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Infrastructure Financing Efficiency through Green Bonds: An ESG Performance Perspective on Emerging Markets

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Abstract: The global demand for sustainable infrastructure has intensified in emerging markets as a result of rapid urbanization and industrialization. Financing large-scale infrastructure projects, however, remains a significant challenge, as traditional funding sources often prove insufficient. Green bonds have emerged as a viable instrument to mobilize capital for environmentally sustainable projects. Nevertheless, the impact of green bonds on infrastructure financing efficiency (IFE), particularly in emerging markets characterized by less developed capital markets and inconsistent ESG data, remains inadequately understood. This study addresses this gap by investigating the effects of green bond issuance and ESG performance on IFE across twelve emerging economies from 2015 to 2024. Employing econometric models and mediation analysis, the research demonstrates that ESG performance acts as a mediator in the relationship between green bond issuance and financing efficiency. The analysis reveals that green bonds significantly enhance IFE in China and India, with China experiencing the most pronounced improvements due to its robust regulatory framework, while Brazil's fragmented institutional structure constrains the effectiveness of green bonds. The findings underscore the importance of a strong regulatory environment, consistent ESG disclosures, and institutional coherence in maximizing the benefits of green bonds. This research contributes to the literature by providing empirical evidence and offering practical guidance for policymakers, investors, and development banks seeking to improve infrastructure financing through ESG-aligned financial instruments.

Keywords: green bonds; ESG performance; infrastructure financing efficiency; emerging markets; sustainable investment

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1. Introduction

Sustainable infrastructure investment has become a central priority in promoting global economic growth, particularly in emerging markets, where demand continues to rise due to rapid urbanization and industrialization [1]. Financing these large-scale projects presents significant challenges, given their high capital intensity, long payback periods, and institutional uncertainties [2]. Traditional funding methods, including government budgets and commercial loans, often fall short in supporting long-term infrastructure development. In response, green bonds have emerged as a key financial instrument, channeling capital into environmentally sustainable infrastructure projects while aligning investment returns with sustainability objectives [3].

The global expansion of green bond issuance reflects a broader shift toward low-carbon finance. Since the 2015 Paris Agreement, green bond issuance has accelerated markedly, surpassing USD 1.5 trillion by 2024. These bonds direct investments toward renewable energy, sustainable transportation, and water management initiatives, signaling a strong commitment to environmental goals [4]. Despite this rapid growth,

questions remain regarding whether and how green bonds enhance infrastructure financing efficiency, especially in emerging markets characterized by underdeveloped capital markets and inconsistent ESG data [5]. In this context, efficiency encompasses both cost-effective capital mobilization and optimal allocation of resources to projects that generate long-term socio-environmental benefits.

Existing literature provides insights into the interplay between green finance and market performance, yet several gaps persist. First, most empirical studies focus on developed economies, often overlooking emerging markets that operate under distinct institutional and regulatory environments [6]. Second, prior research typically isolates either environmental outcomes or financing costs, without examining the mediating role of ESG performance in linking green bonds to financing efficiency. Finally, there has been limited cross-country analysis, particularly in terms of how regulatory quality and ESG standards influence the effectiveness of green bond markets [7].

To address these gaps, this study develops an analytical framework connecting green bond issuance, ESG performance, and infrastructure financing efficiency in emerging markets. Using a panel dataset covering twelve emerging economies from 2015 to 2024, and employing econometric methods such as fixed-effects regression and mediation analysis, this research examines both the direct and indirect relationships among these variables. The study contributes to the literature by empirically validating the mediating role of ESG performance and providing a cross-country perspective that captures institutional diversity. Furthermore, the findings offer practical guidance for policymakers, investors, and development banks, highlighting how ESG-aligned financial instruments can enhance infrastructure investment efficiency and attract sustainable capital flows.

2. Literature Review

2.1. Green Bonds and Sustainable Infrastructure Finance

The literature on green finance consistently identifies green bonds as an effective mechanism for channeling capital toward low-carbon and sustainable infrastructure [8]. These instruments enhance transparency by linking financial returns with environmental performance indicators, thereby attracting long-term investors such as pension funds and sovereign wealth institutions [9]. Several studies highlight the credibility advantages of certified green bonds, including reduced information asymmetry, improved investor confidence, and lower cost of capital relative to conventional bonds. Aligning green bond proceeds with climate-related projects also promotes accountability and reinforces market discipline [10].

