Statistical Modelling of Outage Events, Available Capacity, and Foreign Exchange Rate with Grid-Connected Power Generation in Nigeria

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Abstract – *Electricity is one of the major factors that influence the level of growth of an economy, as well as human development. With applications in diverse spheres of life, it is at the core of human productivity and economic growth. Nations therefore, continually strive to ensure adequate and secured supply. Nigeria's electric power sector experienced a major event in 2013 with the privatization of successor entities, pursuant to the enactment of the Electric Power Sector Reform Act (EPSRA) 2005. With about ten years of the electricity market in Transitional phase, this research sought to assess the impact of key operational and economic factors on the level of her on-grid electricity supply. Multivariate linear regression, a least squares approximation method was adopted considering four independent variables – Available Capacity (MW), Grid Outage Events (Total and partial), and Foreign Exchange Rate (₦/$). The Statsmodel package of python programming language was used for the 45 months' data points for each variable. A weak relationship was found with the combined variables explaining 8.1% of the dataset for power generation from the developed model. However, Available Capacity, Grid Outage Events, and Foreign Exchange Rate are not sufficient to determine the growth of grid connected power generation.*

Keywords: Development, Electricity, Multivariate Linear Regression, Power Generation

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I. Introduction

Electricity consumption and economic development are correlated [1, 2, 3]. The technological development of a nation can be said to be hinged on her available generated electricity [3]. The importance of Electricity as a means of powering human activities, and as an impetus for technological advancement, economic growth, sustainable infrastructures, and comfortable living cannot be over-emphasized. Its applications or uses permeate large areas of human activities, ranging from preservation and processing of farm produce for food supply, preservation of vaccines for healthcare, powering households for daily living, powering equipment and facilities for commercial and industrial activities, lighting up streets for safety and security. In addition, in ongoing global pursuit of environmental sustainability in powering vehicles for decarbonized transportation [4], and thus, an impetus for reversing the much talked about climate change causing the dreaded global warming. Some scholars have posited that as such, it is widely accepted that there is strong correlation between socio-economic development and the availability of electricity [5,6]. In ensuring further development transcending social and community classifications, the need for supply and delivery of adequate and reliable electricity cannot be overemphasized [2, 3].

The electric power sector in Nigeria was privatised in 2013 in tandem with the Electric Power Sector Reform Act (EPSRA) 2005 that sought to develop the sector into a competitive, self-sustaining, and contract-driven market [2]. This is intended to help in changing the tides of insufficient power supply to the populace. Part of the objectives was for the market to attain the level where growth matches the growing demand associated with economic development, and at the same time, present an attractive and thriving environment for all players [7]. In a special report on Power Sector Reform by the Federal Government of Nigeria, the development of the sector was planned to move through the phases of Interim Period, Transitional Electricity Market (TEM), Medium-Term Electricity Market, and Final Market [8].

The desired growth in the power sector is in tandem with the goal to ensure that Nigeria is among the industrialised nations and improve the general wellbeing of her citizens. This goal was hinged on three critical activities that must be effectively achieved [5]:

- Adequate power must be generated;
- The generated power must effectively be transmitted to all parts of the country; and
- Efficiently distributed to the consumers

The electric power sector in Nigeria, operated under the supervision of the Federal Ministry of Power, has three sections in its value chain: the generation, transmission, and distribution [2], which is comprised of various actors having different roles. The power sector currently operates in a manner that the power distribution companies (DisCOs) purchase power from the Nigerian Bulk Electricity Trading Company (NBET), who purchases power generated by the power generating companies (GenCOs). The Transmission Company of Nigeria (TCN) plans, operates, and maintains the transmission infrastructure in ensuring that electricity is evacuated from the GenCos and delivered to DisCos. Presently, the DisCOs and the GenCOs are mainly driven by the private sector while the transmission segment is owned and managed by the Nigerian government.

Nigerian Electricity Regulatory Commission NERC in a bid to allow the sector mature with performance driven growth, heralded the Transition Electricity Market (TEM), which is characterised by vertical price regulation using wholesale contracts based on lifecycle for generation and building blocks model for transmission and distribution entities [2, 9]. Regulated pricing is part of the functions of the Nigerian Electricity Regulatory Commission (NERC), an institution created pursuant to the EPSRA in 2005 as the regulator of the sector [8].

