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YIELD CURVE MODELING FOR ENERGY INFRASTRUCTURE BONDS IN NIGERIA

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Abstract

The Nigerian energy sector faces persistent financing challenges, as government allocations and commercial loans remain inadequate for large-scale infrastructure projects. Energy infrastructure bonds offer a promising alternative, yet the absence of a structured yield curve model complicates pricing, risk assessment, and investment decisions. This study develops a yield curve model tailored to Nigeria's energy bond market, integrating market data, macroeconomic indicators, and statistical modeling techniques to enhance valuation accuracy and risk management. The research employs the Nelson-Siegel, Svensson, and Vasicek models to estimate yield curves, while risk-adjusted return measures such as the Sharpe Ratio assess bond attractiveness. Scenario analysis explores bond performance under varying inflationary conditions, providing valuable insights for policymakers and investors. Findings reveal that inflation significantly erodes real yields, widening the spread between corporate and government bonds. The study recommends inflation-linked bonds, enhanced monetary policy coordination, and diversification of energy bond offerings to foster investment growth. By addressing critical gaps in Nigeria's bond market, this research contributes to energy economics, fixed-income securities, and emerging market investment strategies.

Keywords: Energy Infrastructure Bonds, Fixed-Income Securities, Nigerian Bond Market, Risk-Adjusted Returns, Yield Curve Modeling.

1. Introduction

The Nigerian energy sector is fundamental to the country's socio-economic development, underpinning the delivery of electricity, industrial productivity, and investment in renewable energy. Despite its strategic importance, the sector continues to face chronic underfunding, infrastructural decay, and limited private-sector participation. These problems are further compounded by population growth, rising energy demand, and the urgent need for decarbonization and sustainable energy solutions. Financing large-scale energy infrastructure projects has remained a major barrier to progress, primarily due to the sector's capital-intensive nature and the extended timeframes required for return on investment.

Traditional financing sources such as direct government funding, bank loans, and donor-backed grants have proven insufficient in meeting Nigeria's energy infrastructure needs. Fiscal pressures and macroeconomic instability, including inflation and interest rate volatility, have further restricted government-led initiatives. This financing gap has triggered growing interest in alternative mechanisms, such as energy infrastructure bonds. These bonds, issued by either the government or corporate entities in the energy sector, serve as long-term debt instruments aimed at raising capital from institutional and retail investors.

However, in the absence of efficient market pricing tools, these instruments remain underutilized (Estache & Fay, 2007).

One of the most critical components for effective bond pricing and investor decision-making is the availability of a well-structured yield curve. A yield curve, which plots interest rates across various bond maturities, helps investors evaluate the time value of money and the risk-return profile of debt instruments. Yield curve modeling is essential for proper bond valuation, portfolio construction, and macroeconomic policy planning. In developed markets, such as the United States and the European Union, yield curve models are extensively applied to guide interest rate decisions, predict recessions, and monitor credit risk. Unfortunately, the Nigerian bond market especially within the energy sector lacks a comprehensive and localized yield curve model that accurately reflects its economic realities and institutional risks.

The absence of a reliable yield curve tailored to Nigeria's energy infrastructure bonds introduces significant pricing inefficiencies. Investors are often unable to accurately assess the fair value of energy sector bonds, which can result in either overpricing or underpricing and subsequently discourage participation in the bond market. Furthermore, liquidity constraints arise when market participants cannot easily benchmark investments or assess interest rate risks. Adebayo and Ogunbiyi (2022) emphasize that existing models fail to capture the structural, regulatory, and macroeconomic dynamics unique to the Nigerian context, particularly in the energy sector. As a result, energy projects suffer from inconsistent funding and reduced investor confidence.

This study seeks to address these challenges by developing a yield curve model specifically tailored for Nigerian energy infrastructure bonds. The proposed model will leverage real market data, such as government and corporate bond yields, and incorporate statistical techniques suited for emerging markets. By using actuarial and econometric modeling frameworks, the yield curve will reflect actual market behavior while accommodating the structural nuances of the Nigerian financial landscape (Adegbite & Olayemi, 2020). In doing so, the model will support improved bond pricing, investor risk assessment, and long-term capital allocation for infrastructure development.

