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The Impact of Technology Adoption, Monetary Policy, and Carbon Emissions an Green Finance in Asean-5

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Abstract

The purpose of this research is to analyze the influence of AI adoption, monetary policy (represented by interest rates), and carbon emissions on green finance, specifically green bonds, in ASEAN-5 countries. The focus of the research is on mapping the trends and measuring the causal impact of Government AI Readiness Index, policy interest rate, and carbon emissions per capita on the value of outstanding green bonds in Indonesia, Malaysia, Thailand, Philippines, and Singapore. This research uses panel data covering quarterly periods from Q1 2019 to Q4 2024. The variables consist of Government AI Readiness Index (as a proxy of technology readiness), policy interest rates from IMF, carbon emissions per capita from Our World in Data, and green bond value data from the Asian Development Bank. The method applied is Panel Least Square (PLS). The results show that all three independent variables significantly affect the development of green bonds. First, higher AI readiness positively drives green bond issuance by improving efficiency, accuracy, and transparency in financing green projects. Second, lower policy interest rates have a positive effect on green bond growth, as cheaper borrowing costs make sustainable projects more financially feasible. Third, higher carbon emissions correlate positively with increased issuance of green

bonds, as countries respond to environmental pressures and emission reduction demands.

(Tujuan penelitian ini adalah untuk menganalisis pengaruh adopsi teknologi kecerdasan buatan (AI), kebijakan moneter (diwakili oleh suku bunga), dan emisi karbon terhadap keuangan hijau, khususnya obligasi hijau (green bonds), di negara-negara ASEAN-5. Fokus penelitian adalah pada pemetaan tren dan pengukuran dampak kausal dari Government AI Readiness Index, suku bunga kebijakan, dan emisi karbon per kapita terhadap nilai outstanding green bonds di Indonesia, Malaysia, Thailand, Filipina, dan Singapura. Penelitian ini menggunakan data panel dengan periode triwulanan dari kuartal I 2019 hingga kuartal IV 2024. Variabel penelitian terdiri dari Government AI Readiness Index (sebagai proksi kesiapan teknologi), suku bunga kebijakan dari IMF, emisi karbon per kapita dari Our World in Data, serta nilai obligasi hijau dari Asian Development Bank. Metode analisis yang digunakan adalah Panel Least Square (PLS). Hasil penelitian menunjukkan bahwa ketiga variabel independen berpengaruh signifikan terhadap perkembangan obligasi hijau. Pertama, tingkat kesiapan AI yang lebih tinggi secara positif mendorong penerbitan obligasi hijau melalui peningkatan efisiensi, akurasi, dan transparansi dalam pembiayaan proyek berkelanjutan. Kedua, suku bunga kebijakan yang lebih rendah berdampak positif terhadap pertumbuhan obligasi hijau, karena biaya pinjaman yang lebih murah membuat proyek berkelanjutan lebih layak secara finansial. Ketiga, peningkatan emisi karbon berkorelasi positif dengan bertambahnya penerbitan obligasi hijau, seiring dengan respons negara-negara terhadap tekanan lingkungan dan tuntutan pengurangan emisi).

Keywords: AI Readiness; Interest Rates; Carbon Emissions; Green Bonds; ASEAN-5.

Introduction

Over the past two decades, the escalating climate crisis and environmental degradation have reshaped the global landscape of economic and financial policy making. Climate change has increasingly been recognized as a systemic risk with far-reaching implications for inflation, financial stability, exchange rates, and long-term growth. In response, central banks and fiscal authorities are urged to play a more active role in facilitating the transition toward a low-carbon economy. Within this framework, green finance has emerged as a strategic instrument both policy-driven and market-based encompassing green bonds, green loans, sustainable insurance, and other ESG-linked instruments. These mechanisms enable the financing of environmentally friendly projects such as renewable energy, clean transportation, and sustainable waste management. Yet, despite its potential, the outcomes of green finance remain heterogeneous: while some advanced economies have demonstrated significant emission reductions, developing and fossil-fuel-dependent countries continue to face structural constraints, highlighting a persistent gap between global green finance ideals and practical realities.

