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Quantifying Exchange Rate Volatility and Financial Sensitivity in Indonesia's Energy Transition Financing

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Abstract: *Exchange rate risk remains a major financial barrier to long-term energy transition financing in emerging market economies. In Indonesia, renewable and clean energy projects are frequently exposed to currency mismatches, where revenues are predominantly denominated in Indonesian rupiah while capital expenditures and debt obligations are largely denominated in foreign currency, particularly the United States dollar. Previous studies emphasize that such mismatches significantly increase financial vulnerability in infrastructure projects (Siregar & Wihardja, 2023; OECD, 2024). This study quantitatively examines the magnitude of exchange rate risk and its implications for financial sustainability in Indonesia's energy sector. Using historical USD/IDR data from 2014–2024, exchange rate volatility is estimated and integrated into a scenario-based sensitivity analysis applied to long-term financial projections. The results indicate that while Indonesia's exchange rate volatility remains moderate relative to other emerging economies, its long-term financial implications are substantial when applied to large-scale, foreign-currency-funded energy investments. Sensitivity analysis further shows that exchange rate volatility, although less dominant than revenue growth, constitutes a critical risk factor for financial sustainability when combined with long-term funding exposure. These findings provide quantitative evidence supporting the need for structured currency risk management mechanisms in Indonesia's energy transition financing.*

Keywords: *Exchange Rate Volatility; Sensitivity Analysis; Energy Transition; Financial Sustainability; Indonesia*

Introduction

The acceleration of the global energy transition has increased demand for long-term financing of renewable and low-carbon infrastructure, particularly in emerging market and developing economies (EMDEs) (International Energy Agency [IEA], 2023; McKinsey & Company, 2023). Despite strong policy commitments, private investment remains constrained by structural financial risks, including currency mismatch and funding maturity gaps (World Bank, 2022; OECD, 2024)

Existing literature consistently identifies currency mismatch as a key barrier to infrastructure financing in EMDEs. However, most studies emphasize macro-financial stability or investment climate perspectives rather than project-level financial performance (Aizenman et al., 2012; OECD, 2024). While these studies establish the importance of exchange rate risk, they often stop short of quantifying its direct impact on long-term financial sustainability metrics such as cash flow resilience or debt service capacity.

In Indonesia, energy transition projects are commonly financed through foreign-denominated debt, while project revenues are primarily generated in Indonesian rupiah. This currency mismatch exposes project cash flows to exchange rate fluctuations over long investment horizons. Empirical evidence shows that even moderate exchange rate volatility can materially affect debt service capacity, internal rates of return, and investment incentives in infrastructure projects (Aizenman et al., 2012; Dixit & Pindyck, 1994; Persaud, 2023).

Policy discussions in Indonesia have largely focused on regulatory reform, tariff design, and institutional mechanisms to support renewable energy development (JETP, 2023; PwC, 2023). However, quantitative assessments of exchange rate risk and its direct financial implications remain limited. Existing studies often rely on qualitative analysis or short-term financial instruments that are poorly aligned with the long-term nature of energy infrastructure investments (Frensidy & Mardhaniaty, 2019; Asian Development Bank, 2022).

This indicates a clear empirical gap: although prior studies acknowledge exchange rate risk, there is limited evidence that systematically quantifies its relative importance compared to other financial variables within long-term project finance models. Moreover, existing approaches rarely integrate historical volatility measures into forward-looking financial projections, resulting in a disconnect between observed exchange rate behavior and its modeled financial consequences (Climate Policy Initiative, 2024; World Bank, 2022).

Unlike prior studies that treat exchange rate risk qualitatively or as an exogenous assumption, this study introduces a structured integration of empirically estimated volatility into project-level financial sensitivity analysis. This approach enables a direct comparison of exchange rate risk against conventional financial drivers (e.g., revenue growth, inflation), thereby offering a more granular and operational perspective on financial sustainability in energy transition investments.

Exchange Rate Volatility and Long-Term Project Finance

Exchange rate volatility is a well-established source of financial risk in long-term infrastructure and project finance, particularly in EMDEs. When revenues and liabilities are denominated in different currencies, exchange rate fluctuations can significantly alter debt servicing costs and net cash flows (Campbell et al., 1997; Brealey et al., 2020). Empirical studies show that higher exchange rate volatility increases financing costs and discourages private investment in capital-intensive sectors such as energy and transport (Ben Yahmed et al., 2024; OECD, 2024).