Ultimately, this study aims to contribute to the fixed-income literature by providing an applied yield curve model that enhances financial decision-making in Nigeria's energy bond market. The findings will not only be valuable to investors and policymakers but also to energy firms seeking sustainable financing options for future infrastructure projects.

2. Literature Review

2.1 Yield Curve Modeling in Fixed-Income Securities

The concept of yield curve modeling has been widely studied in the field of financial engineering and actuarial science. The seminal work of Vasicek (1977) introduced a mean-reverting stochastic model for interest rate modeling, laying the foundation for subsequent research. The Nelson-Siegel (1987) and Svensson (1994) models have since been widely applied in estimating yield curves, offering flexible parametric approaches to capture the term structure of interest rates.

Diebold and Li (2006) extended the Nelson-Siegel model into a dynamic framework, allowing for improved forecasting capabilities. These models have been extensively utilized in developed financial markets; however, their application in emerging economies, particularly Nigeria, remains limited due to data availability and market inefficiencies (Adegbite & Olayemi, 2020).

2.2 Infrastructure Bond Markets in Emerging Economies

Infrastructure bonds have emerged as a critical financing tool for large-scale energy projects in emerging economies. Studies by Estache and Fay (2007) highlight that countries with underdeveloped bond markets often face difficulties in attracting long-term investments. The role of government-backed securities in bridging infrastructure financing gaps has been explored in the work of Bhattacharyay (2011), who emphasizes the importance of regulatory frameworks in ensuring bond market stability.

For Nigeria, Oke (2013) examined the effectiveness of infrastructure bonds in financing power projects but found a lack of reliable risk assessment models tailored to the local market conditions. While similar studies have been conducted in South Africa and India (Mukherjee & Sasidharan, 2018), there remains a scarcity of research specific to yield curve modeling for Nigerian energy bonds.

2.3 Energy Sector Financing and Investment Strategies

The Nigerian energy sector has long faced challenges related to inadequate financing mechanisms, limiting its ability to meet growing energy demands and support sustainable development. Structural deficiencies within the sector have been well-documented, with Iwayemi (2008) emphasizing the urgent need for sustainable investment strategies to bridge the infrastructure financing gap. The introduction of green bonds has emerged as a potential solution, as highlighted in the Climate Bonds Initiative report (2021), which discusses Nigeria's pioneering efforts in issuing sovereign green bonds to attract environmentally conscious investors and fund clean energy projects.

Despite these advancements, a significant challenge remains—the absence of a structured yield curve model tailored to Nigeria's energy infrastructure bonds. Adebayo and Ogunbiyi (2022) argue that existing yield curve models, primarily designed for developed markets, do not fully capture the unique risks associated with Nigeria's economic and political landscape. Given the country's exposure to inflation volatility, currency depreciation, and regulatory uncertainties, the reliance on conventional yield curve methodologies may result in suboptimal bond pricing and investment inefficiencies. This underscores the need for localized actuarial models that account for Nigeria's market-specific dynamics.

A review of existing literature reveals that while yield curve modeling is extensively developed in advanced economies, its application to Nigeria's energy infrastructure bond market remains underexplored. Previous research has primarily focused on general bond market development, energy sector financing, and risk management. However, there is limited actuarial research specifically addressing yield curve estimation for Nigerian energy infrastructure bonds, creating a knowledge gap that this study seeks to fill.

This research bridges the gap by developing a robust yield curve model specifically tailored to Nigeria's energy bond market, integrating real market data to enhance pricing accuracy and risk assessment. Furthermore, actuarial techniques are applied to improve investment decision-making and policy formulation, providing a more reliable framework for stakeholders in the energy sector. By addressing these gaps, the study contributes significantly to the body of knowledge on fixed-income securities in emerging markets, with a particular emphasis on Nigeria's evolving energy finance landscape.

3. Methodology

This section details the actuarial approach used in this study, outlining the data sources, modeling techniques, and statistical tools applied to develop an accurate yield curve for Nigerian energy infrastructure bonds.