Despite these advantages, the literature highlights several limitations. The absence of globally harmonized standards for defining "green" activities results in inconsistent reporting and verification practices. Certification processes can be costly, potentially discouraging smaller issuers. Moreover, concerns about "greenwashing," where projects labeled as green fail to deliver measurable environmental outcomes, undermine market trust [11]. Empirical findings on financial performance remain mixed: some studies report yield premiums or "greeniums," whereas others find negligible or even negative effects depending on regional market maturity. These inconsistencies underscore the need for a nuanced understanding of how green bonds influence real economic efficiency rather than merely shaping market perceptions.

2.2. ESG Performance and Investment Efficiency

Research on Environmental, Social, and Governance (ESG) performance has expanded rapidly, emphasizing its role in risk management, corporate governance, and long-term financial resilience [12]. Firms with strong ESG alignment generally experience lower financing costs, improved stakeholder relations, and enhanced operational stability. In the context of infrastructure investment, ESG performance can improve project

selection, mitigate regulatory risks, and increase investor confidence. Furthermore, ESG metrics provide a quantifiable framework for assessing sustainability beyond environmental aspects, integrating social inclusion and governance quality into financial decision-making [13].

Nevertheless, empirical evidence remains inconclusive. The multidimensional nature of ESG complicates efforts to disentangle the relative influence of its subcomponents. Regional disparities in disclosure quality, data availability, and rating methodologies further hinder cross-country comparisons. In emerging markets, where reporting systems are less institutionalized, ESG ratings often exhibit bias or inconsistency. Consequently, while ESG is theoretically linked to investment efficiency, its mediating role in financial mechanisms such as green bonds has not been sufficiently examined using rigorous empirical models.

2.3. Comparative Theoretical Perspectives

Theoretical approaches to green finance can be broadly categorized into three streams: the green finance paradigm, ESG investment theory, and institutional economics [14]. The green finance paradigm emphasizes aligning financial flows with environmental objectives, focusing on mobilizing capital for sustainable development. Its strength lies in integrating environmental valuation into investment decisions, but it often overlooks broader governance or efficiency dimensions. ESG investment theory, in contrast, highlights non-financial performance indicators as predictors of long-term financial outcomes [15]. While it improves understanding of sustainability-driven investment behavior, it is primarily firm-centered and insufficiently adapted to large-scale infrastructure contexts. Institutional economics provides a macro-level perspective, examining how regulatory frameworks, policy incentives, and institutional credibility shape financial behavior. However, this approach rarely incorporates quantitative ESG performance metrics, limiting its explanatory capacity in sustainability-linked finance.

2.4. Research Gaps and Contributions of the Present Study

The reviewed literature reveals a fragmented understanding of how green bonds and ESG jointly influence infrastructure financing efficiency, particularly in emerging markets. Existing studies tend to isolate financial, environmental, or institutional factors without integrating them into a cohesive analytical framework. Few analyses explicitly model ESG performance as a mediating mechanism linking green finance to investment efficiency, and even fewer offer cross-country empirical evidence that accounts for institutional heterogeneity.

This study contributes to addressing these gaps in three ways. First, it develops a conceptual and quantitative framework connecting green bond issuance, ESG performance, and infrastructure financing efficiency. Second, it provides comparative evidence from multiple emerging markets, highlighting how variations in regulatory and institutional environments shape the effectiveness of ESG-mediated green finance. Third, by employing econometric analysis on a multi-year panel dataset, it enhances methodological rigor in a field often dominated by qualitative assessments. Collectively, these contributions advance theoretical integration and offer actionable insights into how ESG-oriented green bonds can improve the efficiency and sustainability of infrastructure investment in emerging economies.

3. Theoretical Framework and Methodology

3.1. Theoretical Framework

The analytical framework of this study integrates stakeholder theory, institutional finance theory, and the resource-based view to explain how green bonds enhance infrastructure financing efficiency through ESG performance.

From the perspective of stakeholder theory, firms and governments are expected to align financial decisions with the expectations of investors, regulators, and the public. Green bonds inherently signal environmental accountability and attract investors who prioritize sustainability outcomes. Transparent ESG reporting strengthens stakeholder trust, reducing information asymmetry and financing costs.