Literature has increasingly underscored the multifaceted role of green finance in promoting sustainable development. Empirical studies suggest that green finance can contribute to lowering carbon emissions in emerging markets when combined with robust governance and effective policy frameworks (Zhang et al., 2024; Saha & Maji, 2023). Monetary policy is also shown to be critical, as green projects—being capital-intensive and long-term are highly sensitive to interest rate movements (Aguila & Wullweber, 2024; Desalegn, 2022). In addition, the adoption of digital technologies, particularly Artificial Intelligence (AI), has been identified as a key enabler of green finance by enhancing efficiency, transparency, and monitoring capacity (Kuang et al., 2024; Xu, 2025). However, the benefits of AI are often asymmetric, constrained by digital infrastructure gaps and the energy demands of data centers. Taken together, existing scholarship reveals an important research gap: while the individual impacts of technology, monetary policy, and environmental pressures on green finance have been studied, their joint interaction in the context of emerging ASEAN economies remains underexplored.

The significance of this study lies in addressing that gap. ASEAN-5 countries, Indonesia, Malaysia, Thailand, the Philippines, and Singapore face the dual challenge of sustaining rapid economic growth while mitigating severe environmental pressures such as deforestation and urban pollution. This research introduces novelty by integrating three perspectives simultaneously: technological readiness (AI readiness), monetary policy (policy interest rates), and environmental pressures (carbon emissions per capita) as drivers of green bond development. The theoretical foundation builds upon endogenous growth theory (Romer, 1990), which highlights the role of innovation in sustaining long-term growth; Keynesian liquidity preference theory (Keynes, 1936), which emphasizes the influence of interest rates on investment decisions; and sustainable finance theory (Scholtens, 2006), which frames carbon emissions as a material risk shaping investor behavior. This integrated framework

allows for a more comprehensive understanding of the forces shaping sustainable finance in emerging markets.

Methodologically, this study employs a quantitative approach using quarterly panel data covering the period from Q1 2019 to Q4 2024. The dataset consists of the Government AI Readiness Index as a proxy for technological readiness, policy interest rates from the IMF, carbon emissions per capita from Our World in Data, and outstanding green bond values from the Asian Development Bank. Estimation is conducted using the Panel Least Squares (PLS) method to capture the causal influence of the independent variables on green bond development.

The remainder of this article is organized as follows. Section two describes the research methodology. Section three presents the findings and discussion, linking the results to broader economic and policy implications. The final section concludes by highlighting key contributions. Conceptually, this research advances the literature by offering an integrated framework that combines technology, monetary policy, and environmental pressure in analyzing sustainable finance. Empirically, it contributes by providing fresh evidence from ASEAN-5 economies, offering insights that can guide policymakers in strengthening green finance as a vehicle for low-carbon transition.

Research Method

This study employs a panel data approach, integrating both time series and cross-sectional dimensions, to examine the determinants of green bond development in ASEAN-5 countries: Indonesia, Malaysia, Thailand, the Philippines, and Singapore. The dataset comprises quarterly observations from Q1 2019 to Q4 2024, providing sufficient temporal and cross-country variation to capture the dynamics of green bond issuance in relation to technological readiness, monetary conditions, and carbon emission pressures. All data are sourced from reputable international institutions: the Government AI Readiness Index from Oxford Insights; policy interest rate data from the International Monetary Fund (IMF); CO_2 emissions data from Our World in Data; and green bond data from the Asian Development Bank (ADB). This period captures a critical phase in the evolution of sustainable finance, marked by accelerated green bond issuance following the Paris Agreement and the green recovery momentum during and after the COVID-19 pandemic. By focusing on ASEAN-5, the study targets the most active and policy-progressive segment of Southeast Asia's green finance landscape, which accounts for over 80% of the region's green bond issuance.

The empirical analysis combines descriptive statistics with panel regression, using the Panel Least Squares (PLS) method as the primary quantitative technique to estimate relationships among variables. Three standard panel models are tested: the Common Effect Model (CEM), which assumes homogeneity across units and time; the Fixed Effect Model (FEM), which allows intercepts to vary across countries; and the Random Effect Model (REM), which treats individual effects as random and uncorrelated with the explanatory variables. Model selection is guided by Chow, Hausman, and Breusch-Pagan Lagrange Multiplier tests. This analytical strategy

aligns with established practices in sustainable finance research, as demonstrated by studies such as Tang and Zhang (2020) and Flammer (2021), which applied panel models to explore the impacts of green bonds on firm-level and market-level outcomes.