3.1 Data Collection

The study relies on secondary data from reputable sources, including:

i. Nigerian Sovereign Investment Authority (NSIA): Infrastructure Fund reports detailing bond issuances.
ii. Central Bank of Nigeria (CBN): Government bond yields, interest rates, and inflation reports.
iii. Nigerian Exchange Group (NGX) & FMDQ OTC Securities Exchange: Corporate bond yields, market capitalization, and liquidity reports.
iv. National Bureau of Statistics (NBS): Macroeconomic indicators such as GDP growth, inflation rates, and foreign exchange reserves.
v. International Monetary Fund (IMF) & Bloomberg Terminal: Global market trends impacting Nigerian bond pricing.

3.2 Yield Curve Estimation Models

A yield curve represents the relationship between bond yields and maturities. Several models were employed to construct and validate the yield curve for Nigerian energy bonds:

3.2.1 Nelson-Siegel Model

The Nelson-Siegel model is widely used for yield curve estimation due to its flexibility and interpretability. It captures short-term, medium-term, and long-term dynamics with the following formula:

$$y(t) = \beta_0 + \beta_1 * (1 - e^{(-\lambda t)}) / (\lambda t) + \beta_2 * ((1 - e^{(-\lambda t)}) / (\lambda t) - e^{(-\lambda t)}) \quad (1)$$

where:

i. $y(t)$ = yield at time t
ii. β_0 = long-term yield component
iii. β_1 = short-term deviation from long-term yield
iv. β_2 = medium-term component
v. λ = decay factor controlling the exponential weight

3.2.2 Svensson Model (Extended Nelson-Siegel)

The Svensson model extends the Nelson-Siegel approach by adding another term to better fit long-term trends:

$$y(t) = \beta_0 + \beta_1 * (1 - e^{(-\lambda_1 t)}) / (\lambda_1 t) + \beta_2 * ((1 - e^{(-\lambda_1 t)}) / (\lambda_1 t) - e^{(-\lambda_1 t)}) + \beta_3 * ((1 - e^{(-\lambda_2 t)}) / (\lambda_2 t) - e^{(-\lambda_2 t)}) \quad (2)$$

3.2.3 Vasicek Interest Rate Model

The Vasicek model is a stochastic process used to model interest rate movements:

$$dr_t = \alpha (\mu - r_t) dt + \sigma dW_t \quad (3)$$

where:

i. r_t = short-term interest rate
ii. α = mean reversion speed
iii. μ = long-term mean interest rate
iv. σ = volatility parameter
v. W_t = Wiener process (random component)

3.3 Risk-Adjusted Return Analysis

To assess bond attractiveness, the Sharpe Ratio was used:

$$S = (R_p - R_f) / \sigma_p \quad (4)$$

where:

i. S = Sharpe Ratio
ii. R_p = Portfolio return (Corporate Bond Yield)
iii. R_f = Risk-free return (Government Bond Yield)
iv. σ_p = Standard deviation of portfolio return

3.4 Scenario Analysis

Future bond yields were simulated under different inflation scenarios:

1. Low Inflation (70% of Current Inflation): Predicting how bond yields react under a stabilized economy.

2. Base Case (Current Inflation of 33.88%): Evaluating existing market conditions.

3. High Inflation (130% of Current Inflation): Assessing worst-case impacts on bond yields.

3.5 Model Validation and Back-Testing

To ensure reliability, the estimated yield curves were validated using:

i. Historical bond pricing data: Comparing model-predicted yields with actual bond prices.
ii. Out-of-sample testing: Evaluating model performance on unseen data.
iii. Error metrics (Root Mean Squared Error - RMSE): Measuring model accuracy.

$$RMSE = \sqrt{(1/n) * \Sigma (y_i - \hat{y}_i)^2} \quad (5)$$

where:

i. y_i = actual bond yield
ii. $\hat{y}_i$ = predicted bond yield
iii. n = number of observations