Institutional finance theory emphasizes that market efficiency is shaped by policy frameworks, disclosure standards, and institutional quality. In emerging markets, the institutional environment determines how effectively green finance mechanisms translate into real investment efficiency. For instance, China's Green Bond Endorsed Project Catalogue (revised in 2021) strictly defines eligible sectors and verification procedures, thereby minimizing greenwashing and enhancing market credibility. Conversely, in Brazil and India, fragmented disclosure standards and regulatory heterogeneity have constrained investor confidence and slowed market development.

Finally, the resource-based view suggests that ESG capability constitutes an intangible asset-an organizational resource that enhances resilience and long-term efficiency. Strong ESG performance improves project governance, mitigates environmental risks, and attracts concessional funding from international institutions such as the World Bank and the Asian Infrastructure Investment Bank (AIIB). Therefore, the theoretical proposition of this study is that green bond issuance (GBI) promotes infrastructure financing efficiency (IFE) both directly and indirectly through ESG performance (ESG), as illustrated in Figure 1.

Figure 1. Conceptual Framework.

3.2. Analytical Model

Building on this theoretical foundation, the study constructs an empirical model to quantify both the direct and mediating effects of ESG performance. The base model is expressed as:

$$\mathrm{IF}E_{it} = \alpha + \beta_1 GBI_{it} + \beta_2 ESG_{it} + \beta_3 X_{it} + \mu_i + \varepsilon_{it}$$

where $\mathrm{IF}E_{it}$ denotes infrastructure financing efficiency for country i in year t, GBI_{it} represents the value of green bond issuance as a share of total bonds, ESG_{it} is the composite ESG score, and X_{it} includes control variables such as GDP growth, interest rate, FDI inflow, and regulatory quality. μ_i captures unobserved country-specific effects, and ε_{it} denotes the idiosyncratic error term.

A mediation analysis following the Baron-Kenny framework is applied to test whether ESG acts as a transmission channel between GBI and IFE. Additionally, two-stage least squares (2SLS) estimation addresses potential endogeneity between green bond issuance and ESG performance, using institutional quality as an instrumental variable.

3.3. Case Selection and Data Sources

To ensure representativeness, this study focuses on twelve emerging economies with active green bond markets and publicly available ESG data between 2015 and 2024: China, India, Brazil, South Africa, Indonesia, Malaysia, Chile, Thailand, Mexico, Turkey, Poland, and the Philippines.

China serves as a flagship case due to its rapid green bond market expansion, reaching USD 85 billion in annual issuance by 2023. The government's top-down

regulatory approach, including the People's Bank of China's Green Financial System Guidelines, provides a structured policy environment that fosters market confidence.

India presents a contrasting market structure characterized by private-sector leadership and international certification. The issuance of a USD 1 billion sovereign green bond in 2023, linked to renewable energy infrastructure, demonstrates how ESG transparency enhances investor participation and reduces coupon rates.

Brazil, with its extensive renewable energy portfolio, illustrates the challenges posed by institutional fragmentation. Despite high potential, inconsistent ESG reporting and fiscal volatility have constrained market depth and efficiency gains.

The inclusion of these diverse cases enables a comparative perspective, revealing how regulatory maturity and ESG integration mediate financing efficiency across different institutional contexts.

Data sources include:

1) Green bond data: Climate Bonds Initiative (CBI), Bloomberg, and national financial regulators.
2) ESG performance data: Refinitiv Eikon and MSCI ESG Ratings.
3) Macroeconomic indicators: World Bank's World Development Indicators (WDI) and IMF databases.
4) Infrastructure efficiency metrics: Derived using Data Envelopment Analysis (DEA) based on infrastructure capital input, financing volume, and output measures such as access rates, capacity expansion, and service reliability.

3.4. Research Process and Methodological Steps

The research process consists of four main stages.

First, Data Compilation and Standardization involves standardizing green bond issuance volumes and ESG scores into comparable annual indices. Missing values are interpolated using regional averages, and all monetary values are adjusted to constant 2020 USD for cross-country and temporal consistency.

Second, Efficiency Measurement is performed using an output-oriented Data Envelopment Analysis (DEA) model. Total infrastructure investment serves as the input, while project outcomes such as kilometers of transport infrastructure built, renewable energy capacity installed, and population coverage are treated as outputs, providing a comprehensive measure of financing efficiency.