However, even after ten years of the Transition Electricity Market (TEM) the Nigerian power sector has experienced major setbacks resulting in the financial distress of many of the sector's participants [8]. There seems to be a disconnect between the policies and reality putting the sector in a state of emergency which could cause further deterioration in power supply and threaten the Power Sector Reform Program (PSRP). This will severely constrain the country's ability to revive growth and restore confidence for private investments; It is a statement of fact that many industries have left the country due to epileptic electricity supplies [2] and the attendant impact is being felt by the populace.

Despite the interventions through reforms in the Nigerian Electricity Supply Industry (NESI), average generation amount hovers between 4000 – 6000 MW while the maximum daily available capacity ever stood at 7851.20MW, and it is not surprising that electricity consumption per capita in the country is about 150 kWh [2]. This is a far cry from the installed capacity of about 12,000 MW [10]. Likewise, literature puts the capacity of the transmission segment below 6000 MW [2] which will make it difficult to wheel electricity to consumers if generation improves, and is not as if there is respite on the distribution sector either. The sector has also continued to suffer several grid collapse, and it is normal to think that the insufficiency of power generation is responsible for the frequent grid outage.

It is however, imperative to state that efforts are underway to reverse this ugly trend. New electricity generation plants are under construction, the government is upgrading the transmission segment with results expected in no distant time, and DisCOs are being encourage to improve their network or face stiff penalties. This is expected to stimulate economic development and thus, lead to an improvement in the living conditions of the populace.

This study centers on the electricity supply side, employing a multivariate linear regression method to explore its correlation with economic development. By analyzing the growth—or lack thereof—of the supply side of the electricity market, the research provides valuable insights into the key factors that influence its performance. Understanding these factors is essential for informed decision-making and for designing strategies to enhance the reliability and sustainability of electricity supply. This approach highlights the critical interplay between energy infrastructure and economic progress, offering a robust framework for addressing challenges in power generation and its broader impact on development in Nigeria.

II. Materials and Methods

The study utilized data for selected variables sourced from open-access industry statistics provided by the Nigerian Electricity Regulatory Commission (NERC) [11]. Employing a multivariate linear regression method, the research aimed to determine the correlation between supply-side dynamics and economic development. The following variables were carefully selected for statistical modeling of grid-connected power generation in Nigeria, drawing from extensive industry expertise:

- Electrical energy generation (MW) – Dependent variable
- GenCos Available Capacity (MW)
- Grid collapse events (partial or total disruptions)
- Foreign exchange rates (due to generation tariffs being indexed in USD)

The analysis focused on identifying patterns and interrelations among these variables, highlighting their influence on the performance of the power generation sector. Trends in available capacity, generation capacity, and foreign exchange rates over a 45-month period were examined, with the results depicted in Figures 1 and 2. This comprehensive approach provides valuable insights into the operational challenges and economic implications of grid-connected power generation in Nigeria.

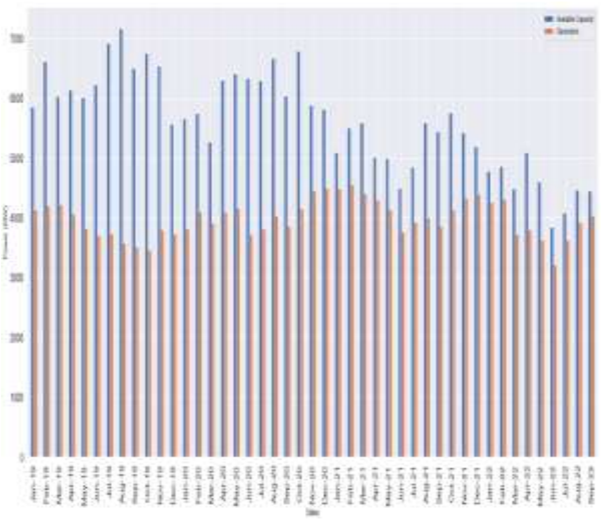

Figure 1. Trend of Available Capacity (MW) and Power Generation (MW) for NESI – NERC [11]