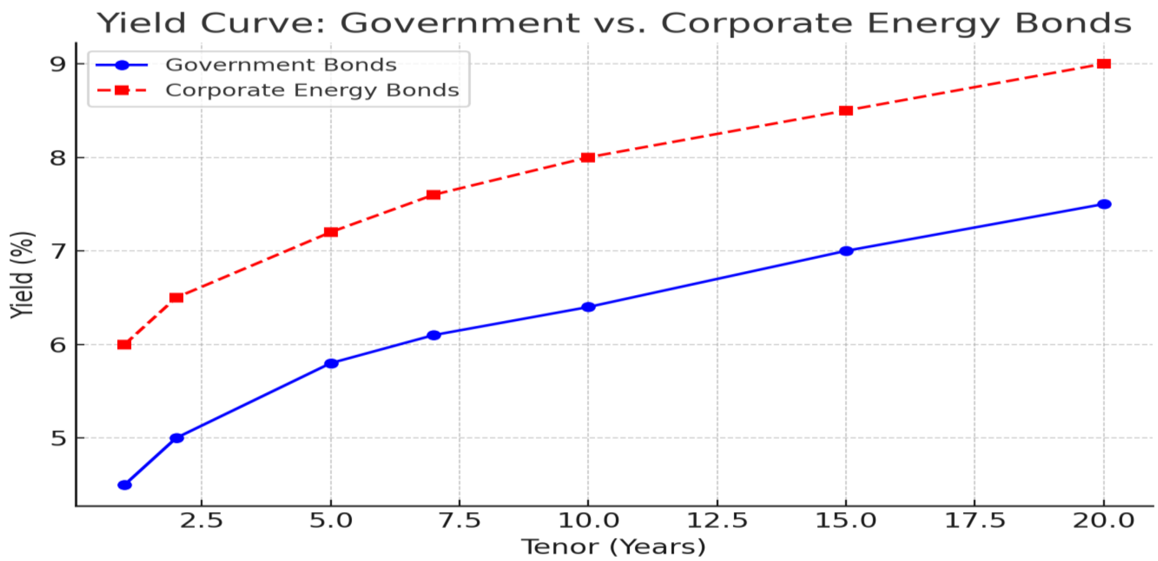
This study integrates yield curve estimation models, stochastic interest rate modeling, risk-adjusted return calculations, and scenario-based forecasting to provide a comprehensive framework for pricing and assessing energy infrastructure bonds in Nigeria. The methodologies chosen ensure accuracy, reliability, and practical applicability for policymakers and investors.

4. Results and Discussion

4.1 Yield Curve Analysis

Figure 1

Yield curve for government vs. corporate bonds



Note. Generated by the authors using data from the Nigerian Exchange Group (2024).

The yield curve is an essential tool for assessing the relationship between bond yields and maturities. In this study, we constructed yield curves for both government and corporate energy infrastructure bonds in Nigeria.

Figure 1 presents the yield curve for government and corporate energy bonds in Nigeria, highlighting distinct patterns in their pricing behavior. Government bonds show lower yields due to their lower risk profile, being backed by sovereign guarantees. In contrast, corporate energy bonds offer higher yields to compensate investors for added credit risk and sector-specific volatility. The upward slope of the yield curve suggests that longer-term bonds require higher returns, aligning with investor expectations for greater compensation over extended horizons. Moreover, the increasing spread between the two bond types reflects the risk premium investors' demand for holding corporate debt, underscoring the critical role of precise yield curve modeling in informed investment and policy decision-making.

4.2 Macroeconomic Impact on Bond Pricing

The pricing of energy infrastructure bonds is directly influenced by key macroeconomic factors such as inflation, interest rates, and exchange rates. High inflation reduces real returns, making bonds less attractive to investors.

Table 1

Real yields after inflation adjustment

Tenor (Years)	Gov Bond Yield (%)	Corp Bond Yield (%)	Real Gov Yield (%)	Real Corp Yield (%)
1.0	4.5	6.0	-21.945	-20.8246
2.0	5.0	6.5	-21.5716	-20.4512

5.0	5.8	7.2	-20.974	-19.9283
7.0	6.1	7.6	-20.7499	-19.6295
10.0	6.4	8.0	-20.5258	-19.3307
15.0	7.0	8.5	-20.0777	-18.9573
20.0	7.5	9.0	-19.7042	-18.5838

Note. Computed by the authors using data from NGX Bond Market Analysis (2024).