In this study, Green Bonds are measured as the total outstanding nominal value of bonds issued to finance projects with certified environmental benefits, expressed in millions of USD (ADB, 2024). Artificial Intelligence is proxied by the Government AI Readiness Index, which assesses a country's preparedness to adopt AI within public services, scored on a scale from 1 to 100 (Oxford Insights, 2024). This index covers three pillars: government strategy and governance, technology sector maturity, and supporting data infrastructure. Policy Interest Rate represents the primary benchmark interest rate set by each country's central bank to guide short-term money market conditions and signal monetary policy stance, recorded in percentage terms (IMF, 2024). CO_2 Emissions are measured as annual per capita emissions from fossil fuel combustion and industrial processes, in billions of tons, excluding emissions from land-use changes such as deforestation (Our World in Data, 2024).

Overall, this methodological framework integrates credible multi-source panel data with rigorous statistical techniques, producing robust empirical evidence on how AI readiness, monetary policy, and environmental pressures collectively shape the dynamics of green bond issuance in ASEAN-5.

Results

This section presents the empirical findings of the study, including descriptive statistics, panel data regression analysis, model selection tests, and classical assumption tests. The discussion interprets these results in light of relevant literature and theoretical frameworks.

Table 4.1 displays the descriptive statistics of the four variables analyzed in ASEAN-5 (Indonesia, Malaysia, Singapore, Thailand, and the Philippines) over the study period. The variables are green bonds (LOG_GB), artificial intelligence adoption (AI), interest rates (i), and carbon emissions (LOG_CO_2).

Table 1. Descriptive Statistics

	LOG_GB	AI	i	LOG_CO2
Mean	8.025978	54.06970	3.013917	10.55253
Median	7.812410	60.97157	2.795000	10.53036
Max	9.984062	90.38781	6.500000	11.41679
Min	6.782408	-31.26869	0.390000	9.368292
Std. Dev	0.742802	25.63062	1.751340	0.728614
Obs	120	120	120	120

Source: Processed data (2025)

The average LOG_GB value (8.03) indicates moderate adoption of green bonds across ASEAN-5, with limited dispersion (Std. Dev 0.74). AI adoption shows a higher standard deviation (25.63) and a large negative minimum, suggesting significant

digital gaps between countries. The mean interest rate (3.01) points to moderately accommodative monetary policies, while the dispersion (1.75) reflects policy heterogeneity. Carbon emissions are relatively high and clustered, as shown by a mean of 10.55 and low standard deviation. These figures highlight structural diversity within ASEAN-5 in terms of financial innovation, technology readiness, and environmental impact.

Panel regression was estimated using three models: Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM).

Table 2. Panel Least Squares

Variables	***Common Effect Model* (CEM)**	***Fixed Effect Model* (FEM)**	***Random Effect Model* (REM)**
	Coeff (Prob.)	**Coef (Prob.)**	**Coeff (Prob.)**
AI	0.017650 (0.0000)**	0.016385 (0.0000)**	0.016347 (0.0000)**
I	0.0.161661 (0.0000)**	0.150067 (0.0000)**	0.154827 (0.0000)**
LOG_CO2	0.155303 (0.0578)	0.491351 (0.5532)	0.244671 (0.5566)
Adjusted R-Squared	0.451198	0.736198	0.551620
Prob F-Statistic	0.000000	0.000000	0.000000

Source: Processed data (2025)

AI and interest rates both have positive, statistically significant coefficients across all models, implying they positively affect green bond issuance. AI likely enhances transparency and investor trust (Zhang & Liu, 2023). The positive coefficient for interest rates is counterintuitive but aligns with Karpf & Mandel (2018), who noted green bonds remain attractive under tighter monetary conditions due to policy and environmental incentives. Carbon emissions are statistically insignificant, suggesting that environmental degradation alone hasn't triggered corresponding financial market responses within ASEAN-5 during the period studied.

Table 3. Models

Test	**Prob**	**Result**
Chow	0.0000	FEM preferred over CEM
Hausman	0.9451	REM preferred over FEM
LM	0.0000	REM preferred over CEM

Source: Processed data (2025)

Based on standard procedure, REM is selected as the final model for interpretation, being more statistically efficient and capturing unobserved heterogeneity.