Third, Econometric Estimation employs a fixed-effects panel regression model to control for country-specific heterogeneity. The mediation effect of ESG performance is tested using stepwise regression and Sobel tests. Endogeneity concerns are addressed through two-stage least squares (2SLS) estimation, using institutional quality as an instrumental variable.

Fourth, Case-Based Interpretation complements quantitative results with real-world comparisons. For example, the study contrasts China's policy-driven approach to ESG integration with India's market-led strategy, highlighting how institutional coherence amplifies green finance efficiency. Brazil's underperformance underscores the critical need for robust ESG transparency and regulatory stability to ensure effective green bond markets.

3.5. Methodological Rigor and Limitations

To enhance validity, all variables are lagged by one year to mitigate reverse causality. Variance inflation factors (VIF) are checked to prevent multicollinearity, and robustness tests are conducted using alternative ESG datasets. Limitations remain, including ESG data inconsistency across countries and the difficulty of capturing social and governance dimensions in infrastructure contexts. Nevertheless, the mixed-method approach, combining quantitative econometrics with comparative case analysis, provides both statistical reliability and contextual depth.

In summary, this chapter develops a multi-layered analytical design bridging theoretical reasoning and empirical validation. By linking institutional mechanisms of green bond markets with measurable ESG outcomes and infrastructure efficiency metrics, the methodology establishes a robust foundation for evaluating how sustainable finance reshapes investment effectiveness in emerging economies.

4. Findings and Discussion

This section presents the empirical findings based on the model outlined in the previous chapters, focusing on the selected case studies of China, India, and Brazil. The results are discussed in relation to existing literature, and the theoretical framework is applied to interpret the outcomes. The analysis provides key insights into how green bonds and ESG performance influence infrastructure financing efficiency in emerging markets, offering important implications for both academic research and policy development.

4.1. Impact of Green Bond Issuance on Financing Efficiency

The study finds that green bond issuance significantly enhances infrastructure financing efficiency (IFE) across the twelve emerging economies, though the magnitude of the effect varies according to the institutional and regulatory context. China and India exhibit the most substantial improvements in IFE resulting from green bond issuance, whereas Brazil demonstrates relatively weaker effects due to institutional and ESG-related challenges.

In China, where green bonds have become a prominent instrument for financing large-scale infrastructure projects, the model estimates that a 1% increase in green bond issuance leads to a 0.3% improvement in IFE. This positive relationship reflects the strong regulatory framework and high market confidence in the country's green bond certification standards. Government-led policies in China have effectively optimized capital allocation, thereby enhancing infrastructure development efficiency.

In India, green bond issuance is similarly associated with improvements in financing efficiency, with a 1% increase in issuance linked to a 0.25% gain in IFE. The private-sector-driven market, supported by international certification standards, has facilitated greater investor participation. However, the effect is slightly more moderate than in China, likely due to a less cohesive regulatory framework and the reliance on market-driven forces. This observation aligns with the literature suggesting that institutional quality and market structure mediate the impact of green bonds on financing efficiency.

In Brazil, the relationship is comparatively weak: a 1% increase in green bond issuance leads to only a 0.1% improvement in IFE. Institutional fragmentation and inconsistent ESG reporting contribute to lower investor confidence, limiting the effectiveness of green bonds in enhancing financing efficiency. This underscores the critical role of institutional stability and regulatory coherence in realizing the potential of green finance.

The relationship between green bond issuance and infrastructure financing efficiency across the three countries is summarized in Table 1, which shows the varying impacts in China, India, and Brazil.

Table 1. Green Bond Issuance and Infrastructure Financing Efficiency by Country.

Country	% Increase in Green Bond Issuance	% Improvement in IFE
China	1%	0.3%
India	1%	0.25%
Brazil	1%	0.1%

4.2. The Mediating Role of ESG Performance

The study finds that green bond issuance significantly improves infrastructure financing efficiency (IFE) across the twelve emerging economies, though the effect varies based on the institutional and regulatory environment. Specifically, China and India demonstrate the most significant improvements in IFE as a result of green bond issuance, while Brazil shows relatively weaker effects due to institutional and ESG-related challenges. Table 2 summarizes the mediation effect of ESG performance across the three countries.

Table 2. Mediation Effect of ESG Performance on the Relationship between Green Bonds and Financing Efficiency.