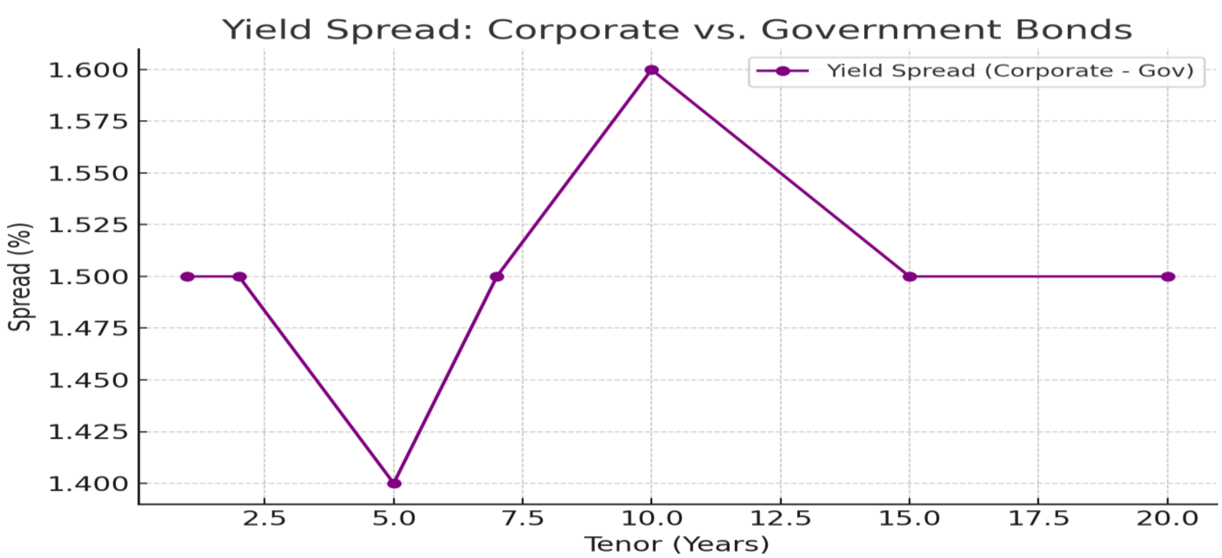
The analysis of real yields reveals that both government and corporate bonds are experiencing negative real returns due to Nigeria's high inflation rate of 33.88%. This erosion of purchasing power diminishes the attractiveness of fixed-income investments. While government bonds provide relatively better protection, their real yields still decline at a slower rate than corporate bonds. Corporate bonds, on the other hand, exhibit greater volatility, as they are more sensitive to macroeconomic fluctuations and inflationary pressures. To enhance bond market stability and investor confidence, policy measures such as the introduction of inflation-linked securities could help mitigate purchasing power risks and improve long-term investment appeal.

4.3 Risk-Adjusted Return Analysis

The risk-adjusted return analysis helps determine whether corporate energy bonds offer sufficient compensation for their additional risk relative to government bonds. The Sharpe Ratio is used to evaluate how much excess return an investor earns per unit of risk.

Figure 2

Yield spread between government and corporate bonds



Note. Produced by the authors using data from NGX Corporate Bond Reports (2024).

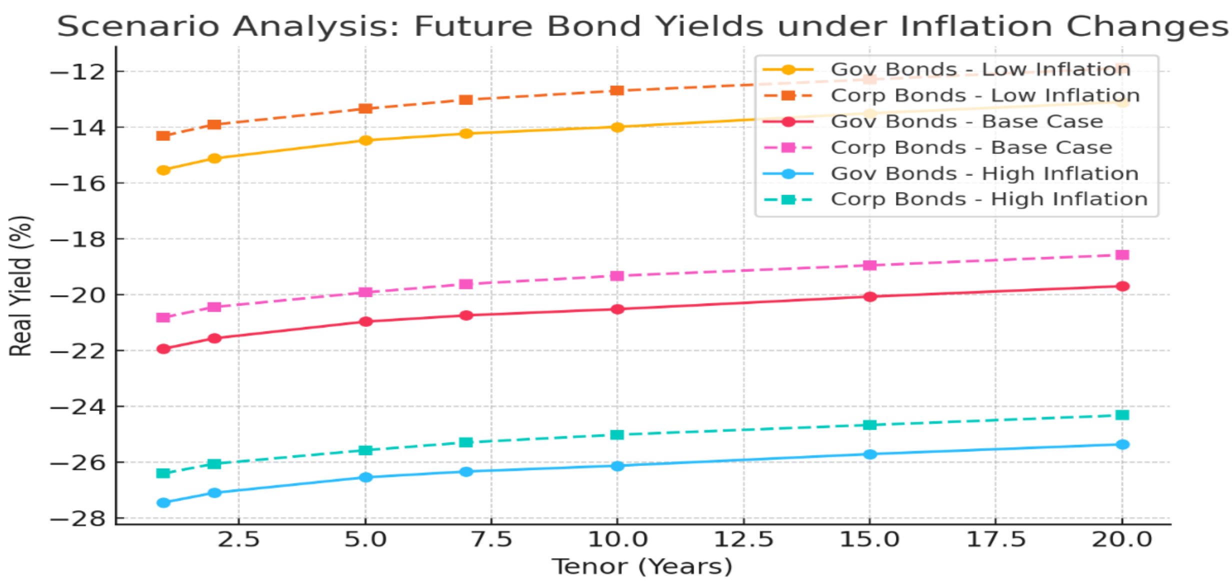
Figure 2 illustrates the yield spread between government and corporate bonds, highlighting the additional compensation investors demand for taking on corporate credit risk. The spread between the two bond types increases as corporate bonds carry higher risk, requiring higher returns to attract investors. This risk premium becomes even more pronounced for longer-tenor bonds, as economic uncertainties over extended periods necessitate greater compensation. Macroeconomic volatility, including inflation fluctuations and currency depreciation, further widens these spreads, reflecting the heightened uncertainty in Nigeria's financial markets. To address this, policy measures aimed at stabilizing inflation and reducing currency volatility could help lower risk premiums, ultimately improving bond market liquidity and encouraging more investment in corporate energy bonds.