Renewable energy projects are especially exposed to this risk due to their long asset lifetimes and limited revenue flexibility. Electricity tariffs are typically fixed through long-term contracts, restricting revenue adjustments in response to currency movements (Gatzert & Kosub, 2016; PwC, 2023). Consequently, prolonged currency depreciation can materially weaken financial performance even when operational indicators remain stable (Kermanshah & Torkamani, 2021).

Quantitative Measurement of Exchange Rate Risk

Quantitative assessments of exchange rate risk commonly rely on historical volatility measures derived from time-series exchange rate data. Historical volatility, calculated as the standard deviation of logarithmic returns, provides a robust empirical estimate of currency fluctuation magnitude (Hull, 2018; Campbell et al., 1997). Although econometric models such as GARCH capture time-varying volatility, descriptive volatility measures remain widely used in applied financial risk analysis due to their transparency and interpretability (Ben Yahmed et al., 2024; IMF, 2023).

In project finance applications, historical volatility is frequently integrated into scenario analysis and stress-testing frameworks. These methods translate abstract volatility measures into concrete financial impacts by simulating adverse exchange rate movements and evaluating their effects on long-term cash flows and financial sustainability (Climate Policy Initiative, 2024; World Bank, 2022).

Sensitivity Analysis in Financial Sustainability Assessment

Sensitivity analysis is a core quantitative technique used to evaluate the robustness of long-term financial projections under uncertainty. By systematically varying key input variables, sensitivity analysis identifies dominant financial risk drivers and their relative importance (Saltelli et al., 2008; Brealey et al., 2020). In infrastructure finance, commonly tested variables include revenue growth, operating costs, inflation, interest rates, and exchange rates (ADB, 2022).

Tornado and spider charts are widely employed to visualize sensitivity results. Tornado charts rank variables based on their marginal impact, while spider charts illustrate financial elasticity under simultaneous parameter changes (Climate Policy Initiative, 2024; McKinsey & Company, 2023).

Exchange Rate Risk in Indonesia's Energy Sector

In Indonesia, several studies highlight structural exposure to foreign exchange risk due to reliance on foreign-denominated financing and limited availability of long-term local currency instruments (Siregar & Wihardja, 2023; World Bank, 2023). Although policy instruments such as government guarantees and tariff indexation have been introduced, empirical evaluations of their quantitative effectiveness remain limited (Asian Development Bank, 2022; IMF, 2023).

This study extends the literature by integrating historical volatility estimation with sensitivity analysis to assess exchange rate risk in a financially explicit manner. By linking macro-level exchange rate dynamics to long-term financial sustainability outcomes, the study contributes to a more operational understanding of currency risk in energy transition financing (Persaud, 2023; Climate Policy Initiative, 2024).

Methodology

Research Design

This study employs a quantitative descriptive research design to assess exchange rate risk and its implications for long-term financial sustainability in Indonesia's energy transition financing. The analysis focuses on two complementary quantitative components: (i) historical exchange rate volatility estimation and (ii) scenario-based sensitivity analysis.

This approach allows for a direct translation of exchange rate fluctuations into measurable financial impacts, consistent with applied financial risk assessment practices in infrastructure finance (Hull, 2018; CPI, 2024).

Rather than estimating predictive econometric models, the study emphasizes empirical volatility measurement and deterministic sensitivity testing. This design is appropriate for evaluating long-term financial exposure under uncertainty while maintaining transparency and interpretability for policy and investment analysis.

Data Sources

Two primary datasets are utilized in this study. First, historical USD/IDR exchange rate data covering the period 2014–2024 are used to estimate exchange rate volatility. The data are obtained from publicly available financial databases and represent end-of-period observations. This period captures multiple phases of global and domestic economic stress, including commodity price shocks and the COVID-19 pandemic, thereby providing a robust basis for volatility estimation.