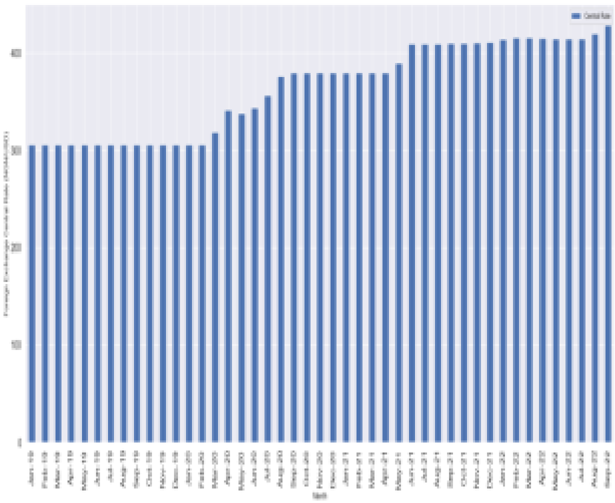

Figure 2. Trend of Foreign Exchange Rate (NGN/USD) – CBN [12]

The data depicted in Figure 1 was compiled from comprehensive records of daily peak generation, daily average energy generation, and daily lowest generation values. These figures, sourced from both literature and industry reports, provide a detailed overview of power generation trends over time. A more granular representation of this data is illustrated in Figure 3, titled "Chart of Daily Peak Generation (MW), Average Daily Energy Generated (MWh/h), and Daily Lowest Generation (MW) – NERC".

Figure 3 offers a clear visualization of the variations in power generation metrics, highlighting key operational patterns and fluctuations within the grid. This analysis underscores the dynamic nature of electricity generation in Nigeria, shedding light on critical factors that impact daily energy availability and reliability.

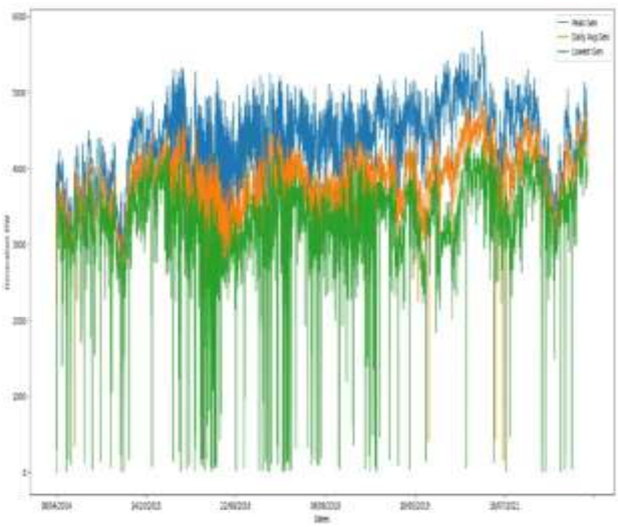

Figure 3. Chart of Daily Peak Generation (MW), Average Daily Energy Generated (MWh/h), and Daily Lowest Generation (MW) – NERC [11]

III. Result and discussion

The analysis was conducted using the Statsmodels package in the Python programming language, leveraging its robust statistical capabilities. The multivariate linear regression model was designed with Power Generation as the dependent variable, while the independent variables included:

- Available Capacity (MW)
- Number of Total Grid Collapses
- Number of Partial Grid Collapses
- Central Rate of Foreign Exchange

The results of the regression analysis, which highlight the relationships and statistical significance of these variables in influencing power generation, are summarized in Figure 4 and Table 1. This methodological approach provides a detailed quantitative framework for understanding the complex interplay between operational capacity, grid reliability, and macroeconomic factors within Nigeria's power sector.

```
y = r6['Generation']
x1 = r6[['Available Capacity', 'Total Collapse', 'Partial Collapse', 'Central Rate']]

x = sm.add_constant(x1)
results = sm.OLS(y,x).fit()
results.summary()
```

OLS Regression Results

Dep. Variable:	Generation	R-squared:	0.081
Model:	OLS	Adj. R-squared:	-0.011
Method:	Least Squares	F-statistic:	0.8846
Date:	Mon, 30 Jan 2023	Prob (F-statistic):	0.482
Time:	05:46:11	Log-Likelihood:	-319.31
No. Observations:	45	AIC:	648.6
Df Residuals:	40	BIC:	657.7
Df Model:	4		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	2476.6702	1000.954	2.474	0.018	453.667	4499.673
Available Capacity	0.1062	0.087	1.225	0.228	-0.069	0.281
Total Collapse	-21.9463	69.339	-0.317	0.753	-162.087	118.194
Partial Collapse	-15.7769	138.741	-0.114	0.910	-296.183	264.629
Central Rate	2.5508	1.560	1.636	0.110	-0.601	5.703