4.4 Scenario Analysis for Future Bond Yields

Scenario analysis was conducted to assess how bond yields respond under different inflation scenarios. The results provide insights into potential future trends and how investors might react to economic conditions.

Figure 3

Scenario analysis of bond yields under inflation variations



Note. Simulated by the authors using data from Nigeria Sovereign Investment Authority (2024).

Figure 3 presents the scenario analysis of bond yields under varying inflation conditions, demonstrating how changes in inflation levels impact bond attractiveness. In a low inflation scenario, bond yields improve, making fixed-income investments more appealing as purchasing power erosion slows down. Under the base case scenario, where inflation remains at its current high level (33.88%), negative real yields persist, reducing investor confidence and making bonds less attractive unless interest rates are adjusted accordingly. In a high inflation scenario, real yields become even more negative, significantly increasing investment risk and discouraging bond purchases due to the diminished value of future cash flows. To mitigate these risks and enhance market stability, Nigeria must implement inflation-targeting policies and introduce instruments such as inflation-indexed bonds, ensuring that investors are protected against inflationary pressures while maintaining a stable and liquid bond market.

5. Conclusion and Recommendations

This study examined yield curve modeling for Nigerian energy infrastructure bonds, focusing on bond pricing, macroeconomic influences, and risk-adjusted returns. The findings reveal that government bonds consistently offer lower yields due to their lower risk profile, while corporate energy bonds require higher yields to compensate for increased credit and market risks. Inflation plays a crucial role in shaping bond market dynamics, as it significantly erodes real yields, making long-term investments less attractive unless returns are adjusted accordingly. Additionally, yield spreads widen over longer tenors, indicating that investors demand higher compensation for uncertainty in corporate bond markets. The scenario analysis further highlights that bond yields are highly sensitive to inflationary pressures and shifts in monetary policy, reinforcing the need for proactive financial strategies to mitigate risks and enhance market efficiency.

To improve bond market stability and investment attractiveness, several key policy measures should be considered. Inflation-protected securities should be introduced, such as inflation-linked bonds, to help investors hedge against purchasing power loss and enhance market confidence. Monetary policy coordination must be strengthened, with the Central Bank of Nigeria (CBN) implementing measures that stabilize inflation and interest rates, ensuring a predictable investment environment. Enhancing corporate bond market liquidity is also critical, as regulatory bodies should encourage greater private sector participation by offering credit enhancements and incentives that reduce financing costs for energy projects. Additionally, diversifying energy bond offerings through the promotion of innovative financial instruments such as green bonds and sukuk structures could attract international investors and foster sustainable energy development. Finally, institutional investors should adopt advanced risk management techniques, utilizing risk-adjusted return models to make informed investment decisions and safeguard portfolio performance in a volatile economic environment.

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