Second, financial data from PLN's income statements (2019–2023) are used as the basis for long-term financial projections. These data are employed to construct a forward-looking financial model for the period 2024–2043, consistent with the long-term funding horizon of energy transition investments. Key variables include revenue growth, operating expenses, inflation, taxation, and foreign currency exposure.

Exchange Rate Volatility Measurement

Exchange rate volatility is measured using historical volatility, calculated as the standard deviation of logarithmic returns of the USD/IDR exchange rate. Let St denote the exchange rate at time ttt. The logarithmic return rt is defined as:

Historical volatility σ is computed as:

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{t=1}^{n}(r_t - \bar{r})^2}$$

where r represents the mean return and n denotes the number of observations. Weekly volatility is derived directly from weekly returns, while annualized volatility is calculated by scaling weekly volatility by the square root of 52, following standard financial practice (Hull, 2018).

This method provides an empirical measure of exchange rate fluctuation magnitude and is widely used in applied risk analysis due to its simplicity and transparency.

Sensitivity Analysis Framework

Sensitivity analysis is conducted to evaluate the relative importance of key financial variables in determining long-term financial outcomes. The analysis focuses on four primary variables: revenue growth, USD/IDR exchange rate volatility, inflation, and tax rate.

Two complementary sensitivity techniques are employed. First, tornado analysis is used to assess the impact of individual variable shocks on long-term financial outcomes. Each variable is independently varied within a predefined range while holding other

variables constant. The resulting changes in projected financial outcomes are ranked to identify dominant risk drivers.

Second, spider analysis is applied to examine the elasticity of financial outcomes under simultaneous changes in multiple variables. This approach provides insight into the relative sensitivity of financial sustainability to concurrent risk factors and highlights potential interaction effects.

Result and Discussion

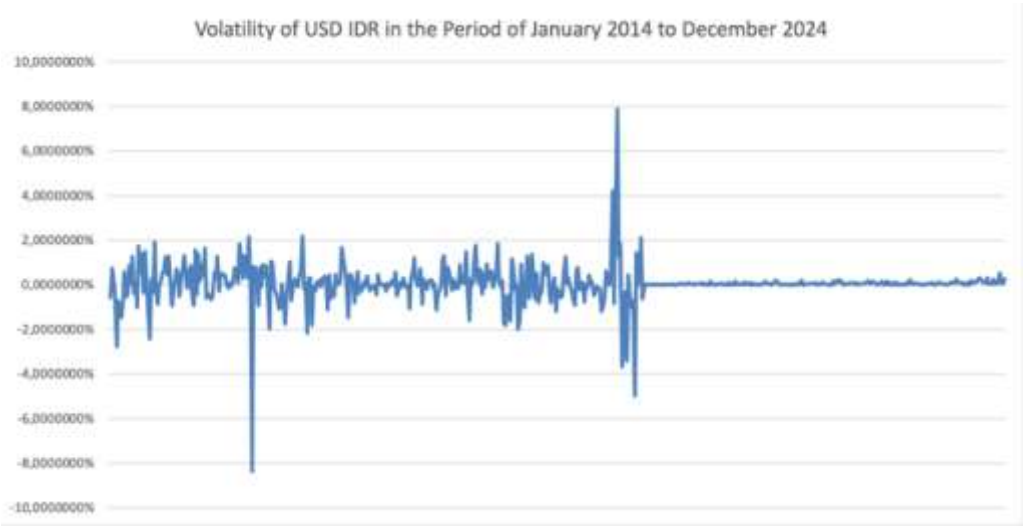

Figure 1. USD/IDR Trends 2014-2024 (Author Analysis, 2025)

The historical analysis of the USD/IDR exchange rate over the period 2014–2024 indicates a moderate but persistent level of volatility. Weekly logarithmic returns exhibit relatively stable dispersion during normal periods, with pronounced spikes observed during episodes of global financial stress, particularly during the COVID-19 pandemic and periods of heightened global monetary tightening.

The estimated annualized volatility of the USD/IDR exchange rate falls within the range commonly observed in emerging market economies. Although this volatility is lower than that of several commodity-dependent or highly dollarized economies, it remains sufficiently large to generate material financial impacts when applied to long-term, foreign-currency-funded energy investments. These findings are consistent with previous empirical studies highlighting that even moderate volatility can translate into substantial financial risk over extended investment horizons (Ben Yahmed et al., 2024; OECD, 2024).