Figure 1: Ordinary Least Square Regression Result using Statsmodel Package in Python

Table 1. Remark on Coefficients of Model

Variables	*Coefficients*	*P-value*	*Remark*
Intercept	2476.670175	0.017689	Significant
Available Capacity	0.106159262	0.227851	Low Impact
Total Collapse	-21.94633599	0.753265	Low Impact
Partial Collapse	-15.77690297	0.910033	Low Impact
Central Rate	2.55077641	0.109787	Low Impact

Decision-making for real-world problems relies heavily on data analysis to identify patterns and develop projections based on specific assumptions. These identified patterns form the basis for creating statistical models, which consist of mathematical formulas and assumptions designed to represent real-world scenarios [13].

This research applied linear multivariate regression modeling to construct a statistical model for grid-connected power generation in Nigeria. The resulting governing equation offers valuable insights into the factors influencing power generation and their relative significance. This equation serves not only as a diagnostic tool but also as a strategic resource for stakeholders, including policymakers and potential investors, to make informed decisions in the energy sector.

The regression model yielded the following equation:

$$P = 2476.6702 + 0.1062AC - 21.9463TC - 15.7769PC + 2.5508FX$$

Where:

$P = Power\ Generated\ (MWh/h)$

$AC = Available\ Capacity\ (MW)$

$TC = Total\ Grid\ Collapse$

$PC = Partial\ Grid\ Collapse$

$FX = Foreign\ Exchange\ Rate\ (Naira/USD)$

This equation encapsulates the interplay of operational capacity, grid reliability, and economic factors, providing a quantitative framework for understanding the dynamics of grid-connected power generation. The positive coefficient of available capacity (AC) highlights its direct contribution to power generation, while the negative coefficients of total and partial grid collapses (TC and PC) underscore their adverse effects. Additionally, the influence of the foreign exchange rate (FX) reflects its significance in a tariff-indexed system.

By offering a nuanced understanding of these relationships, the model acts as a vital tool for designing targeted strategies to improve energy sector performance and attract investment.

It is important to highlight that the regression model yielded an R-squared value of 0.081, indicating that the selected combination of variables could only explain 8% of the variance in the dataset for monthly power generation. This result underscores the limitations of the model in capturing the complex factors driving the growth or decline of power generation in Nigeria.

The low R-squared value suggests that additional variables, possibly including socio-economic, policy, infrastructural, and technological factors, may play a more significant role in influencing power generation. This finding emphasizes the need for a more comprehensive modeling approach that incorporates a broader spectrum of determinants to provide deeper insights into the dynamics of Nigeria's energy sector.

Ultimately, while the current model offers a foundational understanding, it highlights the importance of further research to uncover the latent variables that critically impact power generation, ensuring more robust and actionable outcomes.

IV. Conclusion

The study reaffirms the critical link between energy supply and economic development, emphasizing the need for robust energy budgeting and strategic planning to ensure sustainable value delivery. Through the analysis, the correlation between grid collapses, foreign exchange rates, and available generation capacity on power generation growth was examined, yielding the following key insights:

Collectively, the variables of available generation capacity, count of grid collapses (total and partial), and foreign exchange rates accounted for only 8% of the variance in the 45 monthly power generation observations analyzed. This indicates that these factors, while relevant, are not the primary drivers of growth in power generation within the Nigerian Electricity Supply Industry (NESI).

Although grid collapses (unplanned outage events) significantly impact grid reliability, the analysis shows that they do not have a substantial effect on the overall level of power generation within the grid.

These findings suggest that other factors, beyond those analyzed, play a more critical role in driving growth in power generation. The results underscore the importance of exploring additional variables and adopting a more holistic approach to energy sector analysis. Future research should focus on identifying these latent drivers, with the aim of crafting targeted interventions to enhance energy sector performance and its contribution to economic development.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism

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