, increasing electricity tariffs, and incorporating energy efficiency policies.

2.0. Methodology: Development of the Nigerian Electricity Sector Transition Assessment (NESTAS) Model

System dynamics was used in this study to develop the Nigerian Electricity Sector Transition Assessment (NESTAS) Model. This model aims to elucidate issues related to the diversification of Nigeria's energy mix, the growth of renewable energy, and the electricity tariff increase within the Nigerian electricity sector. Additionally, the NESTAS Model will forecast future electricity demand and supply scenarios under various policy options for a Nigerian case study. Based on these forecasts, policy recommendations will be provided to guide the sector's transition. The model consists of five sectors including the demand forecast, on-grid electricity generation, off-grid generation sector, transmission sector, and investment allocation and decision-making sectors.

Data Inputs

The study relied on secondary data which was gathered from various developed electricity market models and publications. The data was applied for the simulation of current and future electricity generation and transmission capacity, investment, and emission scenarios. In addition, four demand scenarios were adopted to depict the different demand goals for Nigeria. These goals were set based on the business-as-usual case at the current average growth rate of electricity consumption, the goal of attaining the status of an industrialized nation with an average per capita electricity consumption rate of 1 MWh as indicated by Momodu & Addo (2019), the goal of attaining an average per capita consumption rate of BRICS nations of 3MWh and the goal of attaining consumption of developed nations of 5MWh.

3.0. Results and Discussion

The study's outcomes cover a range of significant aspects, from projecting electricity demand to analyzing its dynamics and supply forecasts. Additionally, it delves into investment decisions and examines how electricity Tariffs influence the system's evolution, alongside exploring the evolution of the electricity sector mix.

3.1. Electricity demand projections

Electricity demand projections up to 2060 were based on four scenarios outlined in the foregoing. In the BAU scenario, using the current consumption rate as a projection basis, the model predicted a demand of approximately 15GW, exceeding the current installed on-grid capacity by 12.5GW. The industrialization scenario anticipates a demand increase to 48GW, indicating rapid growth to achieve 1MWh per capita. The accelerated growth scenario projects a demand of 150GW, while the aggressive growth scenario forecasts a demand of 230GW. These latter scenarios show exponential growth due to the assumptions of quickly reaching per capita consumption levels of 3MWh and 5MWh, respectively.

3.2. Dynamics of electricity demand and supply and investment allocation decision

This section discusses investment decisions and supply dynamics in the electricity sector up to 2060 under different demand scenarios. In the business-as-usual scenario, with a 1.6% annual growth rate in per capita demand, the total electricity supply is projected to meet demand, emphasizing the importance of strategic investments in transmission capacity until 2044 to address infrastructure bottlenecks. The industrialization scenario anticipates rapid consumption growth (7% per annum), with supply and demand closely aligning until 2035, after which generation capacity investments are necessary to meet the excess demand. This scenario also highlights the need for timely capacity expansion. In both the accelerated growth and aggressive growth scenarios, supply closely aligns with demand, with initial investments focusing on transmission infrastructure until 2035, followed by generation capacity expansion. The cyclic nature of investments is emphasized, underlining the need for continuous assessment and adaptation of investment strategies.

3.3. Impact of electricity Tariff on system evolution

The study found that higher electricity tariff growth rates (0% to 5%) increase generation capacities by providing more funds for reinvestment. Scenarios with 0% (case 1), 1.6% (case 2), 3.3% (case 3), and 5% (case 4) annual growth rates showed that case 4 had the highest capacity, while case 1 had the lowest. Policymakers may consider gradually raising tariffs to ensure ongoing growth in generation capacity and reliable electricity supply.

3.4. Evolution of the electricity sector mix

The study prioritizes relative benefits to determine the electricity mix, initially focusing on economic criteria with future research including environmental factors. The on-grid mix consists of solar, hydropower, and natural gas, with capacity additions allocated as 17% solar, 59% hydropower, and 14% natural gas based on levelized costs of electricity (LCOE). From 2024 to 2035, investment prioritizes the transmission grid, keeping generation constant. Post-2035, investments boost generation, with solar rising from 32MW to 16.1GW by 2060, hydropower from 2.1GW to 35GW, and natural gas from 10.5GW to 77GW. In addition, Off-grid solutions include biomass, onshore wind, natural gas IPP, Solar PV IPP, and Solar PV Off-grid. Starting with no off-grid capacity, the mix is 23% IPP Solar, 21% Natural gas IPP, 24% Onshore wind, 24% Biomass, and 8% off-grid solar. Total off-grid capacity grows to 9.3GW, with contributions from IPP Solar (2.2GW), Natural gas IPP (1.8GW), Onshore wind (2.3GW), Biomass (2.3GW), and off-grid solar (0.8GW).

4.0. Conclusions and policy recommendation

The NESTAS System Dynamic model was used to analyze Nigeria's electricity sector. It provides key insights into electricity demand projections, supply dynamics, the impact of electricity tariffs, and the evolution of the electricity sector mix. Firstly, the projections indicate that electricity demand could grow significantly, from 15GW to 230GW by 2060, highlighting the necessity for substantial infrastructure development to meet this anticipated demand. The study also emphasizes the importance of prioritizing investments in both transmission and generation infrastructure. This is crucial to ensure the alignment of supply with the growing demand and to maintain a reliable electricity supply.

Moreover, the study finds that higher electricity tariffs can play a pivotal role in incentivizing investment in generation capacity. This can ensure the stability and growth of the electricity sector by providing the necessary funds for expansion. Additionally, the evolution of the electricity sector mix should balance economic and environmental factors. Promoting renewable energy, especially through off-grid solutions, is essential for regions that are distant from the national grid. These insights provide valuable guidance for policymakers in developing strategies that are sustainable, reliable, and affordable, ensuring the long-term growth and stability of Nigeria's electricity sector.

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