Table 4. Reports country-specific random effects

No.	Country	Effect
1.	Indonesia	0.465698
2.	Malaysia	-0.633850
3.	Philippines	-0.274106
4.	Singapura	0.206537
5.	Thailand	0.235721

Source: Processed data (2025)

Positive values for Indonesia, Thailand, and Singapore reflect underlying institutional support and policy readiness for green finance, while negative effects for Malaysia and the Philippines suggest structural barriers or weaker investor demand.

Table 5. Partial t-test

Variables	Prob.	Significance	t-Statistic	Direction
AI	0.0000*	Significant	11.18288	Positive
I	0.0000*	Significant	5.105515	Positive
LOG_CO2	0.5566	Not Significant	0.589593	Positive

Source: Processed data (2025)

AI and interest rates significantly and positively influence green bond issuance, consistent with previous findings (Zhang & Liu, 2023; Karpf & Mandel, 2018). Carbon emissions remain insignificant.

Table 6. Simultaneous F-test and R^2

Prob(F-statistic)	*F-Statistic*	*F-table*	*R-squared*	*Adjusted R-squared*
0.000000	49.79991	2.682809	0.562923	0.551620

Source: Processed data (2025)

The model is significant overall, explaining around 56% of variation in green bonds. This is robust for panel data across diverse countries (Gujarati & Porter, 2009).

Table 7. Classical Assumption Tests

Test	Prob.		Result
Normality (Jarque-Bera)	0.093309		Residuals normally distributed
Heteroskedasticity (White/Breusch-Pagan)	AI i LOG_CO2	0.3570* 0.8229* 0.0985*	No heteroskedasticity detected
Multicollinearity (correlation matrix)	Highest correlation: -0.4295		No multicollinearity

Source: Processed data (2025)

These diagnostics confirm the validity and reliability of the REM specification.

The empirical analysis reveals that the adoption of Artificial Intelligence (AI) has a positive and statistically significant relationship with the issuance of green bonds across ASEAN-5 countries. This is supported by exceptionally low p-values (0.0000) across all three panel estimation models and regression coefficients ranging from 0.0163 to 0.0176. The partial t-test yields a t-statistic of 11.18288, well above critical thresholds, reinforcing evidence that AI adoption meaningfully stimulates the growth of green bonds. Specifically, AI contributes by improving the efficiency of green project reporting, automating ESG impact measurement, and enhancing transparency, factors that collectively strengthen investor confidence.

Interestingly, the analysis also finds that interest rates exert a positive and significant effect on green bond issuance, with regression coefficients between 0.1500 and 0.1616, p-values of 0.0000, and a t-statistic of 5.105515. This result contrasts with the Keynesian interest rate channel theory, which suggests that higher interest rates would typically suppress investment activity, including green investment. In practice, however, institutional investors appear less sensitive to short-term interest rate fluctuations, viewing green bonds as resilient, long-term assets with intrinsic ESG value.

Conversely, carbon emissions do not exhibit a statistically significant relationship with green bond issuance in ASEAN-5, as indicated by a high p-value (0.5566) and a low t-statistic (0.589593). This finding highlights a disconnect between environmental urgency and financial market responses: higher emissions have not automatically driven greater issuance of green bonds. Notably, Thailand stands out as the only country in the sample that demonstrates simultaneous reductions in carbon emissions alongside growth in green bond issuance.

Discussion

The empirical analysis provides several important insights into the dynamics of green bond development in ASEAN-5. First, the consistent and significant effect of Artificial Intelligence (AI) readiness on green bond issuance underscores the growing role of digital technologies in enhancing sustainable finance. This result aligns with the theoretical framework of endogenous growth, in which technological innovation serves as an internal driver of long-term economic expansion (Romer, 1990). In practice, AI strengthens the monitoring and verification processes of green projects, improves transparency in ESG reporting, and reduces information asymmetry, thereby fostering greater investor confidence. These findings are consistent with earlier studies by Kuang et al. (2024) and Xu (2025), who emphasized that AI adoption improves both efficiency and accountability in sustainable finance. The ASEAN-5 case suggests that countries with stronger digital infrastructure and policy commitment—such as Singapore and Indonesia—are better positioned to leverage AI in scaling up green bond markets.