The financial relevance of this "moderate" volatility lies in its cumulative effect rather than its short-term magnitude. In project finance structures, exchange rate fluctuations directly affect debt servicing obligations denominated in foreign currency, while revenues remain fixed in local currency. This creates an asymmetric risk exposure, where downside effects (currency depreciation) are not fully offset by corresponding upside gains, particularly under fixed tariff regimes.

The impact becomes most pronounced under conditions of prolonged depreciation trends, global liquidity tightening, or external shocks that simultaneously affect exchange

rates and financing costs. Under such scenarios, even historically "normal" volatility levels can trigger financial stress, especially in projects with high leverage ratios and limited refinancing flexibility.

From a financial sustainability perspective, the results suggest that exchange rate stability at the macro level does not necessarily imply low project-level currency risk. When foreign-denominated obligations are sustained over 15–20 years, cumulative exposure amplifies the financial effect of relatively small exchange rate movements.

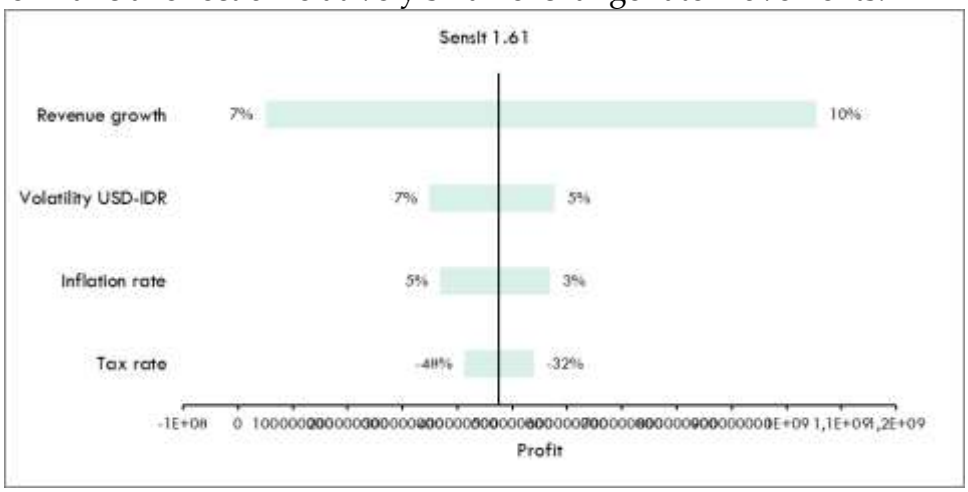

Figure 2. Tornado Chart Sensitivity Analysis (Author Analysis, 2025)

The results of the tornado sensitivity analysis reveal clear differences in the relative importance of financial risk drivers. Revenue growth emerges as the most influential variable affecting long-term financial outcomes. Variations in revenue growth rates produce the largest changes in projected cash flows, reflecting the central role of demand and tariff realization in sustaining long-term financial performance.

Exchange rate volatility ranks as the second most significant risk factor, exceeding the impact of inflation and taxation variables. This finding underscores the importance of currency risk in the financial structure of Indonesia's energy transition financing. While inflation and tax rate changes affect operating margins, their financial impacts are more gradual and partially offset by nominal revenue growth.

Spider analysis further confirms these results by illustrating the elasticity of financial outcomes to simultaneous changes in key variables. Financial sustainability indicators show relatively steep slopes in response to exchange rate shocks, indicating a high degree of sensitivity. This pattern suggests that exchange rate risk does not operate in isolation but compounds other financial pressures, particularly under adverse revenue scenarios.

Based on the findings, this study implies a structured financial risk transmission framework consisting of three interconnected layers:

1. Macroeconomic Layer
   Exchange rate volatility driven by global financial conditions, capital flows, and monetary policy dynamics.
2. Financial Structure Layer

Currency mismatch between foreign-denominated debt and local currency revenues, combined with long-term financing structures.

3. Project-Level Outcomes
   Impacts on cash flow stability, debt service capacity, and overall financial sustainability.