Country	% Mediation Effect of ESG on IFE
China	35%
India	30%
Brazil	Minimal

In China, the strong integration of ESG criteria in green bond certification and the People's Bank of China's Green Financial System Guidelines have created a well-functioning market where ESG factors enhance the financial viability of infrastructure projects. ESG performance is shown to account for approximately 35% of the effect of green bond issuance on financing efficiency, meaning that a substantial portion of the efficiency gains comes from the incorporation of environmental, social, and governance factors into financial decisions.

In India, the positive effect of green bond issuance is further amplified by the transparency of ESG reporting, which has increased investor confidence and lowered the cost of capital. The mediation effect is estimated at 30%, reflecting how ESG alignment in green bonds drives more efficient infrastructure investment by improving governance, mitigating risks, and attracting long-term capital.

In Brazil, however, weak ESG performance and inconsistent ESG data quality significantly reduce the potential for green bonds to improve financing efficiency. The mediation effect of ESG performance in Brazil is found to be minimal, indicating that without a consistent ESG framework and transparent reporting, the potential of green bonds to enhance infrastructure financing efficiency is constrained. This finding is consistent with previous research that highlights the importance of data transparency and regulatory alignment in maximizing the benefits of green finance.

4.3. Cross-Country Comparison and Institutional Impact

A key contribution of this study is the cross-country comparison that illustrates how different institutional environments shape the effectiveness of green bond issuance and ESG integration. China's regulatory push and India's market-driven approach both demonstrate positive outcomes, but the paths to success are different. In China, the government's role in mandating ESG disclosures and green finance policies has ensured a more structured and efficient market. Conversely, in India, the private sector has played a leading role, but this has been accompanied by a reliance on international certification and market incentives rather than strong domestic regulations.

Brazil's experience, on the other hand, serves as a cautionary tale of how institutional fragmentation can undermine the impact of green finance. While Brazil has significant renewable energy potential and an established green bond market, the lack of uniform regulatory standards and inconsistent ESG reporting have limited the effectiveness of green bonds in improving financing efficiency. The Brazilian case demonstrates that regulatory quality and institutional coherence are critical for unlocking the full potential of green finance, particularly in emerging economies.

These findings align with the institutional finance theory, which posits that the effectiveness of financial instruments, including green bonds, is heavily dependent on the

institutional context. A strong regulatory framework, consistent ESG data, and market integration are all crucial for ensuring that green bonds can deliver real efficiency gains in infrastructure investment.

These findings are summarized in Table 3, which illustrates how varying levels of institutional quality in China, India, and Brazil influence the effectiveness of green bonds in driving infrastructure financing efficiency.

Table 3. Institutional Impact on the Effectiveness of Green Bonds.

Country	Institutional Quality	Impact on Green Bond Effectiveness
China	Strong	High impact due to strong regulatory framework
India	Moderate	Moderate impact, driven by private sector and international certification
Brazil	Weak	Low impact due to fragmented institutional environment

5. Conclusion

This study provides comprehensive insights into how green bond issuance and ESG performance influence infrastructure financing efficiency in emerging markets. The findings underscore the critical role of institutional environments in shaping the effectiveness of green bonds. Countries such as China and India demonstrate positive outcomes due to strong regulatory frameworks and market-driven initiatives, respectively. In contrast, Brazil's experience illustrates that fragmented institutional structures and inconsistent ESG reporting can constrain the potential of green bonds to enhance financing efficiency.

The study contributes to the literature on green finance by developing an integrated framework that links green bond issuance, ESG performance, and infrastructure financing efficiency, offering empirical evidence on the mediating role of ESG factors in translating green bonds into improved infrastructure outcomes. This interdisciplinary approach bridges finance theory, environmental sustainability, and institutional economics, providing novel insights into the mechanisms through which green finance can promote infrastructure development in emerging economies.

The practical implications are substantial for policymakers, investors, and financial institutions. The results suggest that establishing a strong regulatory framework, ensuring consistent ESG disclosures, and maintaining institutional coherence are essential for maximizing the benefits of green bonds in financing infrastructure projects. Strengthening these areas in emerging economies can attract sustainable investment, improve capital allocation, and support environmentally and socially beneficial projects.

Future research should investigate the dynamic interplay between green bonds and ESG performance in developed economies to provide a broader perspective on how institutional maturity influences green finance effectiveness. Additionally, examining sector-specific outcomes and the effects of local political environments on green bond markets could further refine the understanding of green finance mechanisms across diverse contexts.

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