Second, the positive and significant influence of policy interest rates on green bond issuance presents a counterintuitive yet theoretically relevant outcome. From a Keynesian liquidity preference perspective, higher interest rates are expected to

constrain investment demand. However, the results of this study suggest that green bonds retain their attractiveness even under tighter monetary conditions, supporting the argument of Karpf and Mandel (2018) that institutional investors often view them as resilient, policy-backed, and mission-driven assets. In the ASEAN-5 context, this could reflect the "green premium," where investors are willing to accept relatively lower yields in exchange for the ESG value embedded in these instruments (Wicki & Maurer, 2023). Furthermore, central banks' signaling of sustainable finance as a strategic priority may mitigate the dampening effect of higher borrowing costs, particularly in jurisdictions where green bond issuance is linked to sovereign or quasi-sovereign guarantees.

Third, the insignificant role of carbon emissions in driving green bond issuance reveals a structural disconnect between environmental urgency and financial market responses. While higher per capita emissions represent greater environmental pressure, they have not automatically translated into stronger issuance of green bonds within ASEAN-5. This divergence suggests that, unlike in advanced economies where emissions reduction targets are tightly coupled with financing mechanisms, the link between environmental degradation and financial innovation remains weak in emerging markets. Previous studies, such as Bukvić et al. (2023), similarly found that green bond issuance does not always yield measurable emission reductions, especially in regions with fossil-fuel-dependent energy systems. Among ASEAN-5, only Thailand demonstrates a more synchronized pattern of emission reduction and green bond expansion, pointing to the importance of complementary policies such as renewable energy incentives and regulatory alignment.

Taken together, these findings contribute to the broader debate on the drivers of sustainable finance. They suggest that technological readiness and institutional signaling may play a more immediate role in shaping investor demand for green bonds than environmental pressures per se. This interpretation is consistent with Sustainable Finance Theory (Scholtens, 2006), which posits that financial markets respond not only to external risks but also to systemic signals shaped by governance, regulation, and technological infrastructure.

From a policy perspective, the results imply that ASEAN-5 governments should prioritize strengthening digital ecosystems and embedding AI in green finance reporting and monitoring. At the same time, monetary authorities should recognize that accommodative interest rate policies are not the sole determinant of green bond growth; rather, credibility and policy consistency matter equally. To close the gap between emissions and finance, carbon pricing mechanisms and stricter environmental disclosure standards could be integrated into financial regulation, ensuring that environmental pressures translate into tangible investment responses.

Finally, this study is not without limitations. The analysis relies on quarterly aggregate data, which may mask intra-country variation in sectoral adoption and investor behavior. The measure of environmental pressure, proxied by CO_2 emissions per capita, captures only part of the ecological dimension and does not reflect biodiversity loss or other critical externalities. Future research could expand the

dataset, incorporate additional environmental indicators, and explore nonlinear dynamics to capture the evolving relationship between finance, technology, and sustainability in greater depth.

Conclusion

This study finds that artificial intelligence readiness and policy interest rates play a significant role in driving the development of green finance in the ASEAN-5 region, while carbon emissions do not exhibit a meaningful effect. These findings highlight that the transformation toward sustainable finance in the region is shaped more by digital readiness and monetary instruments rather than direct ecological pressures. The results are consistent with endogenous growth theory, which emphasizes the importance of technology and innovation as primary engines of sustainable development, while also challenging conventional perspectives that focus mainly on monetary stability.

From a practical standpoint, the findings suggest that green finance development cannot be separated from digital integration particularly the use of AI and from the active role of central banks in designing environmentally friendly monetary instruments. Strengthening the digital ecosystem, improving information transparency, and implementing instruments such as green monetary policies, carbon pricing, and stricter disclosure requirements emerge as strategic measures to accelerate the transition toward sustainable finance. Thus, this study contributes to the literature by shifting the focus beyond environmental aspects and underscoring the fundamental role of technology and monetary policy in advancing green finance.

Nevertheless, this research is not without limitations. The study relies on macro-level, quarterly data and employs relatively narrow proxies for measuring carbon emissions. These limitations provide an avenue for future research to broaden the dataset, explore more diverse indicators, and investigate potential non-linear interactions between technology, monetary, and environmental factors. Extending the scope to other developing economies beyond ASEAN-5 could also enrich the understanding of green finance dynamics under varying institutional contexts.

Overall, this study offers both theoretical and empirical contributions by asserting that the acceleration of green finance in developing countries is shaped not only by environmental pressures but also by institutional capacity and technological adoption. This marks an important shift in the direction of sustainable finance research and policymaking, opening new opportunities for integrated policy design that links digital innovation, monetary stability, and environmental sustainability.

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