The framework operates through a cumulative transmission mechanism: exchange rate shocks affect debt servicing costs → alter net cash flows → reduce financial resilience over time. This effect is amplified by long project durations and limited revenue flexibility. By embedding exchange rate volatility within a sensitivity analysis framework, the model enables explicit comparison between currency risk and other financial variables, providing a more operational tool for risk prioritization in energy transition financing.

Discussion

Combined volatility and sensitivity results indicate that exchange rate risk constitutes a structural vulnerability in Indonesia's energy transition financing. Although revenue growth remains the dominant determinant of financial sustainability, exchange rate volatility significantly affects the resilience of long-term cash flows. In the absence of effective mitigation mechanisms, prolonged currency depreciation can materially weaken debt service capacity and erode financial buffers.

These findings reinforce existing arguments that reliance on foreign-currency financing without adequate risk-sharing mechanisms may undermine the long-term viability of clean energy investments. Importantly, the results suggest that short-term exchange rate stability should not be interpreted as an indicator of long-term financial safety. Instead, cumulative exposure over long maturities amplifies the financial impact of exchange rate movements.

From a comparative standpoint, Indonesia's exchange rate volatility is lower than that observed in several peer emerging economies with higher macroeconomic instability. However, the sensitivity analysis demonstrates that relative volatility levels are less important than financial exposure structure. Economies with similar volatility but lower foreign currency dependence would experience significantly smaller financial impacts.

This observation implies that reducing foreign currency exposure, rather than solely targeting exchange rate stabilization, may offer a more effective pathway to improving financial sustainability. Comparative insights therefore serve as a contextual complement rather than the central focus of the analysis.

Overall, the results highlight that exchange rate volatility represents a quantifiable and material financial risk in Indonesia's energy transition financing. While not the single dominant factor, currency risk interacts with revenue uncertainty to shape long-term financial outcomes. These findings align with prior studies emphasizing the importance of aligning currency denomination of revenues and liabilities in infrastructure finance (Persaud, 2023; CPI, 2024).

The analysis contributes to the literature by providing empirical evidence that bridges macro-level exchange rate dynamics with project-level financial sustainability

assessment. By explicitly quantifying the role of exchange rate volatility within a sensitivity framework, the study offers a clearer basis for evaluating risk mitigation strategies in energy transition financing.

Conclusion

This study provides a quantitative assessment of exchange rate volatility and its implications for long-term financial sustainability in Indonesia's energy transition financing. Using historical USD/IDR exchange rate data and a sensitivity analysis framework applied to long-term financial projections, the study demonstrates that exchange rate volatility constitutes a material financial risk, even when macro-level volatility appears moderate.

The results indicate that revenue growth remains the dominant determinant of long-term financial sustainability. However, exchange rate volatility ranks as the second most influential risk factor, exceeding the impact of inflation and taxation. This finding highlights the structural vulnerability created by foreign currency exposure in long-term energy investments. Over extended maturities, relatively small exchange rate fluctuations can accumulate into substantial financial impacts on cash flows and debt service capacity.

From a theoretical standpoint, this study contributes to the literature by operationalizing exchange rate volatility into quantifiable financial sensitivity outcomes at the project level. It extends existing macroeconomic risk frameworks by explicitly linking exchange rate dynamics with long-term financial sustainability metrics, thereby narrowing the gap between macro-level analysis and project-based financial modeling in the context of energy transition financing.

In terms of practical implications, the findings suggest that enhancing financial sustainability requires a more structural approach beyond conventional regulatory reforms and tariff adjustments. Policymakers and financial institutions should prioritize reducing foreign exchange exposure, expanding access to long-term local currency financing instruments, and developing risk-sharing or hedging mechanisms. These strategies are likely to provide stronger financial resilience compared to reliance on short-term exchange rate stabilization policies alone.

Nevertheless, this study is subject to several limitations. The analysis relies on deterministic assumptions within the sensitivity framework and does not incorporate stochastic or probabilistic simulations that could better capture exchange rate uncertainty. Additionally, the model does not account for dynamic hedging strategies or institutional responses that may mitigate currency risk over time. These limitations suggest avenues for future research, particularly in integrating probabilistic risk modeling, dynamic financial strategies, and cross-country comparative analysis to enhance the robustness and generalizability of the findings.

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